



ABSTRACT BOOK



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Lectures & Communications

THEORETICAL FOUNDATIONS, MODELING AND SIMULATION OF ELECTROSPINNING

33 - FLOW BEHAVIOR OF THE ELECTROSPINNING JET: FROM TAYLOR CONE TO STRAIGHT JET AND SPIRALING JET

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Background/Rationale The existing knowledge of the electrospinning process is that a one-phase polymer solution is continuously stretched when subjected to a strong electric field, considerably reducing the jet diameter, with accompanying solvent evaporation, eventually producing dried nanofibers on the collector. Flow-induced phase separation (FIPS) has been largely ignored. However, this work, along with recent reports [1-3], clearly discloses that phase separation of the initial one-phase solution can occur in the straight jet, leading to the development of internal structures of strings with various widths. These structures serve as precursors to the nanofibers found on the collector after solvent removal.

Materials and Methods In solution electrospinning, fiber formation occurs rapidly (approx. 20–50 ms) as the jet travels from the needle tip to the grounded collector. Understanding how the fluid—emerging from a ~1 mm diameter tip—transforms into sub-micron solid fibers is essential. Along the spinline, three distinct regions were investigated: the Taylor cone at the needle tip, the straight jet, and the spiraling jet.

This study utilized (1) Particle Image Velocimetry (PIV) to reveal vortex flow in the Taylor cone, (2) light scattering to measure jet diameter and derive the extension rate in the straight jet, and (3) high-speed videography to trace the rotation of the spiraling jet.

Results Complex and dynamic vortex formation was observed in the Taylor cone at low polymer concentrations. In the straight jet, the electric-field-induced extension rate exceeded the polymer relaxation rate, resulting in a high Weissenberg number. This suggests that flow-induced phase separation occurs [1], producing hierarchical string-like structures; these were validated by collecting the jet in liquid nitrogen followed by freeze-drying [2]. High-speed videography revealed that the rotation of the spiraling jet may be correlated with the upstream swirl in the Taylor cone, entering the cone-jet transition zone. Furthermore, jet whipping causes the phase-separated jet to split, releasing internal structures of assembled strings that eventually evolve into fibers upon solvent removal.

Conclusions We conclude that flow-induced phase separation plays a vital role in the formation of fibers during electrospinning [3]. On the basis of FIPS, a unifying mechanism has been proposed to successfully consider the diversified morphology of electrospun fibers through self-assembly of the strings in the jet [4].

Key words Taylor cone vortex, flow-induced phase separation, spiral chirality

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35 - ELECTROHYDRODYNAMIC STABILITY ANALYSIS OF NANOPARTICLE-LADEN ELECTROSPINNING JETS FOR CONTROLLED NANOFIBER FORMATION

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Background/Rationale The electrospinning process is governed by complex electrohydrodynamic interactions involving electric, viscoelastic, surface-tension, charge-transport, and solvent-evaporation forces, as well as jet stretching. The stability of the electrospinning jet is central to determining whether smooth fibers, beads-on-string structures, or jet breakup will occur. Earlier work by Deshawar and Chokshi demonstrated that linear stability theory can successfully describe instability in electrospinning jets of polymeric fluids and aid understanding of bead formation. Their study demonstrated the importance of rheology, conductivity, and electrohydrodynamic forces in jet stability. Building on this foundation, the present work focuses on nanoparticle-laden electrospinning jets, where suspended nanoparticles further modify viscosity, conductivity, dielectric behavior, relaxation time, and charge distribution. Although nanoparticles are widely used to improve mechanical, thermal, electrical, antibacterial, catalytic, and barrier properties of electrospun fibers, their influence on electrohydrodynamic stability remains insufficiently understood.

Materials and Methods The study will develop a theoretical and computational framework for the stability of electrospinning jets in the presence of nanoparticles. A polymer solution containing uniformly dispersed nanoparticles will be considered as a charged, viscoelastic, incompressible liquid jet issued from the Taylor cone toward a grounded collector. The governing equations will include conservation of mass, momentum, charge transport, electric field coupling, and viscoelastic constitutive relations. Nanoparticle effects will be incorporated through concentration-dependent viscosity, electrical conductivity, permittivity, surface tension, and relaxation time. A steady base-state solution will first be obtained for the stretched electrospinning jet. Small perturbations will then be introduced in jet radius, axial velocity, pressure, charge density, electric potential, and stress components. Using normal-mode linear stability analysis, a dispersion relation relating the perturbation growth rate to the wavenumber will be derived. The effects of nanoparticle loading, polymer concentration, applied voltage, surface tension, and solvent properties will be systematically studied.

Results Stability analysis is expected to show that nanoparticles such as ZnO and TiO₂ significantly alter the electrohydrodynamic behavior of the electrospinning jet by modifying solution conductivity, viscosity, dielectric response, surface charge distribution, and particle–polymer interactions. At low and well-dispersed nanoparticle loading, both ZnO and TiO₂ may enhance jet stretching, reduce fiber diameter, and suppress bead formation by improving charge transport and electric-field-driven elongation. However, at higher loading, particle agglomeration and increased viscosity may disturb the jet, enhance perturbation growth, and produce beads or non-uniform fibers.

For ZnO-loaded polymer solutions, the semiconducting and polar nature of ZnO is expected to increase electrical conductivity and strengthen electrostatic stretching. Therefore, ZnO may reduce fiber diameter and shift instability toward finer fiber formation within an optimum concentration range. Beyond this range, ZnO agglomerates may cause local charge imbalances and stress concentrations, leading to jet distortion and bead formation.

For TiO₂-loaded polymer solutions, high dielectric constant and strong surface activity may enhance polarization under the applied electric field and modify interfacial electric stresses. Moderate TiO₂ loading may improve jet stability and fiber uniformity, while excessive loading may increase apparent viscosity, broaden fiber diameter distribution, and promote bead-on-string morphology due to aggregation.

The dispersion relation is expected to identify changes in the critical wavenumber, the maximum growth rate, and the dominant instability mode in nanoparticle systems. A comparative stability map may show that ZnO mainly influences conductivity-driven stretching, whereas TiO₂ mainly affects dielectric polarization and interfacial electric stress. The results may define an optimal nanoparticle loading window in which jet stability is improved, bead defects are minimized, and uniform functional nanocomposite fibers are obtained.

Conclusions This work extends the electrohydrodynamic stability framework of polymeric electrospinning jets to nanoparticle-loaded systems. By combining linear stability theory, nanoparticle-modified material properties, the study will provide a predictive basis for controlling nanofiber morphology. The outcomes will reduce trial-and-error optimization and support rational design of nanocomposite electrospun membranes for

various application. The proposed analysis will also strengthen the fundamental understanding of how nanoparticles influence the transition from stable jet stretching to bead formation and whipping instability.

Key words Electrospinning; nanoparticles; electrohydrodynamic stability; nanofibers; viscoelastic jet.

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42 - FROM SOL-GEL CHEMISTRY TO NANOFIBER MEMBRANES: A MODEL-BASED APPROACH TO PREDICTING ELECTROSPINNABILITY

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Background/Rationale Gelation is a fundamental process in which molecular aggregation and network formation govern macroscopic rheological behavior and ultimately determine electrospinnability. Despite its apparent simplicity, gelation arises from a complex interplay between reaction kinetics and network topology making it challenging to predict electrospinnability. In silica-based sol-gel systems the molecular factors that govern electrospinnability remain insufficiently understood. In particular, the complex relationship between reaction kinetics and rheological behavior often forces researchers to rely on empirical trial-and-error methods. Developing a molecularly informed and predictive framework that links network formation during gelation to rheological behavior is therefore essential to rationalize and optimize nanofiber formation.

Materials and Methods A predictive framework was developed for methyltriethoxysilane (MTES)-based sol-gel systems [1]. Hydrolysis and condensation kinetics were characterized using silicon-29 nuclear magnetic resonance spectroscopy (²⁹Si NMR) [2]. These data were integrated into a coupled matrix-based Monte Carlo (CMMC) model [3] to extract Arrhenius parameters and simulate network evolution under various conditions, including non-isothermal synthesis representative of electrospinning with solvent evaporation. The resulting molecular descriptors, such as hydrolysis degree and crosslinking density, were correlated with viscosity evolution measured by rotational rheometry.

Results Network evolution was successfully modeled under conditions leading to electrospinning. A comparative analysis with tetraethoxysilane (TEOS), a more highly crosslinkable precursor, was also performed. Thanks to the model's ability to predict molecular descriptors throughout synthesis, correlations were established between viscosity evolution and parameters such as hydrolysis degree, siloxane yield, and crosslinking density. These correlations allowed the definition of processing windows corresponding to no deposition, electrospraying, and electrospinning. To validate the model, three synthesis conditions were randomly selected based solely on its predictions and their electrospinnability was assessed experimentally. Scanning electron microscopy (SEM) imaging confirmed that the resulting morphologies matched the predicted electrospinnability outcomes, confirming the reliability of the molecular rules derived from the model.

Conclusions In this work [1], the electrospinnability of MTES-based sol-gel systems was successfully predicted by linking viscosity to key molecular network parameters through a combination of experimental data and coupled matrix-based Monte Carlo (CMMC) modeling. Arrhenius parameters for isothermal synthesis were first determined, and the framework was subsequently extended to non-isothermal conditions relevant to electrospinning. This enabled the prediction of molecular descriptors over time and the establishment of direct correlations between these parameters and viscosity. These molecularly driven insights allowed the identification of electrospinnability windows across different sol compositions, significantly reducing reliance on empirical trial-and-error approaches.

The developed and validated framework addresses two critical gaps: it not only enhances the fundamental understanding of sol-gel chemistry and its role in electrospinning, but also offers a predictive tool that links molecular requirements to electrospinnability. As a proof-of-concept, it establishes a foundation for a more general methodology. Future work will extend this approach to other gelation systems to assess its versatility and support the rational design of electrospinning processes.

Key words kinetic Monte Carlo modeling, silica, sol-gel chemistry, electrospinning, rheology

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91 - MODELING ELECTROSPUN JET DYNAMICS: FROM ELECTROHYDRODYNAMIC INSTABILITIES TO FIBER ALIGNMENT

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Background/Rationale Electrospinning is a simple and versatile technique for producing polymer nanofibers, yet its predictive modeling remains a difficult task. The reason is the wide range of length and time scales involved, from the molecular rearrangements at the Taylor cone (10^{-10} m, 10^{-10} s) up to the macroscopic fiber mat (10^{-1} m, 10^0 s), together with the strong coupling between electrohydrodynamic, viscoelastic, and stochastic effects that drive the evolution of the jet. A quantitative description of the bending (whipping) instability, of the final fiber diameter distribution, and of the spatial deposition pattern is needed to guide the design of aligned nanofibrous architectures for applications in filtration, tissue engineering, and energy storage. This contribution reviews a set of physically grounded models developed over the past decade to bridge these scales, combining continuum and discrete approaches.

Materials and Methods Two complementary numerical frameworks are presented. Near the nozzle, where the Taylor cone forms and the jet undergoes strong thinning, we use an entropic lattice Boltzmann (ELBM) model for leaky-dielectric multiphase fluids [1]. The model includes the Korteweg–Helmholtz force density, a surface-charge redistribution term based on local curvature, and a non-Newtonian (Carreau) rheology. Far from the nozzle, where the jet radius drops below the micrometer and a fully resolved Eulerian description becomes too expensive, we switch to a Lagrangian bead–spring representation [2,3]. This includes viscoelastic stresses, Coulomb repulsion, surface tension, gravity, and aerodynamic drag. The air-drag term is treated through a Langevin formulation, and a dynamic mesh-refinement scheme [4] keeps the number of beads under control over the full nozzle-to-collector distance. The framework is implemented in the open-source code JETSPIN [3]. At the smallest scale, reactive atomistic simulations based on a topological algorithm for covalent bond formation are used to estimate the constitutive parameters of the polymer (viscosity, elastic moduli) from first principles [5].

Results The ELBM model reproduces the Taylor cone shape and the early stretching regime, and shows how non-Newtonian rheology affects the axial velocity profile of the jet. The Lagrangian model captures the bending instability predicted by Earnshaw's argument, and reproduces the dependence of the bending cone angle on the applied voltage, in agreement with experiments. When the air-drag is modeled as a non-linear Langevin term, the jet length grows sub-linearly in time, in line with the experimental behavior, while a deterministic treatment overestimates the growth. Three-dimensional simulations of jets in a controlled gas counterflow [6] show that the counterflow broadens the fiber radius distribution and modifies the deposition pattern on the collector. Orthogonal rotating electric fields produce Lissajous-type deposition patterns whose shape can be tuned by frequency and amplitude [7]. The presence of embedded nanoparticles modifies the local viscoelastic response and the morphology of the fiber [8]. Finally, reactive atomistic simulations of HDDMA polymerization provide values of viscosity and Young's modulus that can be passed directly to the mesoscale model [5].

Conclusions A set of models at different scales — atomistic, mesoscale Lagrangian, and lattice Boltzmann — provides a physical understanding of the main effects at play in electrospinning. The framework reproduces qualitative trends and some quantitative features of the experimental observables, such as the bending cone angle, the fiber diameter distribution, and the deposition pattern, and offers a basis for exploring how process parameters and external fields (auxiliary electrodes, rotating fields) influence fiber alignment. Possible directions for future developments include the direct coupling between the ELBM and Lagrangian descriptions and the extension to multi-jet configurations.

Key words Electrospinning; electrohydrodynamics; bending instability; lattice Boltzmann method; Lagrangian model; nanofiber alignment.

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136 - NEW REGIMES AND SPONTANEOUS CIRCULAR DEPOSITION PATTERNS IN MID-FIELD ELECTROSPINNING

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Background/Rationale Since early work by Reneker et al. [1], it has been known that bending instabilities in electrospinning (ES) can produce spiral or helical jet trajectories prior to the onset of chaotic whipping, ultimately resulting in broad and disordered fiber deposition on the collector. Although the chaotic motion has been partially offset through electrostatic and mechanical collection strategies mostly to collect aligned fibers, they do not fully control individual fiber trajectories.

A more direct strategy is near-field electrospinning (NFES), in which the needle-to-collector distance is dramatically reduced, thus enabling precise fiber placement, albeit for very low flow rates with reduced jet speed. Recently, steering electrodes were used for complex trajectory control of fast submicrometer jets [2]. Mid-field electrospinning (MFES) lies between these two regimes, where the jet can remain sufficiently straight over cm's, although it often produces buckled fiber (at the μm range) or even beaded structures. Electrostatic jet stirring was also used in MFES, although only to print simple patterns, like circles [3]. These works prompted us to ask whether precise jet control was possible with MFES but with larger flow rates, including the organized spiraling jets ES. This could open the door to printing at high resolution and speed. In this work, the jet behavior is studied depending on the operating conditions and collection distance.

Materials and Methods Electrospinning experiments were performed using PEO-water based solutions with different molecular weights and polymer concentrations at needle-to-collector distances ranging from 1 to several cm. Jet behavior was investigated through optical observation and high-speed imaging of the in-flight jet trajectory, together with analysis of the resulting deposition patterns. Particular attention was given to the operating conditions on the persistence of spatially confined spiraling trajectories. Rheological characterization and electrical measurements were additionally performed to investigate possible correlations between jet behavior and solution properties.

Results Over nozzle-collector distances of several centimeters, the jet presented straight, spiraling or whipping like regimes. Under specific operating conditions, spiral-like jet trajectories produced confined circular deposition patterns with diameters up to 1 cm. For these lower voltage conditions, the straight jet abruptly opens into high frequency ($\sim 400\text{Hz}$) spontaneous circular deposition. The opening of the spiral envelope can be adjusted with either the applied voltage or the distance. An important factor is the shape of the liquid meniscus from which the jet emerges, where a more rounded drop favors a tighter envelope of a spiraling fiber, thus forming smaller circles on the collector. Hysteretic behavior with respect to the needle-to-collector distance and applied voltage was also observed. When starting at higher voltages the jet is straight, then gradually developing whipping upon lowering the applied voltage, and later falling into the spiraling motion with a shortened straight jet section and narrower or more complex jet-spiraling envelope. A relationship has further been observed between the persistence of organized spiral-like trajectories and the rheological and electrical properties of the polymer solutions. FESEM images confirm that buckling instability or fiber beading can also happen simultaneously, depending on the fiber arrival speed at the collector.

Conclusions MFES is a promising area, in which controlled fiber printing could be achieved by controlling jet trajectories with (a) much higher solution flow rate than in NFES, and (b) within the more forgiving configuration afforded by the larger nozzle-collector separation of several cm (instead of mm's).

We have found that organized electrospinning jet trajectories can persist over significantly larger distances than are typically associated with NFES. Rather than representing a simple transition between stable and unstable regimes, the MFES offers operating conditions in which instability development is delayed and partially ordered motion is sustained through stable spiraling modes. This behavior enables spatially confined deposition of individual fibers without relying on near-field constraints or externally imposed trajectory control and provides new insight into the transition from organized jet motion to chaotic electrospinning deposition.

Key words Mid-field electrospinning, bending instability; jet dynamics; circular deposition; jet spiraling

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2 02.NANOFIBER FABRICATION & PROCESS OPTIMIZATION

6 - KEY CHALLENGES IN INDUSTRIAL ELECTROSPINNING OF HYALURONAN NANOFIBERS: PRODUCTIVITY, HOMOGENEITY AND AUTOMATION

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Background/Rationale Over the past two decades, we have systematically addressed the industrial scale-up of electrostatic spinning, progressing from fundamental laboratory research through pilot-scale validation to fully automated manufacturing of market-ready nanofibrous products. Our work is strongly rooted in the processing of hyaluronan, a material for which we possess in-depth know-how as its producer, enabling us to electrospin both native and chemically modified hyaluronic acid in a wide range of polymer blends.

Materials and Methods This contribution summarizes the key technological challenges encountered and resolved during the development of scalable electrospinning-based processes. The first part focuses on factors governing nanofiber production rate, where solvent evaporation dynamics, airflow assistance, and process thermodynamics play a decisive role. By extending conventional electrospinning toward electroblowing, we achieved a substantial increase in productivity while maintaining fiber quality, demonstrating the feasibility of this approach for industrial manufacturing.

The second part addresses thickness homogeneity of large-area nanofibrous layers, which represents a critical quality parameter for cosmetic, pharmaceutical, and medical applications. Static electric fields inherently lead to non-uniform fiber deposition due to localized charge accumulation. We show that introducing electrodynamic spinning principles, via dynamic electric fields generated by controlled motion of both spinning and collector elements, significantly improves thickness uniformity across large substrates. These solutions enable the preparation of nanofibrous layers that meet stringent quality requirements without the need for extensive post-production sorting.

In the third part, we present a fully automated production machinery that integrates electrospinning, material handling, cutting, and primary packaging into a single continuous process operated in cleanroom conditions. This manufacturing platform incorporates several unique and original design principles, allowing nanofibrous products to be produced and packaged without direct human intervention, thereby ensuring high reproducibility and regulatory compliance.

Results Although the research and development of hyaluronan-based nanofibrous materials for cosmetic applications has been successfully completed and implemented in multiple commercial products, new challenges remain. Current and future R&D activities respond to evolving demands of the cosmetic industry, particularly with respect to material composition, functional additives, and the selection of acceptable and sustainable packaging materials. In parallel, long-term research is directed toward the development of nanofibrous materials for medical applications, especially for the treatment of selected types of chronic and complex wounds.

Conclusions This presentation provides an integrated view of essential technological solutions required for high-quality nanofiber production by electrostatic spinning, from material research through scalable process design to industrial manufacturing, and outlines future challenges toward equally successful applications in modern medicine.

Key words Keywords: scale-up, hyaluronan, electroblowing, electrodynamic spinning, production

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13 - BEYOND THE MAT: LEVERAGING SHORT POLYMER NANOFIBERS FOR ADVANCED 3D TISSUE ENGINEERING AND INJECTABLE THERAPEUTICS

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Background/Rationale Electrospun polymer nanofibers are widely recognized for their biomimetic architecture; however, their conventional nonwoven mat form factor presents significant barriers to clinical translation, including surgical invasiveness and limited cellular infiltration. Although two-dimensional membranes can function as drug-loaded barriers, they lack the spatial precision necessary for deep-tissue applications or “smart” therapeutic delivery. Short nanofibers have emerged as a versatile alternative, bridging the advantages of one-dimensional nanostructures with the processability of injectable colloidal systems.

Materials and Methods Cellulose acetate (CA) with a molecular weight of 30 kDa and 40% acetylation, along with acetic acid, were procured from Sigma-Aldrich, while budesonide was provided as a donation by the Technion-IIT.

Short CA fibers were fabricated following the method outlined in Ref. 1, wherein a spinning solution was formulated by dissolving 17% (w/v) cellulose acetate in glacial acetic acid, and the fibers were subsequently produced at an electric field of approximately 1 kV/cm with a flow rate of 0.4 mL/h.

Results This study evaluates the mechanical, rheological, biological, and pharmacological properties of short polymer nanofibers, highlighting their function as rheological modifiers in bioinks and injectable formulations. We demonstrate their potential to enable the fabrication of biomimetic three-dimensional tissues that combine mechanical integrity with a permissive microenvironment conducive to cellular maturation, while also supporting localized, sustained, and targeted therapeutic delivery.

Conclusions Collectively, these findings position short polymer nanofibers as a transformative platform for minimally invasive tissue engineering and precision therapeutics, offering a scalable and clinically translatable strategy to overcome longstanding limitations of conventional electrospun constructs.

Key words Keywords: Short Nanofibers; Injectable Scaffolds; 3D Bioprinting; Controlled Drug Release

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26 - DECOUPLING FLAME RETARDANCY FROM MECHANICAL EMBRITTLEMENT IN POLYACRYLONITRILE FIBERS VIA CARBON BLACK INTEGRATION

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Background/Rationale Lightweight, flexible, and flame-resistant materials are increasingly required in high-risk environments, including aerospace, transportation, and personal protective equipment, where fire safety must be reconciled with low areal density and mechanical compliance. Polyacrylonitrile (PAN) is widely used as a precursor for thermally stable fibrous materials due to its ability to undergo stabilization and char formation, yet its intrinsic flame resistance in fibrous form remains limited. Conventional flame-retardant strategies are often constrained by toxicity, environmental concerns, or deterioration of mechanical properties.[1] Carbon-based nanoparticles, such as carbon black, offer a promising alternative owing to their thermal stability and ability to promote the formation of protective char.[2] However, the influence of nanoparticle incorporation into electrospun PAN architectures, particularly regarding stabilization behavior and fire response, remains insufficiently understood.

Materials and Methods Nanofibrous PAN-based composites were fabricated by electrospinning with controlled incorporation of carbon black nanoparticles. Both as-spun PAN and oxidatively stabilized PAN fibers were investigated to assess the role of stabilization in combination with nanoparticle addition. Fiber morphology and nanoparticle distribution were characterized by scanning electron microscopy (SEM). Thermal transitions and cyclization behavior were examined by differential scanning calorimetry (DSC), while chemical structure evolution was probed using Fourier-transform infrared spectroscopy (FTIR). Fire behavior was evaluated using microscale combustion calorimetry (MCC) and direct flame exposure tests, providing insight into both intrinsic combustion characteristics and macroscopic flame response. Mechanical properties were assessed under uniaxial tensile loading and compared with corresponding nanoparticle-free reference fibers.

Results Electrospinning produced continuous PAN nanofibers with homogeneous incorporation of carbon black nanoparticles. Thermal and spectroscopic analyses indicated modifications in cyclization behavior and chemical structure associated with nanoparticle incorporation. Comparison between PAN and oxidized PAN revealed distinct differences in flame response related to stabilization state. In both systems, the presence of carbon nanoparticles promoted the formation of a coherent, thermally stable char layer that acted as a barrier to heat and mass transfer, thereby limiting flame propagation. Microcalorimetry measurements indicated reduced heat release relative to nanoparticle-free counterparts, consistent with a condensed-phase flame-retardant mechanism. The fibrous structure and compliance of the materials were preserved following nanoparticle incorporation.

Conclusions The combined evaluation of PAN and oxidized PAN systems demonstrates that carbon black incorporation influences stabilization behavior and enhances flame resistance through char-mediated protection mechanisms. This approach leverages both the intrinsic chemistry of PAN and the thermal functionality of carbon nanoparticles, offering a scalable route toward flame-resistant fibrous materials for advanced engineering applications.

Key words electrospinning, carbon nanoparticles, flame retardancy, nanocomposites, PAN

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39 - FIRE-RESISTANT MICROTUBULAR FIBROUS SPONGES BY COAXIAL ELECTROSPINNING FOR BROADBAND ACOUSTIC ABSORPTION

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Background/Rationale Excessive noise exposure harms mental health and work productivity, but conventional polymeric fibrous sponges for noise absorption are limited by their narrow acoustic bandwidth and flammability.

Materials and Methods Herein, an ultralight organic-inorganic hybrid fiber sponges (HYFS) composed of hierarchically microtubular fibers was fabricated by coaxial electrospinning and template sacrifice, which achieved synergistic enhancement of sound absorption and flame retardancy.

Results Thus, the HYFS demonstrates a remarkable noise reduction coefficient of 0.62 at 270 g/m², along with the broadband sound absorption of effective bandwidth up to 5.5 kHz (sound absorption coefficient >0.90). Moreover, it demonstrates outstanding fire retardancy with a peak heat release rate of 7 kW/m².

Conclusions This work sheds light on a novel avenue for developing ultra-light, fire-safe, and highly efficient broadband acoustic absorbers for practical applications

Key words Microtubular fibrous sponge, Coaxial electrospinning, Fire retardancy, Acoustic absorption

48 - POLY(VINYL ALCOHOL)/SODIUM ALGinate ELECTROSPUN FIBERS - EFFECT OF POLYMER COMPOSITION AND CROSSLINKING STRATEGIES ON FIBERS MORPHOLOGY

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Background/Rationale Electrospinning of sodium alginate (SA) is highly desirable due to its biodegradability, biocompatibility and ability to undergo ionic crosslinking, making it a promising material for various applications as a controlled-release system. However, its limited chain entanglement and poor spinnability hinder the formation of uniform nanofibers. To overcome these limitations, poly(vinyl alcohol) (PVA) is widely employed as a carrier polymer, enabling the fabrication of continuous fibers while partially diluting the SA content [1]. Therefore, increasing the SA content while maintaining spinnability and uniform structure remains a challenge. Post-electrospinning stabilization of PVA/SA fibers can be achieved through different mechanisms depending on the crosslinking agent. Calcium chloride enables ionic crosslinking of alginate chains, tannic acid introduces hydrogen bonding and polyphenolic interactions, while boric acid forms complexes with hydroxyl groups, primarily affecting the PVA part [2].

Materials and Methods Polymer solutions with concentrations of 10% for PVA and 6% for SA were prepared and mixed in varying PVA/SA weight ratios (3:1, 2:1, 1:1), then electrospun under optimized conditions to evaluate the effect of composition on fiber formation. For electrospinning, a 20-needle nozzle and a rotating collector was applied to obtain a large surface area of fibers in the form of mats. For crosslinking, three crosslinking media were used: calcium chloride, tannic acid and boric acid, and their two- and three-component formulations. The resulting fibrous mats were analyzed for morphology and structural integrity using Scanning Electron Microscopy (SEM). Moreover, Fourier transform infrared spectroscopy (FTIR) analysis and the mechanical properties of the obtained fibrous mats were evaluated.

Results SEM analysis confirmed that all samples formed continuous fibers, however, their morphology strongly depended on the PVA/SA ratio. Increasing the alginate content reduced process stability, resulting in more defects and a decrease in average fiber diameter. In contrast, higher PVA content improved fiber uniformity, although a broader fiber diameter distribution was observed. Among the tested compositions, the PVA/SA ratio of 2:1 showed a good compromise between fiber uniformity and achieving a relatively high SA content. The selected fibrous mat was subjected to crosslinking using different media, including calcium chloride, tannic acid, boric acid, and their combinations, to evaluate the influence of different interaction mechanisms on fiber morphology and the properties of obtained mats.

Conclusions The results of this research provide a necessary foundation for the development of alginate-based electrospun materials and enable further investigation of crosslinking strategies to tailor the properties of the resulting fibrous mats for advanced applications.

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Key words alginate, poly(vinyl alcohol), electrospinning, crosslinking

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53 - STRUCTURE AND PROPERTY CONTROL OF NANOFIBROUS MATERIALS FOR SPECIFIC APPLICATIONS

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Background/Rationale Elmarco is a technology focused company specializing in industrial scale electrospinning solutions for the production of nanofibrous materials. Its technologies enable the processing of a wide range of polymers, allowing the formation of nanofibrous layers with tailored structural and functional properties. Nanofibrous materials are characterized by a very high specific surface area, high porosity, and low pressure drop, which makes them particularly attractive for filtration and separation applications. The ability to precisely control fiber and pore structure is essential for designing materials with defined performance characteristics.

Materials and Methods Nanofibrous layers were produced using the needle-less electrospinning technology Nanospider®, which enables continuous and scalable nanofiber production. Various polymer systems were selected and processed under controlled electrospinning conditions, allowing systematic modification of fiber morphology. The modification of fiber morphology combined with the appropriate selection of polymer type enables tuning of nanofibrous materials toward specific applications. Selected samples were subjected to thermal treatment after electrospinning to further influence the internal structure of the nanofibrous layer. Fiber morphology was analyzed using scanning electron microscopy (SEM). Functional properties were evaluated by capillary flow porometry for pore size distribution, air permeability measurements, and filtration efficiency testing.

Results The Nanospider® technology demonstrated high flexibility in controlling nanofiber morphology and structural properties. Fiber diameters were tunable within a broad range from approximately 50 nm to 500 nm by adjusting material composition and process parameters. Correspondingly, the pore size distribution of the nanofibrous layers could be tailored from approximately 120 nm up to values exceeding 1 µm. Thermal treatment applied after electrospinning was found to significantly influence pore size and overall structure, enabling further modification of air permeability and filtration behavior.

Conclusions Elmarco demonstrates a high level of flexibility in the production of nanofibrous materials, offering multiple approaches to control fiber diameter, pore size, and functional performance. The combination of needle less electrospinning and post processing methods enables effective tuning of nanofibrous properties to meet specific application requirements.

Key words Electrospinning; Nanospider®; Nanofibrous materials; Fiber diameter; Pore size; Filtration; Air permeability; membrane

References Elmarco Team, R&D department, design department

60 - QUERCETIN-LOADED ELECTROSPUN FILMS FOR ACTIVE AND BIODEGRADABLE FOOD PACKAGING

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Background/Rationale Electrospun films for food packaging remain underexplored but are promising for active delivery, functional protection, and biodegradable packaging design. This study aimed to develop zein-based electrospun films with stable fibre morphology and improved quercetin (Que) retention for future antioxidant food packaging applications.

Materials and Methods Method:

Zein and hydroxypropyl cellulose (HPC) were blended at different mass ratios to prepare electrospun films, and Que was incorporated at different concentrations to regulate fiber formation and provide functional activity. The morphology, molecular interactions, thermal behaviour, Que encapsulation, storage stability, release behaviour, antioxidant activity, and biodegradability of the films were evaluated.

Results SEM results showed that blending zein with HPC improved the morphology of electrospun films compared with single-polymer systems. Among the ratios, zein:HPC = 8:2 produced the most continuous fibre network with fewer visible defects and was selected as the optimal base formulation with average diameters of 318.72 ± 184.61 nm. The addition of Que further affected fibre formation. When Que added at 0.50% w/v and 1.00% w/v, Que improved fibre uniformity, while Que promoted aggregation and ribbon-like structures at 1.50% w/v, due to increased solute content and reduced drying efficiency disturbed jet stretching and solvent evaporation. The optimal Que concentration was identified as 1.00% w/v. This formulation also showed the highest encapsulation efficiency and a relatively high loading capacity, indicating that outstanding fibre morphology was closely related to effective Que incorporation. FTIR and TGA results suggested that zein and HPC mainly interacted through hydrogen bonding, contributing to improved structural stability. ZH-1.00Q showed the lowest Que degradation after 30 days, with only 8.257% at 4 °C and 9.067% at room temperature. In 10% v/v ethanol food simulant, Que release remained below 10% under room temperature or lower storage conditions, and ZH-1.00Q showed the lowest release with only 4.55%. All Que-loaded films exhibited good antioxidant activity. In addition, partial degradation was observed after 12 days of soil burial, confirming their biodegradability.

Conclusions This work demonstrates that morphology control, molecular interaction, and active compound retention can be combined in zein-HPC electrospun films to develop functional biodegradable packaging. This system provides a mild and scalable route for designing active food packaging that can protect sensitive bioactives, support controlled migration, and contribute to sustainable food preservation.

Key words Electrospun; Zein; Food packaging; Antioxidant; Biodegradable

63 - PHOTOPOLYMERIZATION OF SOLVENT-FREE OLIGOMERS FORMULATION DURING ELECTROSPINNING PROCESS FOR FIBROUS MEMBRANE FABRICATION

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Background/Rationale Electrospinning combined with in-situ photopolymerization provides a powerful strategy to broaden the range of processable materials. In particular, the use of low molecular weight oligomers enables direct electrospinning of liquid precursors at room temperature. In this approach, a jet is generated from a low-viscosity formulation, while UV irradiation induces photopolymerization during flight. The rapid formation of a covalent network leads to fiber solidification, effectively converting liquid precursors into stable thermoset nanofibers. This solvent-free approach is especially attractive as it provides access to fibrous materials that are difficult to obtain using conventional electrospinning. It eliminates the need for solvents, elevated temperatures, and post-processing, offering a more sustainable and energy-efficient route. However, successful implementation requires careful formulation design to satisfy both viscoelastic requirements and photopolymerization kinetics. The process involves a very short residence time between the needle and the collector (less than one second) and a jet velocity of approximately 0.5 m.s⁻¹ [1]. Under these conditions, jet elongation strongly depends on the viscoelastic properties of the formulation. Controlling these properties, while ensuring sufficiently fast photopolymerization, remains a key challenge. This study aims to demonstrate the feasibility of in-flight photopolymerization during electrospinning of solvent free systems for advanced membrane applications. For their broad application, high mechanical properties polyurethane was used as model [2].

Materials and Methods Liquid polyurethane acrylate (PUA) oligomers were used. Rheological properties of the formulations were tuned by adding 1,6-hexanediol diacrylate (HDDA) as a reactive diluent. Photopolymerization kinetics were adjusted by varying the concentration of type I photoinitiator and irradiation conditions. To limit oxygen inhibition during the radical photopolymerization, the effect of adding a multifunctional thiol (PETMP) was investigated [3]. Rheological and kinetics properties of the formulations were characterized using real-time Fourier transform infrared spectroscopy (RT-FTIR) and photo-rheology measurements.

Electrospinning was performed using a custom setup coupled with a UV-LED. Different process parameters were investigated to evaluate their influence on the final morphology and conversion of the fibers. The resulting mats were characterized by SEM and differential scanning calorimetry (DSC).

Results The study of the formulation demonstrated that the introduction of PETMP both improved photopolymerization kinetics under air conditions and decreased the amount of photoinitiator to reach high acrylate conversion. In parallel, rheological studies enabled the selection of suitable oligomers and the design of blends with appropriate viscoelastic properties for stable jet formation. The coupling of electrospinning and photopolymerization was systematically investigated by varying both formulation and processing parameters. Under the tested conditions, the jet did not exhibit whipping movement, leading to the formation of continuous fibers with diameters ranging from 96 µm to 15 µm. The degree of conversion within the fibers was evaluated after electrospinning and post-curing as well as the membrane mechanical properties.

Conclusions This study demonstrates the feasibility of coupling electrospinning with in-flight photopolymerization using solvent-free formulations. The introduction of thiols effectively overcomes oxygen inhibition and enables faster curing kinetics under air conditions. This approach paves the way for designing electrospun fibrous membranes for application such as liquid filtration, water harvesting and others related fields.

Key words solvent-free electrospinning; photopolymerization; polyurethane acrylate

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69 - HIERARCHICAL BUCKLED ELECTROSPUN ARCHITECTURES WITH TISSUE-LIKE MECHANICS FOR FIBROBLAST GROWTH

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Background/Rationale Load-bearing biological tissues such as skin, cartilage, and adipose tissue exhibit a characteristic J-shaped stress–strain response, defined by an initial low-stiffness region followed by a progressive increase in stiffness at higher strains. This nonlinear mechanical behavior arises from the gradual straightening and recruitment of crimped or wavy fibers within the hierarchical extracellular matrix, primarily composed of collagen and elastin. Replicating both the structural morphology and mechanical behavior of such tissues remains a significant challenge in biofabrication design. Electrospinning provides a versatile platform for fabricating fibrous scaffolds; however, most reported approaches rely on post-treatment strategies (e.g., thermal annealing, solvent exposure, or mechanical pre-straining) to induce fiber crimping. These additional steps can compromise fiber integrity and reproducibility. To date, there are limited reports on the direct fabrication of intrinsically crimped or buckled electrospun fibers without post-processing. In this work, we present a straightforward one-pot electrospinning approach that enables the direct formation of buckled and crimped fibers through careful selection of material combinations and processing parameters, aiming to reproduce the J-shaped mechanical response of native tissues while maintaining structural fidelity.

Materials and Methods Electrospun mats were fabricated using a dual-material system consisting of a soft, elastic thermoplastic polyurethane (TPU) and a stiffer polyester, polycaprolactone (PCL), to emulate elastin- and collagen-like components, respectively. By systematically tuning electrospinning parameters (e.g., voltage, flow rate, and collector distance), crimped, wavy, and buckled fiber morphologies were achieved without post-treatment. Both unidirectional and bidirectional (0°/90°) fiber orientations were produced, with the latter forming layered, cross-aligned architectures. Structural morphology and fiber topology were characterized using scanning electron microscopy (SEM), confirming the presence of crimped and interwoven fiber networks. Mechanical properties were characterized using uniaxial and cyclic tensile testing. Biological performance was assessed by seeding fibroblasts onto the scaffolds. To assess the biocompatibility of these scaffolds, cell viability and proliferation were investigated over one week.

Results SEM analysis confirmed the successful formation of crimped, wavy, and buckled fibers. The induced buckling led to a measurable contraction of the nonwoven mats, resulting in reduced sample dimensions post-fabrication, indicative of internal stress relaxation and structural reorganization. Importantly, no evidence of delamination was observed, indicating effective interlocking between TPU and PCL fibers despite their contrasting mechanical properties. Mechanical testing demonstrated tunable J-shaped stress–strain behavior, with properties that closely match those of a range of soft biological tissues, including cartilage, skin, and adipose tissue. By adjusting the pre-stretching conditions of the electrospun mats, the strain-stiffening response could be precisely modulated. The scaffolds achieved elastic moduli as low as ~10 kPa, stiffening ratios up to 600, and transition strains approaching 50%, effectively spanning the mechanical spectrum of these tissues. This tunability highlights the ability of the system to replicate tissue-specific mechanical profiles within a single material platform. Furthermore, the mats maintained mechanical integrity over 350 loading cycles without significant macroscopic damage, demonstrating excellent fatigue resistance. Bidirectional fiber architectures contributed to enhanced mechanical stability and anisotropy. In vitro studies showed excellent cytocompatibility, with ~99% fibroblast viability after one week and the formation of a uniform monolayer across the scaffold surface, confirming the suitability of the scaffolds for cell culture applications.

Conclusions This study shows that biomimetic electrospun scaffolds with crimped fiber architectures and J-shaped mechanical behavior can be produced by optimizing electrospinning parameters and material choice, eliminating the need for post-processing while preserving fiber integrity and mechanical consistency. The resulting TPU/PCL scaffolds offer tunable strain-stiffening, robust structure, and strong fibroblast support, highlighting the importance of process control for developing functional biomaterials for tissue engineering applications.

Key words Electrospinning; Biomimetic scaffolds; Strain-stiffening; Crimped fibers; biological tissues

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77 - ELECTROSPUN NANOFIBROUS SCAFFOLDS FOR POTENTIAL WOUND HEALING APPLICATIONS: EFFECTS OF SALT AND HUMIDITY

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Background/Rationale Electrospun fibrous structures are composed of nano- and micro-scale fibres that create an interconnected network closely resembling the extracellular matrix (ECM) surrounding connective tissue cells in the human body. Their structural similarity to natural tissues, combined with the possibility of implanting a patient's cells onto the fibrous scaffold, can promote more efficient tissue regeneration and accelerate the healing process of wounds and hernias (Molnar 2018, Voniatis 2020). However, despite these advantages, one of the major limitations of electrospun scaffolds is the relatively small pore size between the fibres. If the pores are too small, cells are unable to migrate into the interior of the structure, which restricts cell infiltration, and the development of their native morphology. Several approaches have been proposed to overcome this limitation and increase pore size. Among these methods, the addition of salts to the polymer solution and the modification of environmental humidity during electrospinning have shown promising results. In the present work, calcium chloride (CaCl₂) was selected as the salt additive, as preliminary studies identified it as the most suitable candidate for promoting structural modification. The primary aim of this research was therefore to determine the optimal salt concentration and to investigate the combined effects of relative humidity and salt addition on the morphology, structure, and properties of the resulting fibrous meshes.

Materials and Methods During the experiments, polymer solutions with varying polysuccinimide (PSI) concentrations (17–25 w/w%) and calcium chloride concentrations (3–7 w/w%) were prepared using dimethylformamide (DMF) as solvent. Electrospinning was then carried out under controlled environmental conditions. In this process, a high electric field is applied to the viscous polymer solution, resulting in the formation of solid fibres through solvent evaporation. In addition to morphological characterization, mechanical tests were carried out to evaluate the relationship between environmental humidity, solution composition, and the mechanical durability of the electrospun meshes. To further understand the molecular background of these observations, Fourier-transform infrared spectroscopy (FTIR), XRD, TGA, and molecular dynamics simulations were conducted.

Results The morphology of the resulting fibres strongly depended on both the polymer concentration and the presence of salt. Lower PSI concentration solutions (20 w/w%) produced thinner fibres; however, these samples also exhibited bead formation, indicating instability during the electrospinning process. Interestingly, the addition of CaCl₂ or the increase of polymer concentration to 22.5 and 25 w/w% successfully eliminated bead formation, and fibres with significantly larger diameters were obtained. Furthermore, the incorporation of CaCl₂ induced the formation of a wrinkled surface morphology on the fibres. Environmental humidity also played a crucial role in determining the final structure of the electrospun meshes. Above a relative humidity level of 48%, the presence of salts enabled the formation of three-dimensional fibrous structures, a phenomenon that was not observed in salt-free systems under similar conditions. Statistical analysis confirmed that polymer concentration, salt concentration, and relative humidity collectively influenced fibre diameter and structural properties.

Conclusions In conclusion, the experimental work shows that polymer and salt concentrations, and relative humidity all have a significant effect on the fibre formation. Salt addition and higher polysuccinimide concentration created bead-less fibres, CaCl₂ created a wrinkled surface, while the increased polymer concentration significantly enlarged the diameter of the fibres. A relative humidity of 48% is a threshold above which all samples with added salt became three-dimensional. Experiments made with FTIR, XRD and TGA have shown the molecular interactions between the different components of the solutions. These findings and conclusions provide valuable insight into the design of optimized fibrous scaffolds for future biomedical applications, particularly in tissue engineering and regenerative medicine.

Key words

wound dressing, nanomaterials, electrospinning, humidity, fibrous scaffold

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88 - WATER- AND HEAT-RESISTANT COAXIAL ELECTROSPUN NANOFIBERS FOR ARCHIVAL DNA DATA STORAGE AND CONTROLLED DATA RETRIEVAL

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Background/Rationale Deoxyribonucleic acid (DNA) has emerged as a promising digital data storage medium, due to its high information density and energy-free data retention properties. [1] Advances in DNA synthesis and sequencing techniques, as well as in data-to-DNA encoding schemes, have made DNA data storage a more approachable solution.

Numerous methods have been studied to shield DNA from oxidative damage in order to ensure the longevity and preservation of the stored data. In our recent research, we have shown a tunable method for storing digital data in synthetic DNA incorporated within electrospun polymer fibers. [2],[3] However, it is essential to improve the stability of these fibers, as well as to provide protection to DNA and data integrity against environmental conditions, and to bring a controlled release mechanism for on-demand data retrieval. Indeed, blend electrospinning does not ensure that the DNA goes inside the fibers or if there is a partial exposure along their surface.

In this race, we have explored different ways of enhancing fiber and DNA stability and controlling even more the DNA release mechanisms. Among these ways, we have optimized and perfected the coaxial electrospinning technique, where we have successfully encapsulated DNA in a core-polymer that is hydrophilic, shelled by a water- and heat-resistant polymer.

Materials and Methods - Polymer solutions. Four batches are prepared: 1) core hydrophilic polymer, 2) shell water-resistant polymer, these two for coaxial electrospinning; 3) hydrophilic polymer (same as core polymer), 4) water-resistant polymer (same as shell polymer), these two for blend electrospinning on their own. For a homogeneous dissolution, each polymer solution is left stirring overnight.

- DNA encapsulation. A specific concentration of encoded data-DNA is added to the core polymer solution for coaxial electrospinning, and to the control water-resistant polymer for blend electrospinning. For a homogeneous mix, these added DNA solutions are left stirring some time.

- Coaxial electrospinning set-up. Using optimum needle systems, core-shell electrospinning is performed, applying high voltage at the final needle end.

- Blend electrospinning is used for the control hydrophilic and hydrophilic polymers.

- Environmental Scanning Electron Microscopy (ESEM) characterization. To verify the core-shell structure of the fibers, ESEM humidity measurements are performed. At ESEM, flooding cycles are run to check the water-resistance of each sample. If the fibers have a core-shell structure, the shell and subsequently the fiber morphology should remain intact.

- DNA passive release and aging experiments. DNA release is compared between DNA-in-core-shelled coaxial nanofibers and DNA in blend hydrophobic polymer electrospun fibers. Accelerated aging experiments are performed to check and compare the on-demand DNA release and integrity in both systems.

Results The control group of hydrophilic fibers, representing the core polymer, followed the expected outcome after two humidity cycles by completely merging when observed under ESEM. In contrast, the coaxial samples successfully survived these humidity cycles, with the fibers adopting the characteristics of the shell upon exposure due to the shell being thicker than the core, based on needle diameter.

When evaluating the hydrophobic/DNA blend electrospun nanofibers, two limitations were observed; this formulation does not allow control over DNA location along the fibers, leaving it unclear whether the DNA is fully encapsulated or partially exposed on the surface. Also, the blend mesh lacks any control over DNA release.

The coaxial fibers demonstrated better performance by preventing any DNA release when immersed in water, highlighting no significant passive release from the core component compared to the blend electrospun fibers. Instead, the shell provides targeted, on-demand release under specific conditions. This encapsulation efficiency was further proven in aging experiments, where the coaxial fibers survived with no DNA release in water. Release was achieved exclusively after dissolving the shell, all while keeping the DNA integrity during the aging process.

Conclusions Coaxial electrospinning offers a second layer of protection to the encapsulated DNA, and allows longer-term storage under ambient conditions, without affecting the integrity of the stored data/DNA. These shell/core nanofibers offer a localized DNA encapsulation characteristic and an on-demand data retrieval, triggering the DNA release under specific conditions.

Key words Coaxial electrospinning, DNA data storage, DNA encapsulation, on-demand data retrieval

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98 - IN SITU MONITORING OF HUMIDITY EFFECT DURING ELECTROSPINNING AND ITS IMPACT ON FINAL MAT STRUCTURE

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Background/Rationale Electrospinning is a versatile technique for producing nanofibrous materials for a wide range of emerging technologies[1]. The electrohydrodynamic behavior of polymer jets during flight strongly influences fiber morphology at length scales ranging from the non-woven mat, the nanofibers themselves down to the polymer crystal, and thus, the resulting final properties of the produced material. Among the several processing parameters, relative humidity plays a critical role in controlling solvent evaporation and polymer solidification kinetics, thereby affecting the diameter, porosity and morphology of the fibers. Its effect depends strongly on polymer hydrophilicity. For hydrophilic polymers, high relative humidity slows down evaporation and delays solidification, leading to finer but often irregular fibers with beads-on-a-string morphologies. Conversely, for hydrophobic polymers, water vapor acts as a non-solvent, promoting rapid polymer precipitation and generating thicker or porous fibers through phase separation or condensation mechanisms [2].

Materials and Methods In this work, several methodologies were developed to visualize the electrospinning jet using high-speed imaging and fluorophore-assisted observation, as well as to monitor surface potential during and after deposition [3]. Experiments were performed using aqueous PVA solutions under relative humidity conditions ranging from 20 to 65%. The structural properties of the resulting mats were characterized by SEM for fiber diameter analysis and by capillary flow porometry for mean pore size measurement.

Results Online visualization revealed that increasing relative humidity strongly affected jet instabilities, thereby modifying fiber deposition on the collector as shown by SEM images of mats. Simultaneously, surface potential measurements during deposition provided insights into the evolution of the fibrous structure. The characteristic discharge time (τ_m), interpreted using a resistance-capacitance (RC) model [4], correlated with the structural organization of the fibrous membrane. These observations were further supported by pore size measurements obtained by capillary flow porometry. The combined online monitoring and structural characterization methodology enabled the establishment of a correlation between surface potential discharge behavior and pore size which was tested for different types of formulations.

Conclusions Overall, the developed methodology provides a powerful approach for real-time monitoring of electrospinning dynamics and the prediction of final mat morphology. The approach can be extended to hydrophobic polymers and paves the way for new opportunities for controlling the design and structural properties of advanced nanofibrous materials through humidity regulation.

Key words jet visualization, Instability of jet, electrical properties, fibrous structure, humidity

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103 - ELECTROSPUN MULTIFUNCTIONAL AND TUNABLE POLYSTYRENE COMPOSITES WITH CONTROLLED WATER HARVESTING AND THERMAL PROPERTIES

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Background/Rationale

Polystyrene (PS), known for its hydrophobic nature and low thermal conductivity, can be engineered into multifunctional materials via electrospinning. This process enables the formation of micro- and nanofibrous meshes with high surface area, allowing control over wettability, mechanical properties, and heat transport. Incorporating secondary polymers or functional fillers further expands their functionality, enabling the design of advanced systems addressing both water scarcity and energy efficiency. In this work, we develop multifunctional and tunable electrospun PS-based composite meshes with tailored architectures for efficient fog water harvesting and adjustable thermal transport, ranging from insulation to enhanced conductivity.

Materials and Methods Polystyrene (PS) was used as the base polymer and combined with polyamide 6 (PA6), cellulose acetate (CA), thermoplastic polyurethane (TPU), and exfoliated graphite (EG) to fabricate composite systems. Electrospun fiber meshes were produced using different configurations, including dual-needle electrospinning for hierarchical PS–PA6 structures, side-by-side electrospinning for Janus PS–CA fibers, coaxial electrospinning for hollow PS–TPU fibers, and blend electrospinning for PS–EG conductive composites. Fog water collection was tested in a controlled chamber, and efficiency was determined by measuring collected water mass over time and normalizing it to mesh area for PS–PA6 and PS–CA systems. Thermal behavior was analyzed using a heating plate combined with thermal imaging to monitor temperature evolution and evaluate conductivity (PS–EG) and insulation performance (PS–TPU).

Results Electrospun PS-based composites combining hydrophobic PS with hydrophilic PA6 or CA were successfully fabricated as hierarchical and Janus fibre structures. The hydrophilic domains enhanced droplet capture, whereas hydrophobic PS promoted water transport and drainage, leading to improved fog collection efficiency. Optimized PS–CA Janus fibers achieved collection rates of $\sim 71 \text{ mg} \cdot \text{cm}^{-2} \cdot \text{h}^{-1}$, while hierarchical PS–PA6 meshes reached $\sim 56 \text{ mg} \cdot \text{cm}^{-2} \cdot \text{h}^{-1}$, both outperforming pristine PS ($\sim 45 \text{ mg} \cdot \text{cm}^{-2} \cdot \text{h}^{-1}$). These results demonstrate that controlling the hydrophobic–hydrophilic balance is essential for efficient water harvesting. The thermal behaviour of PS-based composites was effectively tuned through structural engineering and filler incorporation. Hollow and porous PS–TPU fibers produced by coaxial electrospinning exhibited low thermal conductivity ($\sim 0.031 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$), providing lightweight thermal insulation. In contrast, PS–EG composites showed enhanced heat transfer due to conductive pathways formed by exfoliated graphite, with thermal imaging revealing surface temperature increases of $\sim 2.5 \text{ }^{\circ}\text{C}$ under heating. Overall, the electrospun PS systems demonstrated multifunctional and tunable thermal performance ranging from insulation to enhanced conductivity.

Conclusions Electrospun PS-based composites provide a promising approach for the development of multifunctional materials with adjustable properties. Through careful control of fibre architecture and composition, the obtained systems can combine efficient fog water collection with tunable thermal performance, ranging from thermal insulation to enhanced heat transfer. The ability to tailor these functionalities highlights the potential of electrospun PS composites for sustainable technologies related to water harvesting and energy-efficient thermal management.

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Key words fibers, electrospinning, fog water collection, thermal conductivity, thermal insulation

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109 - ENHANCED PIEZOELECTRIC RESPONSE OF ELECTROSPUN P(VDF-TRFE) NANOFIBERS VIA TRIFUNCTIONAL CROSSLINKING

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Background/Rationale Piezoelectric polymers are functional materials that convert external mechanical deformation into electrical signals through changes in their internal polarization state. Among them, poly(vinylidene fluoride-co-trifluoroethylene) [P(VDF-TrFE)], a copolymer of poly(vinylidene fluoride) (PVDF), readily forms a highly polar β -phase because the steric hindrance introduced by TrFE units favors an all-trans chain conformation. However, due to the restricted dipole-dipole polarization mobility within dense lamellar structures, the mechanical-to-electric polarization behavior is suppressed, resulting in large coercive fields and insufficient spontaneous polarization. To overcome these limitations, we introduced trifunctional crosslinking into P(VDF-TrFE) chains and synergistically integrated this crosslinking strategy with electrospinning to increase the polar crystalline fraction. The electrospinning process induces highly polar uncoiled chain segments through chain stretching and orientation, while the crosslinked network serves to relax dense lamellar packing and create a locally less constrained environment, thereby facilitating dipole reorientation and improving polarization switching mobility.

Materials and Methods P(VDF-TrFE) precursor solutions were prepared by incorporating benzoyl peroxide (BPO) as a radical initiator and triallyl isocyanurate (TAIC) as a trifunctional crosslinker at concentrations of 0, 3, 5, 7, 9 wt% (relative to polymer). The solutions were electrospun at an applied voltage of 9.5–10.5 kV and a flow rate of 500 $\mu\text{L h}^{-1}$ for 4 h to produce nanofiber mats, followed by thermal annealing at 120 °C for 3 h to induce peroxide-radical-mediated crosslinked network formation. Solution-cast films with identical compositions were prepared as comparative counterparts. Fiber morphology was examined by scanning electron microscopy (SEM), and the polar β -phase fraction was evaluated by FT-IR spectroscopy. Thermal and crystalline characteristics were analyzed by DSC and X-ray diffraction (XRD), respectively. Local electromechanical response and polarization switching behavior were assessed by piezoresponse force microscopy (PFM), from which amplitude responses and coercive voltage spans were extracted.

Results Electrospun P(VDF-TrFE) nanofiber mats preserved a continuous fibrous morphology after thermal annealing, with average fiber diameters remaining in the ~600–700 nm range without a clear monotonic dependence on crosslinking density. FT-IR analysis showed that the β -phase fraction remained substantially higher in nanofibers (~69–74%) than in solution-cast films (~54–58%) across all crosslinker contents, confirming the effectiveness of electrospinning in constructing a polar crystalline framework, while crosslinker incorporation caused only minor phase-composition changes. XRD patterns remained nearly unchanged before and after thermal annealing regardless of crosslinker contents, indicating that network formation did not induce a major crystalline phase transformation. In contrast, DSC revealed a progressive decrease in nanofiber crystallinity from ~68% to ~47% with increasing crosslinker contents, suggesting partial relaxation of densely packed crystalline domains without disrupting the primary polar framework. Consistent with this structural modulation, PFM showed enhanced local electromechanical behavior: the piezoresponse amplitude increased from ~0.5 to 1.4 mV, while the coercive voltage span decreased from ~10 to 4 V. These trends were not observed in solution-cast films, supporting the synergistic effect of electrospinning-induced polar chain organization and trifunctional crosslinking.

Conclusions These results demonstrate that trifunctional crosslinking and electrospinning cooperatively regulate the structure–polarization relationship of P(VDF-TrFE) nanofibers. Electrospinning establishes a highly polar crystalline framework, while crosslinked network formation modulates crystalline packing without inducing a major phase transformation, thereby facilitating local dipole switching and enhancing electromechanical response. This work provides a structural design strategy for improving the functional polarization behavior of piezoelectric polymer nanofibers.

Key words Electrospinning, P(VDF-TrFE) nanofibers, piezoelectric polymer, trifunctional crosslinking

110 - SOLVENT-DRIVEN STRUCTURE-PROPERTY TAILORING OF ELECTROSPUN PVDF-HFP NANOFIBERS FOR PASSIVE RADIATIVE COOLING APPLICATIONS

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Background/Rationale Passive daytime radiative cooling (PDRC) has emerged as a promising energy-free strategy to address the increasing global demand for sustainable cooling technologies¹. PDRC materials are designed to maximize solar reflectance in the 0.3–2.5 μm spectral range, while exhibiting high thermal emittance within the atmospheric transparency window (8–13 μm)². Among the available fabrication approaches, electrospinning has attracted considerable interest because it enables the production of highly porous nanofibrous coatings with controllable morphology, large surface area, and enhanced light-scattering capability³. In particular, electrospun poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) is considered an attractive material for PDRC due to its negligible solar absorption and selective infrared emissivity associated with C–F bonds.

Beyond material selection, the solvent system plays a critical role in determining the final fiber architecture and, consequently, the optical response of electrospun coatings. Solvent properties such as volatility, viscosity, conductivity, and polymer–solvent interactions directly influence jet stability, fiber formation, diameter distribution, porosity, and surface morphology⁴. Therefore, solvent engineering represents an effective strategy for structure–property tailoring of electrospun materials. Moreover, conventional electrospinning of PVDF-HFP typically relies on toxic or hazardous solvents, including N,N-dimethylformamide (DMF), dimethylacetamide (DMA), and acetone-based systems. The development of safer alternatives is therefore essential to improve process sustainability. In this work, the effect of the complete substitution of conventional solvents (i.e., acetone) on the fiber design was investigated by using dimethyl sulfoxide (DMSO), a less hazardous solvent, as the sole solvent for the electrospinning process.

Materials and Methods PVDF-HFP Kynar Flex® 2801 copolymer powder was supplied by Arkema, while DMSO and acetone were purchased from Sigma Aldrich (Milan, Italy). A 20 wt.% PVDF-HFP solution was prepared using pure acetone, pure DMSO, or acetone/DMSO mixtures with different ratios, followed by magnetic stirring at room temperature for 3 h.

Electrospinning was performed using an E-fiber system (SKE Research Equipment) with a flow rate of 1 mL h^{−1}, a tip-to-collector distance of 15 cm, a 1 mm spinneret, and an applied voltage of 6–15 kV. Coatings were deposited on aluminum substrates for 45–180 min to optimize thickness, process stability, and surface uniformity.

Morphology and fiber diameter distribution were analyzed by FE-SEM (ZEISS Supra 40) and ImageJ software. Wettability was evaluated through water contact angle measurements using the sessile drop method, while optical properties were characterized by UV/VIS/NIR and FTIR spectroscopy with integrating sphere.

Results The electrospinning process was optimized by tuning both solution properties and processing parameters, enabling the fabrication of stable and uniform PVDF-HFP nanofibrous coatings with all the investigated solvent systems. Well-defined, continuous, and homogeneous fibers confirmed the feasibility of using DMSO as the sole solvent for PVDF-HFP electrospinning.

The resulting nanofibrous coatings reached a thickness up to ~1 mm and exhibited pronounced hydrophobicity (water contact angle >120°). FE-SEM analysis revealed that the solvent system strongly influenced fiber morphology and diameter distribution, highlighting the key role of solvent engineering in structure–property tailoring. In particular, DMSO-based coatings exhibited fibers with an average diameter of ~780 nm, broad size distribution (FWHM $\approx$ 500 nm), and hierarchical porous morphology, features that enhance solar light scattering and thermal emission. Consequently, DMSO-derived coatings showed lower UV–Vis–NIR absorbance (α = 0.05), higher solar reflectivity (SR = 96%), and improved sub-ambient cooling performance, compared with acetone-derived counterparts.

Conclusions This study demonstrated the feasibility of completely replacing conventional hazardous acetone-based systems with DMSO for the electrospinning of PVDF-HFP nanofibrous coatings for PDRC applications, while simultaneously enhancing their radiative cooling performance. Beyond improving process sustainability and safety, solvent substitution actively tailored nanofiber morphology and influenced the optical and thermal properties of the coatings. These findings highlight solvent engineering as an effective strategy for structure–property optimization and scalable design of electrospun materials for PDRC applications.

Key words Nanofibrous coatings; passive radiative cooling; PVDF-HFP; dimethyl sulfoxide; mat morphology; optical properties.

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113 - DIRECT ELECTROSPINNING OF SHORT FIBERS WITH CONTROLLED DIMENSIONS FOR COMPOSITE REINFORCEMENT

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Background/Rationale Short polymer fibers are widely used as reinforcements in composite materials because they can improve stress transfer, toughness, impact resistance, and processability. However, conventional methods for producing short fibers, such as mechanical cutting, homogenization, or ultrasonication of continuous electrospun mats, often generate fibers with broad length distributions, uncontrolled aspect ratios, and surface defects. These limitations reduce reproducibility and may negatively affect composite performance. This study investigates direct electrospinning as a one-step strategy for producing short poly(methyl methacrylate) (PMMA) fibers with controlled diameter, length, and aspect ratio, eliminating the need for post-processing.

Materials and Methods PMMA was used as a model polymer. Continuous fibers were electrospun from 12 wt% PMMA with high molecular weight, while short fibers were directly electrospun from 52 wt% PMMA with low molecular weight. Electrospinning was carried out using a single-nozzle system under controlled temperature and humidity. The effects of applied voltage, nozzle-to-collector distance, electric field strength, and polymer solution flow rate were investigated. For comparison, continuous PMMA mats were homogenized for 10, 30, and 60 minutes to produce mechanically chopped fibers. Fiber morphology and dimensions were analyzed using scanning electron microscopy, while high-speed imaging was used to observe polymer jet behavior during continuous and short fiber formation. Differential scanning calorimetry and FTIR spectroscopy were applied to verify possible structural changes in the produced fibers.

Results High-speed imaging revealed clear differences between continuous and short-fiber electrospinning. Continuous fiber formation involved a stable jet with bending instability and whipping, whereas short-fiber electrospinning showed jet breakage and omission of the whipping stage. Direct electrospinning enabled the production of PMMA short fibers with diameters below 1 μm and lengths around 4 μm , as well as larger fibers with diameters of a few micrometers and lengths up to approximately 14–15 μm . Increasing applied voltage from 10 to 23 kV reduced the average fiber diameter from $2.36 \pm 0.73 \mu\text{m}$ to $0.87 \pm 0.24 \mu\text{m}$ and the average fiber length from $13.30 \pm 6.95 \mu\text{m}$ to $3.79 \pm 1.86 \mu\text{m}$. The polymer flow rate and nozzle-to-collector distance also significantly influenced fiber dimensions and aspect ratio. In contrast, homogenization reduced fiber length with increasing processing time but produced broader length distributions and visible microcracks on the fiber surface. Thermal and FTIR analyses showed no major structural changes caused by either direct electrospinning or homogenization.

Conclusions Direct electrospinning provides a precise and reproducible route for manufacturing short PMMA fibers with narrow size distributions and controlled aspect ratios. Compared with homogenization, this method avoids mechanical damage and enables better control over both fiber diameter and length. The results show that electrospinning parameters can be used as effective tools to tune short-fiber morphology for future applications in polymer composites, hydrogels, sponges, drug delivery systems, and other fiber-reinforced materials.

Key words Short fibers; electrospinning; PMMA; polymer composites; fiber reinforcement; homogenization; aspect ratio

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121 - HYBRID ELECTROSPINNING FOR STRUCTURE-PROPERTY TAILORING OF NANOFIBROUS SCAFFOLDS

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Background/Rationale Electrospinning is a well-established method to produce nanofibrous materials with high specific surface area, interconnected polymer network and controlled porosity, and tuneable fibre diameter and morphology, enabling the design of functional biomaterials. Despite its versatility, electrospinning charged biopolymers remains difficult because strong intermolecular interactions and unfavourable rheological characteristics can suppress stable jet elongation, promote defects, and yield mechanically weak fibre networks.

Materials and Methods A hybrid electrospinning approach was reported in which positively charged lipid nanoparticles are integrated into a negatively charged biopolymer system to modulate electrostatic interactions and overcome the surface tension during jet formation. The embedded nanoparticles significantly enhance electrospinnability, yielding improved jet stability and more controlled nanofibre architectures. Structure-mechanical analysis via tensile-SAXS studies demonstrates that these electrostatic interactions promote fibre cohesion and cross-linking.

Results Systematic tuning of solution composition and electrospinning conditions controlled nanofibre morphology and mechanical performance, as demonstrated by imaging techniques and cell studies.

Conclusions Our findings demonstrate that the hybrid electrospinning can be used to bring additional functionality to nanofiber materials, offering new applications in tissue engineering and cultivated meat manufacturing.

Key words Electrospinning, Lipid-Polymer hybrid biomaterials, Nanofiber, structure-function correlation

131 - CROSS-DIMENSIONAL BIOMIMETIC FIBROUS ARCHITECTURES FOR FILTRATION, ACOUSTIC PROTECTION, AND THERMAL MANAGEMENT

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Background/Rationale High-performance fibrous materials increasingly rely on precise control of micro- and nanoscale architectures to achieve integrated functions. Natural systems provide useful structural models for this purpose, including the efficient interception networks of spider webs, the solar-harvesting behavior of sunflowers, and the hollow thermal-insulation structures of polar bear fur. Inspired by these biological interfaces and internal architectures, this study develops environmentally friendly fibrous systems that combine air filtration, acoustic protection, photothermal conversion, electrothermal regulation, and passive thermal insulation.

Materials and Methods For spider-web-inspired two-dimensional (2D) membranes, a super-spreading phase inversion strategy was used to regulate polymer-solution spreading on nanoscale fiber surfaces. Solvent evaporation and non-solvent-induced phase separation (NIPS) were coordinated to construct monolayer nanonetworks with bubble-raft-like features. Electro-netting was then applied to tune the interactions within a metastable green polymer/solvent/nonsolvent system, enabling self-assembly of a Centroidal Voronoi Tessellation (CVT)-like topology and the fabrication of fluorine-free biomimetic spider-web membranes.

For biomimetic porous and hollow fibers, the solar-harvesting mechanism of sunflowers was translated into a dual-aerogelation strategy. Size-matched carbon black (CB) nanoparticles were introduced in situ into the nanopores of transparent poly(methyl methacrylate) (PMMA) fibers to form a hierarchical porous aerogel architecture. In parallel, carbon nanofiber super-fabrics with confined hollow cavities were fabricated through phase separation during aerogelation, mimicking the thermal-insulation mechanism of polar bear fur.

Results The 2D spider-web membranes, with nanoscale fiber diameters of approximately 40 nm and a monolayer architecture, showed high porosity (90.3%), small pore size (approximately 270 nm), and an ultrathin thickness of approximately 800 nm. These structural features enabled efficient, low-resistance air filtration, achieving 99.8% removal efficiency for particulate matter with an aerodynamic diameter of 0.3 micrometers (PM_{0.3}) at a pressure drop below 40 Pa. The CVT topology also provided strong protective performance, with hydrostatic pressure reaching the 100 kPa level, while maintaining excellent acoustic transparency across 0.1-20 kHz with acoustic loss below 1 dB. This combination helps resolve the common trade-off between environmental protection and acoustic transmission in microelectronic devices.

The PMMA/CB energy-storage fiber membranes improved thermal storage and passive thermal performance, achieving a radiant energy retention rate of 65% and a low thermal conductivity of 15.8 mW m⁻¹ K⁻¹. The biomimetic hollow carbon fibers, with diameters of approximately 75 nm, contained continuous internal channels that suppressed out-of-plane heat transfer. Their porous shell structure, with pore size of approximately 22 nm and specific surface area of approximately 800 m² g⁻¹, enabled thermal regulation through the Knudsen effect and Anderson localization. The fibers also demonstrated efficient photothermal conversion, with a temperature increase of up to 44 degrees Celsius; broad electrothermal tunability from 28 to 163 degrees Celsius; and strong passive thermal insulation, maintaining a surface temperature 4 degrees Celsius lower than that of commercial cotton fabrics and closer to ambient conditions.

Conclusions This work demonstrates a biomimetic design route from 2D interfacial networks to hierarchical aerogel fibers. Spider-web-inspired topological design enables low-resistance air filtration and acoustic transparency, while sunflower- and polar bear fur-inspired porous and hollow architectures enhance thermal regulation by suppressing heat conduction and strengthening energy harvesting. This cross-dimensional biomimetic strategy offers a general design paradigm for next-generation eco-friendly protective equipment and flexible thermal-management systems.

Key words Biomimetic design; Nanofibers; Two-dimensional networks; Aerogel fibers; Phase separation

132 - HYBRID ELECTROSPINNING-ELECTROSPRAYING FABRICATION OF PVDF-HFP/PLGA NANOPLATFORMS FOR LOCALIZED CANCER THERAPY

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Background/Rationale Localized drug delivery systems offer an attractive strategy for cancer treatment by enhancing drug concentration at the tumor site while minimizing systemic toxicity [1]. Although polymeric nanoparticles have demonstrated significant potential as drug carriers, achieving sustained local drug retention remains challenging due to rapid diffusion and burst-release phenomena. To address these limitations, this study proposes a hybrid nanoplatform combining electrospun fibrous scaffolds with electrosprayed drug-loaded nanoparticles, aiming to provide controlled and localized chemotherapy delivery.

Materials and Methods Hybrid nanoplatforms were fabricated by integrating electrospun poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) fibers with electrosprayed poly(lactic-co-glycolic acid) (PLGA) nanoparticles. Electrospray processing parameters, including polymer concentration, applied voltage, collector configuration, and solvent system, were systematically investigated to optimize nanoparticle morphology and size distribution. Different solvent systems, including hexafluoroisopropanol (HFIP), dichloromethane (DCM), and DCM:methanol (70:30 v/v), were evaluated. Fluorescein sodium salt and doxorubicin hydrochloride were selected as model compounds for encapsulation within PLGA nanoparticles. Morphological characterization was performed using microscopy techniques, while chemical characterization confirmed the successful integration of fibers and nanoparticles. Drug release studies were conducted to evaluate release kinetics and retention behavior.

Results Electrospray parameters significantly influenced nanoparticle morphology. Using HFIP, higher polymer concentrations generated larger spherical particles and, under certain conditions, particle-fiber mixtures. In contrast, DCM-based formulations produced particle-only structures, with morphology strongly dependent on concentration and applied voltage. The DCM:methanol solvent system yielded the most uniform spherical nanoparticles across all tested conditions, resulting in optimized particles with an average diameter of approximately $0.3 \pm 0.1 \mu\text{m}$.

The hybrid fabrication strategy successfully enabled the deposition of drug-loaded PLGA nanoparticles onto PVDF-HFP fibrous substrates. Microscopy observations confirmed homogeneous nanoparticle distribution on the fiber surface for both fluorescein- and doxorubicin-loaded formulations. Chemical characterization further verified the successful incorporation of both polymeric components.

Drug release studies demonstrated the advantages of the hybrid architecture. Fluorescein-loaded PLGA nanoparticles immobilized on PVDF-HFP fibers exhibited reduced burst release and a more sustained release profile compared with free nanoparticles. Doxorubicin-loaded systems showed high drug retention, maintaining approximately 76% residual drug content after 24 hours, indicating effective encapsulation and controlled release behavior. These findings suggest that the fibrous scaffold contributes to prolonging drug residence time while supporting localized delivery.

Conclusions A hybrid electrospinning-electrospraying approach was successfully developed to fabricate PVDF-HFP/PLGA nanoplatforms for localized cancer therapy. Optimization of electrospray conditions enabled the production of uniform PLGA nanoparticles with controlled morphology and size. The resulting hybrid systems exhibited reduced burst release, enhanced drug retention, and sustained release characteristics, demonstrating their potential as localized chemotherapy delivery platforms. This strategy represents a promising route toward advanced nanostructured systems for controlled anticancer drug administration.

Key words Electrospinning; Electrospraying; PVDF-HFP; PLGA Nanoparticles; Local Drug Delivery

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141 - A FRAMEWORK FOR OVERCOMING THE ELECTROSPINNING STABILITY-QUALITY-SAFETY TRADE-OFF

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Background/Rationale Fluoropolymers such as poly(vinylidene fluoride-co-trifluoroethylene) (P(VDF-TrFE)) are piezoelectric, and popular in sensing, energy harvesting, and tissue engineering applications. While electrospinning is the preferred fabrication method for fibrous membranes with high crystallinity and piezoelectricity, the process historically relies on toxic solvents such as dimethyl formamide, posing significant health risks and limiting end-use in biomedical or food-related domains. When other less toxic solvents are sometimes used, they pose other challenges: While low-boiling solvents are capable of generating uniform fibres, they often lead to the formation of dendrites that block the nozzle. This necessitates frequent manual cleaning and constant adjustment of process parameters, ultimately undermining the reliability and consistency of the recipe. Conversely, high-boiling solvents support a stable, undisturbed process, at the cost of poor-quality fibres featuring beads or cross-welds. We present a framework to identify ideal solvents based on their chemical interactions with the polymer as well as their physical properties, and apply the same to demonstrate a balance between process stability and fibre quality, while simultaneously prioritising chemical safety.

Materials and Methods In our study of electrospun P(VDF-TrFE), we systematically investigated the dual impact of solvent boiling point on process stability and fibre morphology. Beginning with established yet suboptimal solvents such as acetone, 2-butanone, dimethyl sulfoxide, and N-methyl-2-pyrrolidone, we applied the concept of Hansen Solubility Parameters alongside the fundamental organic chemistry principles of molecular structure to navigate the chemical space. This methodology allowed us to identify a non-toxic solvent that ideally suited our experimental requirements.

Subsequently, the effects of spinning distance and feed rate were investigated to optimise fibre diameter, alignment, and crystallinity. We have also looked into the poling process on P(VDF-TrFE) fibres, specifically evaluating how piezoelectric coefficients are affected by poling parameters and mat thickness.

Additionally, we introduced an innovative, automated image-analysis protocol designed to quantify fibre orientation through two key metrics: Sharpness (A_s) and Degree (A_d) of Alignment. These are defined as statistical aggregates of the image-processing outputs, providing a robust method for handling extensive datasets. This system was specifically engineered to assess alignment quality while eliminating subjective human error and bias.

Results Through our solvent selection framework, 2-pentanone was found to be ideal for our work, with optimal volatility, solvency, and safety characteristics. It enabled us to develop a robust, "set-and-forget" recipe for producing high-quality aligned P(VDF-TrFE) fibres, opening new avenues for the sustainable fabrication of functional polymer membranes. Our findings reveal that P(VDF-TrFE) fibres processed with 2-pentanone exhibit high-quality mutual alignment and a ferroelectric phase content comparable to those produced using traditional toxic solvents, as confirmed by Fourier-transform infrared spectroscopy, differential scanning calorimetry, and X-ray diffraction.

Further, we have observed through quantitative assessments that the quality of mutual alignment of electrospun fibres has an inverse relationship with the feed rate and a direct relationship with the spinning distance. Finally, we will present findings from our ongoing evaluations regarding the poling effect, specifically detailing how mat thickness and poling parameters influence the final piezoelectric coefficients.

Conclusions This study leads to a more general framework to optimise electrospinning recipes with a high level of process stability, ease, and consistency, which produce high-quality output. This is all achieved while minimizing health and environmental risks due to solvent chemistry. We hope that our approach to characterizing fiber alignment through the quality metrics A_s and A_d , and the insights on the effects of process parameters presented in this paper, will be of help to the electrospinning community.

Key words Green electrospinning, process stability, solvent selection, alignment quantification, functional nanofibres

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144 - ULTRALIGHT AND SUPERELASTIC POLYIMIDE CURLY NANOFIBROUS AEROGELS FOR HIGH-PERFORMANCE THERMAL INSULATION UNDER EXTREME TEMPERATURE

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Background/Rationale Maintaining human body temperature is one of the basic needs for living, which requires high-performance thermal insulation materials to prevent heat exchange with external environment. However, the most widely used fibrous thermal insulation materials always suffer from the heavy weight, weak mechanical property, and moderate capacity to suppress heat transfer, resulting in limited personal cold and thermal protection performance. The burgeoning nanofibrous aerogel, which realizes the porous aerogel structure by constructing the nanofibers into 3D architectures, can be an alternatively next-generation thermal insulation material for personal protection under extreme temperature. Recently, electrospun nanofibers were reconstructed into the highly porous nanofibrous aerogels by freeze-drying method by freeze-drying method, thus improving the capacity to reduce the heat exchange. However, the resulted aerogels always undergo unpredictable pore structures and weak mechanical property in the applications, since the porous structures are built by removing randomly growing ice crystals between discontinuous staple fibers. Moreover, the disadvantages of complex process and long manufacturing time caused by the complicated and immature equipment limit the direct and facile synthesis of nanofibrous aerogels. The challenge is to directly construct an ultralight and mechanically robust nanofibrous aerogel with both robust extreme temperature tolerance and high-efficiency thermal insulation performance.

Materials and Methods The synthesis process of PI curly nanofibrous aerogels, which involves multiple-jet ejection of charged fluids, formation and interlock of curly nanofibers, and imidization cross-linking reaction. With regulating the charge density of the polyamide acid (PAA) fluids, the concentration of electrical field on the tip of Taylor cone was suppressed and turned to the edge of the nozzle, thereby enabling the formation of multiple jets. Under the high-voltage electric field, the stability of the ejected jets noticeably decreased and the jets experienced whipping instability, leading to a curly structure; subsequently, the rapid phase inversion of whipping hydrophobic jets caused the formation of curly nanofibers. Just as the formation of molecule chains cross-linked networks during the gelation process, the abundant hydrophobic curly nanofibers interlocked with each other to create the stable 3D aerogel structure. Ultimately, the resulted porous structure was further strengthened during the imidization cross-linking process, in which the cross-linking points were generated with PAA transforming into PI component.

Results The obtained polyimide (PI) curly nanofibers with diameter of ~750 nm and crimp percentage of 28.5%, for the first time, are created and further interlock with each other to form unique 3D porous aerogel structure with small pore size (~1.57 μm) and high porosity (99.8%). The synergistic effect of these structure characteristics allows the aerogel to exhibit ultralight weight (volume density of 2.4 mg cm^{-3}), robust mechanical property (plastic deformation of nearly 0% over 1000-cycle stretching or compression), and remarkable thermal insulation performance (ultralow thermal conductivity of 22.4 $\text{mW m}^{-1} \text{K}^{-1}$). Moreover, the PI nanofibrous aerogel also exhibits extreme temperature tolerance with significant flame retardance and structural stability over a wide temperature range from -196 $^{\circ}\text{C}$ to 300 $^{\circ}\text{C}$, thus enabling the promising candidates for personal protection under extreme temperature.

Conclusions In this work, we demonstrate a unique method for creating ultralight and mechanically robust polyimide PI curly nanofibrous aerogels for high-performance thermal insulation based on multiple-jet electrospinning technique. Such fascinating PI curly nanofibrous aerogel, which function as high-performance thermal insulators, will provide numerous opportunities for applications in individual protection, energy, and engineering.

Key words polyimide curly nanofibers, nanofibrous aerogels, ultralight, extreme temperature tolerance, thermal insulation

147 - HIGH-PERFORMANCE AND SUSTAINABLE FUNCTIONAL PAPER COATINGS VIA ELECTROHYDRODYNAMIC PROCESSING

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Background/Rationale In 2023, the European Union generated 79.7 million tonnes of packaging waste, with paper and cardboard, representing 40.4% of the total [1]. Despite their widespread use, these materials present notable limitations for food packaging applications due to their low barrier performance and inherent hydrophilicity [2]. In this context, the development of paper-based packaging with sustainable biopolymer coatings has emerged as a key strategy, since these coatings could not only improve barrier properties and resistance to water and grease, but also enable additional functionalities, such as active properties, while addressing environmental concerns.

Among the available technologies, room-temperature electrohydrodynamic processes stand out as a particularly promising alternative, since these techniques allow the deposition of ultrathin layers without direct solvent–substrate contact, thereby preserving the integrity of the cellulosic matrix, as well as preserving thermolabile compounds. Within this framework, the present study provides a comprehensive assessment of the potential of electrohydrodynamic techniques for paper coating.

Materials and Methods Different biopolyesters were selected for the development of sustainable coatings due to their demonstrated potential in food packaging applications. The use of additives such as lignocellulosic fillers and waxes was also considered to enhance the barrier, hydrophobicity and surface properties. A Fluidnatek LE-500 (Bioinicia S.L., Valencia, Spain) was used to coat paper substrates, which were subsequently fixed onto the paper substrates through a thermal post-treatment (4122-model press from Carver, IN, USA). The coated paper samples were characterized in terms of morphology, barrier performance, water and oil absorptiveness (Cobb test), optical properties, water contact angle (WCA°), grease resistance (Kit test), thermosealability and mechanical behaviour. The coated papers were converted into sachet prototypes, which were evaluated for sealability and packaged-product stability. Finally, prototypes were assessed for biodegradation under industrial composting conditions.

Results By carefully selecting both the processing mode and the biopolymer system, paper-based materials with tailored functionalities were successfully developed. The electrospraying of a low molecular weight biopolyester with waxes followed by a non-contact thermal treatment, enabled the production of a superrepellent paper with a WCA of 145°. When higher molecular weight biopolyesters were employed, electrospun fibers mats with different grammages were fabricated to assess the effect of coating grammage on water vapor barrier performance. Ultrathin coatings did not significantly improve barrier properties; however, they imparted thermosealability and enhanced hydrophobicity (Kit 12). Increasing coating grammage led to improve light transmission, resulting in translucent paper with enhanced barrier properties. The incorporation of suitable fillers into the coating formulation enabled the application of a reduced coating grammage of 10 gsm, while further improving barrier performance, e.g. oxygen transmission rates below 1 cm³/m²·d and water vapour transmission rate below 5 g/m²·d. Based on these findings, best formulation was selected to produce sachets for evaluating the stability of package food simulants and products. The prototype demonstrated a clear extension of shelf-life, confirming the protective effect of the developed coating. Furthermore, the coatings exhibited biodegradation, highlighting their suitability for sustainable packaging applications.

Conclusions This study demonstrates the strong potential of electrohydrodynamic processes combined with biopolymers for advancing high-performance sustainable paper-coating technologies with tailored functionalities. These findings constitute a significant step forward in the development of sustainable paper coating solutions, meeting both industrial requirements and current environmental priorities and regulatory frameworks.

Key words Electrohydrodynamic processing, paper-based packaging, biopolymers, sustainable coatings.

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153 - ELECTROSPUN CELLULOSE ACETATE AND PECTIN BASED HYBRID NANOFIBROUS STRUCTURES FOR FOOD PACKAGING APPLICATIONS

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Background/Rationale Electrospinning is an efficient technique to produce ultrafine fibers and has attracted academic interest since the beginning of 90s. Its simplicity, cost-effectiveness, and flexibility made it a common method utilized in both academic research and in industrial scale productions (Min et al., 2022; Ji et al., 2024). Electrospun nanofibrous mats exhibit lots of advantages such as lightness, enhanced aspect ratio, adjustable porosity, functionality and surface characteristics (Aghababaei et al, 2024). These advantages make them ideal structures for food packaging applications, like tailored bio-coating systems.

The synthesis of sustainable value-added nanofibrous structures from polymers derived entirely from plant wastes via electrospinning is of great importance in terms of green method application, the use of bio-based raw materials, and the development of sustainable materials. This study is a preliminary study for a comprehensive research project aimed at developing bio-coatings for fresh fig coating applications using cellulose acetate and pectin synthesized from fig tree, leaf, and branch wastes. Preliminary study findings conducted with commercial cellulose acetate and pectin are presented here.

Materials and Methods In this study, nanofiber structures with potential applications in food systems were successfully produced using the electrospinning method. Natural and biocompatible cellulose acetate (CA) and pectin polymers were chosen for electrospinning. Since it is difficult to electrospin pectin alone, poly (ethylene oxide) (PEO) was utilized as an auxiliary polymer to acquire nanofiber formation. CA and pectin/PEO pristine nanofibrous structures were produced separately. Moreover, hybrid nanofibrous mats were fabricated via side-by-side electrospinning using two solution feeding syringes and four needle tips. Solution characterizations (electrical conductivity, pH, and viscosity measurements) were performed to analyze whether the solutions exhibited properties within spinnable range. Morphological characterization was conducted using Scanning Electron Microscope (SEM). Surface porosity was quantitatively determined from SEM images with the help of ImageJ software. Structural characterizations were conducted using Fourier-Transform Infrared Spectroscopy (FTIR). Since water vapor permeability (WVP) and water absorption capacity (WAC) properties are critical in food applications, they were evaluated for the created nanofibrous mats. Textural analyses were carried out to investigate the mechanical properties of the mats.

Results Both polymer solutions possessed solution properties within a suitable range for electrospinning process. The SEM images showed that both uniform fiber morphologies and bead on string structures were obtained with two polymer solutions. The porosity of the mats varied depending on the nanofiber morphology. Polymer type directly affected the WVP and the WAC. Since the pectin/PEO nanofibrous structure is more hydrophilic than CA, the WVP and the WAC values were the highest in pristine pectin/PEO mats and the lowest in the CA mats. The values of hybrid structures were moderate. Hydrophilic nature of pectin/PEO was changed by addition of hydrophobic CA to the structure and interaction with water vapor and water absorbance were decreased. In the fingerprint area of FTIR spectra (1500-400 cm⁻¹), pristine nanofibrous mats exhibited different peaks according to the bending and stretching of organic molecules they contained. Some shifts and changes in peak intensities were also observed.

In texture analysis of nanofibrous mats, it was observed that CA mats had higher hardness and deformation resistance than pectin/PEO mats. On the other hand, pectin/PEO mat showed higher compressibility and adhesiveness.

Conclusions The hybrid structure produced using pectin/PEO and CA together allowed for the adjustment of all properties produced within the scope of the study. Tuning the hydrophilicity/hydrophobicity, and mechanical strength properties enabled the resulting hybrid structures to exhibit balanced characteristics for use in food applications.

Overall, the results demonstrate that nanofiber systems produced by electrospinning can be effectively used to obtain suitable barriers and good mechanical properties for food packaging applications. CA and pectin-based hybrid structures have high potential for developing functional and safe coating materials for food preservation purposes.

Key words electrospinning, nanofiber, food packaging, cellulose acetate, pectin

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154 - THE SURFACE STRUCTURE OF MELT ELECTROWRITTEN POLY(CAPROLACTONE) FIBRES, PURE AND WITH CONDUCTIVE ADDITIVES

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Background/Rationale In many cases, tissue engineering requires mechanically strong scaffolds as provided by Melt ElectroWriting (MEW). An instructive example is the stem cell-based therapy against cardiac infarction, where the cardiomyocytes-to-be require a scaffold that sustains heartbeat (10% elongation at 1 Hz) for months. Poly(caprolactone) (PCL) is the material of choice, but electrical conductivity is wished for. Crucial for the mentioned application are the surface structures of pure and modified PCL.

Materials and Methods We employed a plethora of standard methods and tools. The non-standard tools were: Novaspider.com for MEW, FEI Quanta250 for environmental SEM, JPK-Bruker Nanowizard V for AFM, Agilent 5500 for AFM, Attocube Neascope for nanoFTIR

Results We tuned the fibre diameter by melt temperature, distance, voltage, printing speed, and hydrostatic pressure. The geometry of the scaffold can be freely chosen, as also the number of fibre layers. This determines the mechanical characteristics. We here chose realistic conditions of cyclic extension in the Hz range, as present in the heart.

The PCL surface is, as also the bulk, hydrophobic. Each fibre presents microscale spherulites, and nanoscale lines. The height of the lines can be below 5 nm. AFM phase images revealed spots, down to 100 nm in diameter, of unusually low mechanical phase. The analysis by NanoFTIR showed minute frequency shifts of molecular vibrations, which cannot be detected with conventional (far field) FTIR or Raman techniques.

We tested bulk modifications with mixing graphene oxide and poly(pyrrole) to PCL and writing it. Surface modifications were the synthesis of poly(aniline) on the surface of a MEW scaffold, and alternatively sputtering gold on it. Satisfactory conductivity was only attained by the latter technique. Biocompatibility with cardiomyocyte stem cells was good.

Conclusions The unusual micro-and nanoscale features of the apparently smooth and featureless PCL surface point towards semicrystallinity, but also to very localized crystallinity differences, specifically for the ester vibration (COO). We discuss the importance of these features with respect to cell scaffolding. Conductive additives have either little effect or impede MEW. A suitable compromise is gold sputtering, which affects the mechanical behaviour little, and induces electrical conductivity.

Key words Melt electrowriting, PCL, SEM, AFM, IR, Raman, nanoFTIR

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155 - GOING AGAINST GRAVITY: UPWARD ELECTROSPINNING FOR FINER FIBERS WITH SMALLER PORE SIZE

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Background/Rationale While electrospinning research has explored a wide range of process, solution, and environmental parameters, the effects of gravity have received little attention. By systematically comparing three distinct nozzle orientations, we demonstrate that gravity is not merely a background force but a significant factor that can be leveraged to produce fine, uniform nanofibers across diverse polymer systems. As the demand for structural precision in nanofibers increases, it is critical to recognize gravitational force as an important parameter. Despite its potential to alter jet trajectory and Taylor cone stability, gravity remains an under-investigated parameter. This study addresses this gap by investigating how spatial orientation, and thereby the gravitational vector serves as a tunable tool to refine fiber morphology.

Materials and Methods The study utilized three distinct polymer systems: Polystyrene (PS), Polycaprolactone (PCL), and Polyacrylonitrile (PAN). Solutions were prepared using N,N-Dimethylformamide (DMF) and Chloroform. Electrospinning was conducted using a conventional setup with fixed parameters, including voltage, flow rate, and tip-to-collector distance. To isolate the effects of gravity, the apparatus was operated in three spatial orientations: Horizontal Configuration (H→), Vertical Downward Configuration (V↓), where the jet travels with gravity, and Vertical Upward Configuration (V↑), where the jet travels against gravity. The resulting morphologies were assessed via Scanning Electron Microscopy (SEM), with quantitative analysis of fiber diameter and pore distribution performed via ImageJ software.

Results The experimental findings revealed that the V↑ consistently yielded superior morphological refinements. For PS, this orientation suppressed bead formation and reduced fiber diameter from 1.1 μm H→ to 0.5 μm. PCL exhibited the most dramatic shift, with a 62% reduction in diameter and a 70% decrease in standard deviation, indicating significantly enhanced uniformity. While PAN showed a more subtle reduction, it maintained the highest structural precision across all modes. SEM analysis confirmed that these thinner fibers led to more compact mat architectures, with pore sizes in PCL and PS contracting by over a half. Notably, the production yield remained stable across all configurations, confirming that electrospinning against gravity enhances precision without a trade-off in efficiency.

Conclusions While gravity is often considered secondary to electrostatic stress, this study establishes that its magnitude is significant enough to fundamentally alter nanofiber outcomes. In the V↑, gravity opposes jet transport, promoting a tension-dominated jet that undergoes increased extensional deformation. This results in significantly thinner, more uniform fibers and more homogenous pore distributions. By analyzing the axial momentum balance, a generalized relationship was established showing that reversing the spinning direction changes the sign of the gravitational contribution, directly influencing jet attenuation. Ultimately, gravity should be treated as a vital tunable parameter in electrospinning apparatus design. Future work integrating these empirical results with computational modeling will enable the rational design of optimized fiber diameter and pore size (e.g., for cell culture scaffolds, filtration membranes) and industrial-scale nanofiber production.

Key words Electrospinning, Gravitational Effect, Nanofiber Morphology, Fiber Diameter, Pore Size

156 - BEYOND AMBIENT ELECTROSPINNING: MAPPING THE IMPACT OF COLLECTOR TEMPERATURE ACROSS CRYOGENIC AND HIGH-TEMPERATURE REGIMES

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Background/Rationale In electrospinning, research has traditionally focused on parameters such as applied voltage, flow rate, solution concentration, and molecular weight, while collector temperature has remained largely overlooked—typically treated as a fixed ambient condition rather than an adjustable parameter. Yet temperature directly controls solvent evaporation, solution viscosity, and surface tension, which in turn govern jet formation, whipping and elongation, and ultimately fiber diameter, uniformity, and morphology. No systematic study has mapped its influence across a wide thermal range. This study addresses that gap by investigating a broad window from $-40\text{ }^{\circ}\text{C}$ to $110\text{ }^{\circ}\text{C}$, spanning three regimes—cryogenic (-40 to $0\text{ }^{\circ}\text{C}$), ambient (10 to $50\text{ }^{\circ}\text{C}$), and high-temperature (60 to $110\text{ }^{\circ}\text{C}$). Combining many temperature points with four polymers across two solvent systems (aqueous and organic), it provides a complete picture of how thermal energy can tune fiber architecture and production efficiency beyond conventional room-temperature electrospinning.

Materials and Methods Four polymer systems were studied: polyacrylonitrile (PAN), polycaprolactone (PCL), polyvinylpyrrolidone (PVP), and polyvinyl alcohol (PVA). Organic solutions (PAN in DMF; PCL in DMF:HFP) and aqueous solutions (PVP and PVA in deionized water) were prepared using standardized sonication and thermal stirring. Electrospinning used a needleless (wire/coil-based, nozzle-free) countercurrent setup with a rotating drum collector. To isolate the thermal effect, collector temperature was varied across the full $-40\text{ }^{\circ}\text{C}$ to $110\text{ }^{\circ}\text{C}$ range while other parameters were held constant. Fiber morphology was characterized by SEM, and diameter distributions quantified from micrographs using ImageJ. Statistical significance was assessed using Grubbs' test for outliers, followed by one-way ANOVA and the non-parametric Kruskal–Wallis test, in R.

Results In the aqueous systems, both PVP and PVA showed a positive correlation between collector temperature and fiber diameter. PVP diameter rose from $222.5 \pm 77.9\text{ nm}$ at room temperature to a peak of $874.1 \pm 238.6\text{ nm}$ at $91\text{ }^{\circ}\text{C}$, declining slightly to $781.0 \pm 240.7\text{ nm}$ at $110\text{ }^{\circ}\text{C}$ with progressively widening distributions. Its production rate tracked the same trend, climbing from 228 mg/h to a maximum of 1398 mg/h at $91\text{ }^{\circ}\text{C}$ before easing to 1224 mg/h at $110\text{ }^{\circ}\text{C}$. PVA fibers remained smooth and bead-free throughout, with diameters increasing from $302 \pm 85\text{ nm}$ to $820.4 \pm 322.9\text{ nm}$ at $111\text{ }^{\circ}\text{C}$ —most sharply between $52\text{ }^{\circ}\text{C}$ and $72\text{ }^{\circ}\text{C}$ —then plateauing. Notably, PVA production rate followed a U-shaped trajectory, falling to a minimum of 126 mg/h at $71\text{ }^{\circ}\text{C}$ before rebounding to 210 mg/h at $111\text{ }^{\circ}\text{C}$.

The organic systems diverged sharply. PAN displayed a polynomial diameter trend, peaking at $180 \pm 77.4\text{ nm}$ at $34.8\text{ }^{\circ}\text{C}$ before declining, while its fiber quality improved with heat as bead defects diminished and aligned fibers emerged; its production rate fell 78.7% (623.8 to 133.1 mg/h). PCL showed the opposite morphological response: diameter increased 22.8% (294 to 361 nm) with rising temperature, but fiber quality degraded through surface bumps and merging, and production rate fluctuated without a clear trend. Statistical testing confirmed temperature significantly affects fiber diameter for both PAN and PCL ($P < 0.01$), and production rate for PAN but not PCL. Collector temperature thus acts as a dominant driver of both morphology and production dynamics, though the response is highly dependent on the polymer–solvent system.

Conclusions This research highlights collector temperature as a key mechanism for controlling nanofiber characteristics. While heat generally increases fiber diameter, the specific morphological response—bead-defect reduction in PAN or quality degradation in PCL—is highly polymer dependent. The significant differences in production rates (positive for PVP, negative for PAN) further suggest thermal control is essential for process optimization and scalability. These findings matter because they show that, by selecting the appropriate thermal regime, fiber diameter, size distribution, uniformity, morphology, and throughput can all be deliberately engineered for a given polymer–solvent system. The ability to operate seamlessly across cryogenic, ambient, and high-temperature regimes within one platform opens a new dimension of process control, enabling specialized fiber architectures and a practical lever for scale-up that conventional ambient electrospinning cannot provide.

Key words nozzle-free electrospinning; collector temperature; cryo-electrospinning; nanofiber morphology; fiber diameter.

157 - SCALABILITY OF ELECTROSPINNING: OVERCOMING PROCESS CHALLENGES FOR INDUSTRIAL PRODUCTIVITY

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Background/Rationale Electrospinning has proven a versatile technique in industry for material production because of its wide range of material processability, tunable form factors, along with a variety of configuration options, from single-emitter setups to over 5,000 emitters, and needleless techniques.^{1,2} This flexibility combined with precise control of multi-variable parameters enables nanomaterial production tailored for advanced devices, coatings, biomaterials, implants, drug delivery systems, and more.³⁻⁵ However, challenges arise when scaling the electrospinning process, and many have considered the task unfeasible or inefficient. This work illustrates a clear pathway for scalability, specifically navigating challenges associated with process scaling, and highlights an example of current production throughput capabilities using commonly electrospun polymer polycaprolactone⁶ and Fluidnatek electrospinning equipment. Key aspects, challenges, and corresponding solutions of the scale-up process are explored, including environmental control (temperature (T), relative humidity (RH), air flow), emitter quantity and translation, and uniformity of electric field.

Materials and Methods Polycaprolactone (PCL, 80k MW) and hexafluoroisopropanol (HFIP) were blended to form 5-14 w/v% solutions. Electrospun fibers were generated using the solutions and the Fluidnatek LE-500 unit with environmental control. Samples were electrospun using 1-60 emitters (20 Ga, 0.5in blunt needles). A roll-to-roll collector was employed for continuous deposition of PCL fibers onto polyethylene with carbon black (PECB) substrate. Process efficacy was evaluated in terms of solution spinnability, fiber mat macro/micro-uniformity, and process stability. The final sample was electrospun for 4 h with applied voltage (20-21 kV), collector voltage (-2 kV), emitter translation (1.5 cm, 5-20 mm/s), and substrate translation (1-5 mm/s). Fiber morphology was analyzed using Phenom XL SEM (10-15 kV, WD=7.2mm). Fiber mat area density (g/m²) was calculated measuring 9mm diameter samples in triplicate in 13 locations across the final sample.

Results Process stability was achieved as indicated by elimination of emitter dripping/clogging, uninterrupted spinning, and visual homogeneity of the deposited fibers of a representative run with stable development over 4 h. (Process video: <https://vimeo.com/1022603396/0b44e21f9c?fl=pl&fe=sh>) Fibers along the extremities of the overall sample were less uniform as a result of nonuniform charge distribution along the perimeter of the sample as fiber deposition increased over time. This “edge effect” was not observed in the final sample, where fiber morphology was uniform with overall average fiber diameters of $1.66 \pm 0.21\mu\text{m}$, mat thickness $0.853 \pm 0.113\text{mm}$, and area density 161 g/m^2 . Minimizing working distance (emitter to collector) and implementing field deflectors to offset jet charge repulsion enhanced fiber deposition efficiency. Optimizing emitter translation (20mm/s) and roll speed (1mm/s) allowed uniform deposition. Controlled temperature, humidity, and air flow ($25 \pm 3^\circ\text{C}$, $35 \pm 5\%$, 100 m³/h) were essential to eliminate emitter clogging and/or buildup for stable spinning conditions and remove residual solvent for dry fiber morphology.

Conclusions Successful scaled electrospinning (60 emitters) of PCL fibrous mats up to 173 g/m² was achieved. Challenges of process stability, solution spinnability, deposition area, and fiber mat macro/micro-uniformity were explored and addressed for improved overall sample material outcomes. Future work will include continued scaling of electrospun PCL and other relevant materials to higher throughputs using increased emitter counts (60-370 needles), incorporation of additives, and/or exploration of co-spinning options. These results indicate electrospinning as a promising, scalable, and versatile nanomaterial processing method for device production and modification landscape.

Key words polycaprolactone, electrospinning, scalability

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163 - FLEXIBLE/ELASTIC CERAMIC NANOFIBROUS MATERIALS

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Background/Rationale Ceramic fibrous materials have attracted extensive attention owing to their outstanding thermal stability, corrosion resistance, and multifunctionality, making them indispensable in aerospace, energy, environmental protection, and advanced manufacturing. Reducing fiber diameter to the nanoscale is a long-standing strategy for enhancing material performance and expanding application possibilities. Among various fabrication technologies, electrospinning has emerged as the most versatile approach for producing ceramic nanofibers because of its broad material compatibility, structural tunability, and scalability. However, conventional ceramic nanofibers and aerogels generally suffer from intrinsic brittleness, poor mechanical reliability, and limited structural resilience, which severely restrict their practical applications. Therefore, developing flexible and elastic ceramic nanofibrous materials while preserving their excellent thermal and functional properties has become a major challenge in the field.

Materials and Methods This work summarizes our recent advances in the controllable fabrication and functional design of electrospun ceramic nanofibrous materials. Through rational regulation of precursor chemistry, fiber architecture, and assembly strategies, a series of flexible ceramic nanofibers and highly resilient ceramic nanofibrous aerogels were successfully developed. Novel structural engineering approaches were proposed to overcome the intrinsic brittleness of traditional ceramics, including the construction of defect-tolerant nanofibrous networks and multiscale hierarchical architectures. In addition, two innovative assembly methodologies were established to fabricate ultralight and superelastic ceramic nanofibrous aerogels with controllable microstructures and exceptional thermo-mechanical performance.

Results The developed ceramic nanofibers exhibited unprecedented flexibility compared with conventional ceramic fibers, enabling repeated deformation without catastrophic fracture. These flexible ceramic nanofibrous materials demonstrated excellent thermal insulation performance and expanded the application scope of ceramics in wearable and complex-shaped thermal management systems. Furthermore, the newly developed ceramic nanofibrous aerogels combined ultralow density, high porosity, remarkable elasticity, and outstanding thermal stability. Benefiting from their unique three-dimensional interconnected nanofibrous networks, the aerogels could withstand large compressive strains and recover their original structures repeatedly. The resulting materials exhibited superior performance in high-temperature thermal insulation, fire protection, thermal management, flame retardancy, and acoustic attenuation. These studies provide new insights into overcoming the traditional trade-off between mechanical robustness and functional performance in ceramic materials.

Conclusions Electrospinning offers a powerful platform for designing next-generation ceramic nanofibrous materials with tailored structures and multifunctional properties. By addressing the long-standing brittleness issue of ceramics, flexible ceramic nanofibers and superelastic ceramic nanofibrous aerogels have been successfully developed, significantly broadening the application prospects of ceramic materials. The proposed material design concepts and fabrication strategies establish a foundation for future developments in advanced thermal protection systems, energy-efficient insulation, fire safety technologies, and other extreme-environment applications.

Key words Electrospinning, Ceramic nanofibers, Nanofibrous aerogels, Flexibility, Elasticity

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164 - TiO₂-V₂O₅ FIBERS FROM WATER-SOLUBLE PRECURSORS PREPARED BY CENTRIFUGAL SPINNING AND THEIR CATALYTIC ACTIVITY

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Background/Rationale Centrifugal spinning is a viable alternative to electrospinning, as shown in our recent papers [1-3]. The presentation demonstrates, for the first time, the synthesis of uniform and crystalline mixed TiO₂/V₂O₅ (with different Ti:V ratios) fibers with a diameter of $\approx 1 \mu\text{m}$ via centrifugal spinning [4].

Materials and Methods These mixed fibers were achieved in three steps: i) mixing two stable aqueous precursor solutions based on ammonium bis(oxalato)oxotitanate(IV) hydrate and ammonium metavanadate, then ii) centrifugal spinning of the resulting solution into precursor fibers, followed by iii) their annealing at 450 °C for 1 h in air to obtain crystalline fibers.

Results The catalytic activity of these fibers was assessed in the partial oxidation of ethanol, compared with reference TiO₂ fibers and nanoparticles, both impregnated with V₂O₅ and also TiO₂/V₂O₅ nanoparticles. The results showed the highest catalytic activity for fibers with a composition of 95 at.% Ti/5 at.% V, then TiO₂ fibers impregnated with vanadium atoms on the surface.

Conclusions The fibers possess good mechanical and chemical stability. Experimental details and achieved results will be discussed.

Key words TiO₂/V₂O₅, fibers, centrifugal spinning, partial oxidation of ethanol

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176 - DIRECT SYNTHESIS OF HIGHLY STRETCHABLE CERAMIC NANOFIBROUS AEROGELS VIA 3D REACTION ELECTROSPINNING

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Background/Rationale Ceramic aerogels are attractive for many applications due to their ultralow density, high porosity, and multifunctionality but are limited by the typical trade-off relationship between mechanical properties and thermal stability when used in extreme environments. Prior efforts to improve mechanical properties of ceramic aerogels by manufacturing ceramic aerogel materials with continuous structural units, such as nanofibre or nanosheet. Due to the absence of necklace-like structures and defects, these continuous elements could yield additional degrees of freedom to avoid brittle failure of building blocks for improving compressive brittleness of ceramic aerogels, but cannot address the stretchable brittleness. When used as the main medium for protecting the human body and equipment, the poor stretchable properties of ceramic aerogels have resulted in limited applications in extreme environments such as aerospace and defense. Therefore, exploiting a simple, rapid, and low-cost mass-production strategy for the preparation of ceramic nanofibres with complex shapes is the key to making a breakthrough in ceramic aerogels with stretchable properties.

Materials and Methods Fabrication of ICCAs. Stretchable and flexible mullite nanofibre aerogels were prepared through sol-gel and electrospinning. First, the mullite sol with a molar composition of aluminum chloride hexahydrate : aluminum isopropoxide: tetraethyl orthosilicate: oxalic acid : H₂O : ethanol = 1 :2.5 :1.16 :0.033 :80 :16 was prepared through hydrolysis and condensation, which was stirred at 25 °C for 10 h. Subsequently, a series of sols were obtained by decreasing the pH of the unprotonated sol from 2.6 to 1.7 and 0.8 through dropwise addition of ethanol-diluted hydrochloric acid solution. PEO (Mn = 60 w, Aladdin) was added to the mullite sol with a sol/PEO weight ratio of 1000: 1 with stirring for another 8 h. Then, the mullite nanofibre aerogel precursors were directly produced by using the obtained solution with the electrospinning method. The process of calcination can be divided into four stages: rapid heating at 15 °C min⁻¹ from 20 to 1000 °C; maintenance at 1000 °C for 1 h; heating at 10 °C min⁻¹ from 1000 °C to the set temperature (1100~1500 °C); and maintenance at the set temperature for 1 h.

Results Here, we designed a unique electrohydrodynamic methodology, 3D reaction electrospinning, to directly manufacture ceramic nanofibrous aerogels with interwoven crimped-nanofibre structures. The 3D interwoven crimped-nanofibre structured ceramic aerogels (ICCAs) exhibited superior performance such as ultralight weight, flexibility, stretchability, compressibility, fatigue-tolerance, and ultralow thermal conductivity. The ICCAs could be stretched from their original morphology to 100% tensile strain without fracture and simultaneously exhibited superior restoring capacity in response to large deformations of more than 40% tensile, 60% compressive or 90% bucking strain, as well as robust fatigue-tolerance for 100,000 cycles. Moreover, the mullite phase provided the ceramic aerogel with thermal stability from -196 to 1400 °C, and the aerogels still had repeatable stretchability after calcination at 1300 °C for 1 h. Finally, we demonstrated that ICCAs can be applied as high-performance thermal insulation materials. Meanwhile, we prepared a huge nanofibrous aerogel with 170 cm long, 130 cm wide, and 12 cm high via the unique method. These results have broad technological and engineering implications for personal protective equipment, thermal protection systems in space vehicles and flexible wearable-electronics.

Conclusions In this work, we design and synthesize ceramic nanofibrous aerogels with three-dimensional (3D) interwoven crimped-nanofibre structures that endow the aerogels with superior mechanical performances and high thermal stability. These ceramic aerogels are synthesized by a direct and facile route, 3D reaction electrospinning. They display robust structural stability with structure-derived mechanical ultra-stretchability up to 100% tensile strain and superior restoring capacity up to 40% tensile strain, 95% bending strain and 60% compressive strain, high thermal stability from -196 to 1400 °C, repeatable stretchability at working temperatures up to 1300 °C, and a low thermal conductivity of 0.0228 W m⁻¹ K⁻¹ in air. This work would enable the innovative design of high-performance ceramic aerogels for various applications.

Key words Ceramic nanofibrous aerogels, reaction electrospinning, stretchable, thermal insulation

3 03.BIOMEDICAL AND HEALTHCARE APPLICATIONS

7 - EMERGING NANOFIBER MATERIALS FOR BIOMEDICAL APPLICATIONS

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Background/Rationale Electrospinning has emerged as a versatile and transformative technique for fabricating nanofiber materials with significant potential across a wide range of biomedical applications.¹ Despite considerable advances, several fundamental challenges remain unresolved. Can a reliable method be developed to produce three-dimensional nanofiber scaffolds with well-defined geometries and tunable properties? Is it feasible to enable minimally invasive implantation of these scaffolds, reducing or eliminating the need for conventional surgical procedures? Furthermore, can electrospun nanofibers be engineered into microspheres or microcarriers suitable for injectable therapies, and how effectively can they be combined with other emerging technologies? This study seeks to investigate and address these important questions.

Materials and Methods Three-dimensional (3D) electrospun nanofiber scaffolds were generated by converting two-dimensional (2D) nanofiber membranes via a gas-foaming expansion approach. In addition, aerogels and microspheres were fabricated through the assembly of short nanofiber segments.

Results We developed and optimized a gas-foaming expansion technique to convert two-dimensional (2D) electrospun nanofiber membranes into three-dimensional (3D) scaffolds with precisely tunable geometries, pore sizes, and porosities.² This approach enables the fabrication of highly controllable nanofiber architectures while maintaining the inherent fibrous structure and mechanical integrity of the electrospun network. The resulting 3D scaffolds exhibit remarkable superelasticity and shape-memory properties, allowing them to recover their original configurations after deformation. These characteristics make them especially well-suited for minimally invasive implantation, as they can be compressed or rolled during delivery and subsequently regain their predefined shapes in situ.³ In addition, we established a method for producing nanofiber-based aerogels and microspheres through the controlled assembly of short nanofiber segments.^{4,5} This strategy offers a versatile platform for creating lightweight, highly porous materials with large surface areas and tunable mechanical properties. Furthermore, we successfully integrated electrospun nanofibers with emerging microtechnologies, including microfluidic systems, microneedle arrays, and microfibers, to develop multifunctional hybrid platforms.⁶⁻⁸ These integrated systems extend the capabilities of electrospun materials beyond conventional scaffolding by enabling precise spatial control, enhanced functionality, and synergistic performance. The practical utility of these advanced nanofiber-based systems was demonstrated in a range of biomedical applications, including the prevention and treatment of wound infections, acceleration of wound healing, promotion of bone regeneration, facilitation of biological sample collection, and rapid induction of hemostasis.⁹⁻¹² Collectively, these results underscore the broad applicability and transformative potential of electrospun nanofiber technologies in biomedical fields.

Conclusions We established a robust and reproducible method for fabricating 3D electrospun nanofiber scaffolds with precisely defined geometries and tunable structural features, including fiber alignment, porosity, and pore size. These scaffolds can be implanted using minimally invasive techniques due to their flexibility, compressibility, and shape-memory properties. We also developed approaches to process electrospun nanofibers into microspheres for injectable therapies, enabling localized and controlled drug delivery. Furthermore, we integrated electrospun nanofibers with microfluidic systems, microneedle arrays, and other microstructured platforms to create multifunctional systems with enhanced biomedical performance and versatility.

Key words gas-foaming expansion, 3D nanofiber scaffolds, aerogels, microparticles, biomedical applications

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8 - PROCESS WINDOW DEFINITION AND STRUCTURAL CONTROL IN THE ELECTROSPINNING OF SILK FIBROIN FOR GUIDED BONE REGENERATION MEMBRANES

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Background/Rationale Electrospinning of silk fibroin has attracted increasing attention for biomedical membrane applications due to its biocompatibility, biodegradability, and structural similarity to extracellular matrix architectures. For guided bone regeneration (GBR) membranes, structural parameters such as fiber diameter, pore architecture, thickness, and reproducibility of fabrication are critical, as they determine barrier function, permeability, and mechanical stability. However, stable electrospinning of aqueous silk fibroin solutions remains challenging, particularly at lower concentrations, where jet instabilities and bead formation frequently occur.

The present study aims to define a reproducible electrospinning process window for concentrated silk fibroin solutions and to establish clear process–structure relationships relevant for membrane fabrication.

Materials and Methods Aqueous silk fibroin solutions with concentrations ≥ 25 wt% were investigated. Preliminary trials showed that stable electrospinning could only be achieved above a critical concentration threshold. Solutions were concentrated via controlled heating to enable stable jet formation.

A standardized 27 wt% fibroin solution was selected for systematic investigations. A one-factor-at-a-time (OFAT) approach was applied to isolate the influence of key electrospinning parameters, including applied voltage, flow rate, and needle-to-collector distance. Environmental conditions were controlled to ensure process stability.

Fiber morphology was analyzed via light microscopy and scanning electron microscopy (SEM). Mean fiber diameters were determined from micrographs. Membrane thickness was adjusted by varying spinning time and measured using thickness analysis across defined sample regions.

Results Stable and continuous fiber formation was only achievable at fibroin concentrations ≥ 25 wt%, confirming the existence of a critical concentration required for process stability. Below this threshold, jet breakup, droplet formation, and irregular deposition were observed.

Using the standardized 27 wt% solution and optimized parameter settings, uniform nonwoven membranes were reproducibly fabricated. Mean fiber diameters of approximately 2.5 μm were achieved. This diameter range lies within the microfibrillar regime and enables mechanically stable nonwoven structures with interconnected pore architecture.

Membrane thickness could be precisely adjusted by controlling spinning time. Thin membranes exhibited average thicknesses of 0.13–0.16 mm, while extended deposition resulted in thicker variants up to 0.37 mm. Thickness scaled consistently with deposition time, demonstrating controlled material build-up.

SEM analysis confirmed homogeneous fiber morphology with well-defined, straight fibers and an open, interconnected pore structure. The resulting architecture provides structural integrity while maintaining permeability—characteristics essential for membrane-based biomedical applications such as GBR.

Conclusions This study establishes a defined electrospinning process window for concentrated silk fibroin solutions and demonstrates clear process–structure relationships governing microfiber formation and membrane build-up. A critical concentration threshold was identified as a key factor for stable jet formation and reproducible membrane fabrication.

The achieved microfibrillar architecture (mean diameter ~ 2.5 μm) enables a balanced combination of mechanical stability, controlled thickness, and open pore structure. These findings highlight the importance of concentration-driven process stabilization in silk fibroin electrospinning and provide a reproducible framework for the fabrication of structurally tunable membranes for biomedical applications.

Key words Electrospinning; silk fibroin; GBR membranes; guided bone regeneration

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9 - INNOVATIVE BIOMATERIAL SCAFFOLDS FOR CARDIOVASCULAR REGENERATION AND REPAIR

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Background/Rationale Cardiovascular diseases are prevalent worldwide, which adversely affect the quality-of-life. Autografts are gold standard treatment options albeit their limited numbers. Synthetic polyesters are alternative candidates; however, they are plagued with poor regeneration ability, and they additionally lack cell-adhesion cues. In situ tissue regeneration through endogenous stem/progenitor cells (SPCs) mobilization and immune-modulation offers an alternative platform to fabricate functional small-diameter vascular grafts [1]. The overarching objective of our research is to synthesise mechano-elastic poly(L-lactide-co- ϵ -caprolactone) (PLCL) copolymers and modify them with stem cell inducing/recruiting bioactive cues to encourage cell mobilization and recruitment and promote the hemocompatibility of vascular scaffolds for cell-free tissue regeneration and repair.

Materials and Methods We synthesised linear and star-shaped PLCL copolymers and modified them with different types of bioactive cues, such as neuropeptide substance P (SP), stromal cell-derived factor 1- α (SDF-1 α) peptide, endothelial progenitor cell (EPC)-recruiting peptide (TPS) and mesenchymal stem cell (MSC)-affinity peptide (E7) [1-2]. Moreover, we modified polycaprolactone (PCL) with vascular endothelial growth factor (VEGF)-binding prominin-1-derived peptide (PR1P) and SDF-1 α peptide. Further, we prepared heparin-conjugated polymers to confer hemocompatibility to vascular scaffolds. We fabricated electrospun membranes and tubular-shaped small-diameter vascular grafts (SDVGs) using electrospinning with varying topographies and the proportion of bioactive cues. We also fabricated polycaprolactone/collagen-based vascular scaffolds and cardiac patches loaded with bioactive peptides. We evaluated the biocompatibility of different vascular scaffolds in vitro, and additionally implanted them as abdominal aorta substitutes and performed histological and immuno-histochemical analysis.

Results We successfully synthesised linear and star-shaped PLCL copolymers and modified them with different types of bioactive cues to induce in situ vascular tissue engineering. Heparin-conjugated vascular scaffolds possessed good blood compatibility as revealed by lower platelet adhesion and activation and prolonged activated partial thromboplastin time (APTT) and prothrombin time (PT), while peptides-laden grafts encouraged cell mobilization and recruitment in vitro and in vivo. Vascular scaffolds modified with TPS peptide induced the preferential binding of EPC over endothelial cells. Similarly, nanofibers functionalized with E7 increased the adhesion and spreading of MSCs. Vascular scaffolds modified with stem cell inducing/recruiting peptides showed enhanced cell infiltration, rapid re-endothelialization, and improved vascular remodeling when transplanted as abdominal aorta substitutes in rats. Similarly, the concurrent delivery of VEGF-binding PR1P peptide and SDF-1 α improved endothelialization and smooth muscle cell (SMC) regeneration. Further, these vascular scaffolds showed the recruitment of stem cell antigen (Sca)-1-positive SPCs as well as their colocalization with ECs and SMCs markers. Vascular scaffolds loaded with either SDF-1 α or SP using degradable collagen-based hydrogels also induced in situ blood vessel regeneration; the SP-loaded vascular scaffolds outperformed SDF-1 α -loaded scaffolds in terms of SPC recruitment and immune-modulation. Similarly, electrospun polycaprolactone-based cardiac patches co-loaded with insulin-like growth factor (IGF)-1C peptide and SP recruited significantly more number of CD29-positive SPC and showed less numbers of Tunel-positive cells compared with the groups loaded with only a single peptide [3].

Conclusions Taken together, SPCs account an invaluable cell source for in situ regeneration of blood vessels as well as the remodeling of vascular grafts. Further, bulk-modified polymers can be processed into different types of shapes and structures as required for tissue engineering (TE) applications. The combined delivery of stem cell inducing/recruiting bioactive cues and angiogenic or cardioprotective factors may have a synergistic effect than that of the delivery of only a single factor. The topography (e.g., fiber size, fibers' architecture) of vascular scaffolds can be further varied to modulate foreign body response (FBR) to an implanted biomaterial. In summary, the incorporation of bioactive molecules in vascular scaffolds may have broad implications to engineer the next generation of off-the-shelf vascular grafts using electrospinning, which may also have broad implications for the development of in vitro vascular tissue/disease models.

Key words Cardiovascular regeneration, immune-modulation, vascular scaffolds, in situ tissue regeneration, blood vessels, electrospinning, nanofibers

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10 - RELEASE OF HYDROPHILIC AND HYDROPHOBIC OPHTHALMIC DRUGS FROM ELECTROSPUN MONOLITHIC AND CORE-SHELL NANOFIBER MATS

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Background/Rationale Sustained ophthalmic drug delivery is essential after corneal surgery, yet conventional eye drops provide low bioavailability and rely heavily on patient compliance.

Materials and Methods The present study develops electrospun monolithic and core-shell nanofiber systems for controlled delivery of hydrophobic (Dexamethasone, Drug A) and hydrophilic (Tobramycin, Drug B) ophthalmic drugs. A broad range of poly(lactic-co-glycolic acid) (PLGA), poly(methyl methacrylate) (PMMA), poly(vinyl alcohol) (PVA), and poly(ethylene oxide) (PEO)-based monolithic and core-shell electrospun nanofibers was evaluated.

Results Core-shell nanofibers were fabricated via co-electrospinning using coaxial needles, enabling spatial separation of the shell from the drug-loaded core. Although a PLGA/PVA system in hydrofluoroisopropanol (HFIP)/deionized water produced high-quality dissolvable monolithic nanofibers in phosphate-buffered saline (PBS), drug-loaded mats released nearly all the incorporated drug within minutes. These results demonstrate that monolithic electrospun nanofibers exhibit dissolution-dominated burst release and are unsuitable for sustained ophthalmic therapy, even when polymer molecular weight is increased. To overcome this limitation, core-shell nanofibers with either PLGA (45–55 kDa) or PMMA shells and PLGA-based drug-loaded cores were fabricated. The introduction of a concentric shell architecture fundamentally altered the release regime. In particular, PLGA–PLGA core-shell nanofibers reduced early burst release of Drug B from ~65–80% (from monolithic fibers) to ~3% within the first 6 h, while maintaining gradual release over 60 days. PMMA–PLGA and PLGA–PLGA+PVA architectures exhibited intermediate behavior, confirming that shell material governs early burst suppression, whereas the core composition modulates sustained transport.

Conclusions Release profiles were interpreted using the physically sound desorption-limited transport model consistent with the observations. The results revealed the architectural design as a dominant feature controlling ophthalmic drug release from electrospun nanofibers and provide a fundamental approach to long-acting ocular inserts for postoperative therapy.

Key words Electrospinning, Co-electrospinning, Core-shell nanofibers, Ophthalmic drug delivery, Dexamethasone, Tobramycin, Sustained release, Desorption-limited drug

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15 - DEVELOPMENT OF CAFFEINE MULTILAYER ELECTROSPUN PATCHES FOR TRANSDERMAL DRUG DELIVERY

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Background/Rationale The aim of this study was to develop a model electrospun multilayer patch platform from polymeric biomaterials to evaluate transdermal drug delivery. Polyethylene oxide (PEO) was selected as the active layer material to investigate the release properties and mechanism of a model compound, caffeine. The electrospun nanofibers were characterized using scanning electron microscopy (SEM), attenuated total reflectance Fourier-transform infrared spectroscopy (ATR-FTIR), and wide-angle X-ray scattering (WAXS). Drug permeation was analyzed using a Franz diffusion cell, initially with a multilayer synthetic membrane, followed by testing on human biopsy skin membranes to assess the best candidate.

Materials and Methods The electrospinning process was performed using a high-throughput Fluidnatek™ LE-100 system equipped with a 15-multi-emitter injector from Bioinicia S.L. (Valencia, Spain). For this study, bi-layer and three-layer patches were fabricated. A hydrophobic backing layer of electrospun polycaprolactone (PCL) fibers was prepared separately and laminated onto the other layers.

Skin biopsy specimens from a healthy 39-year-old man, stored at -80°C, were provided by the Biobank of the Valencia Region, Spain.

The release experiments were performed using a Franz diffusion cell equipment with an effective diffusion area of 1 cm².

Results The results indicated that patches containing polyethylene glycol and oleic acid as enhancers exhibited the highest synergistic effect on the caffeine permeability when tested with an artificial membrane. The best performing patch was further assessed in transdermal assays using ex vivo human SC specimens from two very different donors as the membranes, suggesting higher variability in the permeation with longer testing times, which was ascribed to the small size of the patch tested in the Franz cell, i.e., 1 cm², and potential tissue deterioration over longer testing periods. The best-performing platform achieved average drug permeation rates of 0.73 mg/cm² across the synthetic membrane after 24 h.

Conclusions This study demonstrates the feasibility of high-throughput electrospinning technology for generating innovative self-adhesive multilayer platforms for transdermal drug delivery of hydrophilic drugs, using caffeine as the model compound. As expected, the use of specific enhancers compatible with both the drug and skin composition was confirmed to enhance transdermal delivery.

Key words Electrospinning, Transdermal patches, Pharmaceutical applications

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16 - DEVELOPING “PHORMULATIONS” FOR PHAGES

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Background/Rationale Bacterial infections contribute to millions of deaths (7.7M in 2019). The most common medical intervention to combat these is the use of antibiotics. However, the emergence of multi-drug-resistant bacteria is a significant and growing threat associated with ca. 4.95M deaths in 2019 [1]. *Pseudomonas aeruginosa* (*P. aeruginosa*) is a particularly problematic bacterial pathogen, commonly seen in e.g. wounds and lung infections. Bacteriophages, or phages, are viruses which infect bacteria. They are highly specific to particular strains of bacteria, and can be used safely without the risk of off-target effects on e.g. the gut microbiome. Phages offer a natural alternative to antibiotics, and are self-amplifying and adaptable. They are thus capable of circumventing bacterial resistance.

The clinical efficacy of phages is well established. However, most studies prepare phages as simple liquid suspensions: this causes challenges with transport and stability, and there is a pressing need to develop solid phage formulations. In this presentation, we will discuss recent work to develop such formulations using electrohydrodynamic atomization (EHDA; electrospinning and electrospraying). EHDA applies electrical energy to dry a polymer/active component solution, offering a number of advantages over more conventional approaches such as spray drying and freeze drying in terms of simplicity and the lack of heat application.

Materials and Methods Anti-*P. aeruginosa* Neko phages were isolated from puddle water. They were first characterized and then processed into fibers by electrospinning and particles by electrospraying, using polymer and sugar excipients. The resultant products were characterized for their morphology (electron microscopy), phage content, and effectiveness in anti-bacterial assays.

Results The phage-loaded fibers are found to be cylindrical and smooth [2], while regular spherical particles of ca. 1-2 μm in diameter can be generated by electrospraying [3]. We find a loss of phage activity after EHDA processing, but this can be minimized by careful optimization of the formulation. The optimal phage formulations can effectively delay or prevent bacterial growth, with no reduction in activity compared to “fresh” phages. Furthermore, preparing systems where phages are combined with antibiotics allows for synergistic effects.

Conclusions We thus conclude that EHDA approaches have great potential for the development of solid phage formulations.

Key words electrospinning; phages; antibacterial; antimicrobial resistance

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17 - HUMIDITY-RESPONSIVE TENSILE BEHAVIOR AND SHAPE MEMORY OF PHOTO-CROSSLINKED POLY(2-ETHYL-2-OXAZOLINE) NANOFIBERS FOR SMART WOUND DRESSING APPLICATIONS

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Background/Rationale Electrospun nanofiber membranes fabricated from biocompatible polymers are of great interest for biomedical and healthcare applications, especially for advanced wound dressings that benefit from their high surface area and porosity. Apart from biocompatibility, next-generation wound care materials must demonstrate robust, adaptable mechanical performance under varying ambient conditions. Poly(2-alkyl-2-oxazoline)s are ideal candidates for nanofiber wound dressing design due to their versatility and tunable hydrophilicity. For instance, poly(2-ethyl-2-oxazoline) (PEtOx) is a highly hydrophilic and hygroscopic polymer with excellent biocompatibility, yet its water solubility and humidity sensitivity complicate handling and application. To address these limitations, a straightforward photo-crosslinking approach was recently developed, relying on cinnamoyl modification of PEtOx (PCx).[1] Incorporating cinnamoyl groups enables UVB-activated $[2\pi+2\pi]$ cycloaddition, forming covalent dimer crosslinks that enhance water stability and help preserve the fiber morphology in humid environments. This work investigates the mechanical performance of these PCx electrospun nanofiber membranes under relevant humidity levels, while aiming for humidity-responsive biomedical textiles that are actuated by ambient moisture for controlled, active wound-closure dressings.

Materials and Methods High-molar-mass PEtOx was partially hydrolyzed and functionalized with 5 and 10 mol% cinnamoyl groups (PC5 and PC10). Nanofiber membranes were fabricated via solvent electrospinning from 'green' ethanol/water mixtures, producing uniform fibers of approximately 250 nm in diameter. Postprocessing UVB irradiation induced cinnamoyl dimerization and generated covalent crosslinks within the fibrous network. The resulting membranes were equilibrated at low (25% RH) or high (65% RH) relative humidity for 24 h prior to testing. Fiber morphology was examined by SEM, water sorption behavior by dynamic vapor sorption, and humidity-dependent glass transition temperatures (T_g) via modulated DSC. Tensile properties were measured directly within the climate of interest. Shape memory capability was evaluated by programming temporary elongated shapes at 65% RH, fixing them via humidity-induced stiffening at 25% RH, and quantifying strain recovery when returned to 65% RH.

Results Cinnamoyl modification and UVB crosslinking significantly enhanced the morphological stability of the electrospun membranes under humid conditions. While non-crosslinked PEtOx fibers easily transformed into film-like structures at elevated humidity, crosslinked PCx membranes, particularly PC10, retained a stable nanofibrous morphology at 65% RH. This preserved open structure enabled rapid moisture sorption, hereby accelerating plasticization compared to non-crosslinked membranes. At 25% RH, all crosslinked PCx membranes remained in their glassy state with high stiffness, low elongation at break, and excellent shape fixity. At 65% RH, moisture-induced T_g reduction transitioned the networks into their rubbery state, resulting in a dramatic shift from brittle to highly ductile and elastomeric behavior. Crosslinked PC10 nanofibers demonstrated the strongest effect, reaching strains above 90% without failure. This humidity-driven mechanical tunability enabled robust single-switch shape-memory behavior: temporary stretched shapes retained more than 98% fixity at low humidity and achieved rapid recovery upon re-humidification, with 90% strain recovery within 45 minutes. This response is substantially faster than previously reported humidity-responsive PEtOx bulk materials and is attributed to the high specific surface area and rapid water-diffusion kinetics inherent to the nanofibrous morphology.[2]

Conclusions This work positions cinnamoyl-crosslinked PEtOx nanofiber membranes as highly promising humidity-responsive materials for biomedical applications. Their ability to transition between stiff, glassy mats in dry environments and flexible, elastomeric membranes under elevated ambient humidity, combined with efficient, single-switch shape-memory behavior, supports their potential as gentle, humidity-actuated wound-closure materials. Due to their swift response to relatively small humidity changes, these nanofibers can exploit ambient humidity or wound exudate as built-in actuation stimuli. Integrating humidity-responsive PCx nonwovens into multifunctional wound dressings with real-time monitoring and controlled antimicrobial capabilities offers a promising route toward advanced treatments for chronic and difficult-to-heal wounds, like diabetic ulcers.

Key words Poly(2-ethyl-2-oxazoline), photo-crosslinking, humidity-responsivity, mechanical performance

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21 - ELECTROSPUN ORGANIC AND INORGANIC NANOFIBERS FOR SOFT AND HARD TISSUE ENGINEERING

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Background/Rationale The discipline of tissue engineering has proposed the use of porous and degradable scaffolds to temporarily replace damaged tissues and guide the regeneration of new tissues, with the scaffolds eventually degrading. This approach requires the porous scaffolds to function as the extracellular matrix of tissues. Electrospun nanofibers can be used to fabricate porous tissue engineering scaffolds that mimic the nanofiber structure of the extracellular matrix of tissues, promoting tissue regeneration. The research group led by Xiumei Mo has successfully fabricated nanofiber membrane, tube, and block scaffolds, which have been successfully applied in the regeneration of skin, nerve, vascular, and bone cartilage tissues.

Materials and Methods Inject the degradable polymer solution into a syringe, under high pressure, a jet is formed and the solvent evaporates to obtain nanofibers. When collect by a flat plate, a membrane-like nanofiber membrane is obtained, which is used for skin tissue regeneration. When collect by a rotating rod, a tubular scaffold is obtained, which is used for vascular and neural tissue regeneration. Cut the nanofiber membrane into pieces, homogenize it, and freeze-dry it in a three-dimensional mold to obtain a block scaffold, which is used for bone and cartilage tissue regeneration.

Results A 12-amino acid polypeptide of BP was mixed with PLCL and gelatin and electrospun to obtain nanofibers for skin tissue regeneration, which promoted the repair of skin defects in diabetic rats. Boron-doped silica nanofibers were prepared by sol-gel electrospinning and dispersed in chitosan solution, followed by freeze-drying to obtain a three-dimensional porous scaffold for rat cranial bone repair. Silica nanofibers were dispersed in sodium alginate to make 3D printing ink, and 3D printing was used to obtain a three-dimensional scaffold, which was successfully used for rat cranial bone repair. Nanofiber membranes were immersed in sodium borohydride aqueous solution, and the bubbles in the solution expanded the nanofiber membranes to obtain a porous scaffold with a certain thickness, which was successfully used for patellar cartilage repair in rabbits. EGCGCu and bivalirudin were mixed with PLCL and gelatin and electrospun on a rotating drum to obtain tubular scaffolds, which promoted the proliferation of endothelial cells, inhibited the proliferation of smooth muscle cells, and were implanted in the abdominal aortic defect of rats, maintaining vascular patency and regenerating vascular tissue. A thermosensitive polymer was used to prepare a self-rolling neural conduit at body temperature, which was successfully used for neural tissue regeneration. Nanowires with a core layer of silk fibroin microfibers and a skin layer of PCL, silk fibroin and β -TCP mixture nanofibers were prepared by conjugate electrospinning, and multiple nanowires were combined to obtain sutures, which were used for the reconstruction of avulsed Achilles tendon. Yarns with a core layer of silk fibroin microfibers and a skin layer of PLCL nanofibers were prepared by conjugate electrospinning, and the yarns were woven into fabrics as tendon scaffolds. The two ends of the tendon scaffolds were immersed in PLA solution, and bone scaffolds were prepared by phase separation and freeze-drying, thereby obtaining a three-segment bone-tendon-bone scaffold, which was successfully used for bone-tendon-bone repair of rabbit ACL.

Conclusions Electrospun nanofibers can mimic the nanoscale filamentous structure of the extracellular matrix of biological tissues, promoting tissue regeneration.

Key words Electrospinning, nanofibers, scaffolds, tissue regeneration

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30 - THE “INS-AND-OUTS” OF DRUG LOADED NANOFIBERS

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Background/Rationale Electrospun nano/microfiber membranes are characterized by very high surface area (compared to solid, gel and liquid formulations), highly porous structure, flexible form factor, availability of many polymer materials and ease of incorporation of functional molecules. As a result, these membranes have found multiple applications in the biomedical and health care fields, including bone, tissue and neural regeneration, wound healing/antimicrobial systems, transdermal drug delivery, controlled local delivery of chemotherapeutic drugs, stimuli-responsive membrane for contraception and gastro-retentive drug delivery.

While several methods exist for fabricating fiber membranes (including melt spinning and phase separation), here we focus on fiber electrospinning, which is a widely utilized and very versatile technique in which an electric field extracts a liquid jet from a polymer solution through a metal nozzle, forming continuous fibers.

Materials and Methods We review key strategies and approaches for incorporating drug molecules into electrospun fibers and mechanisms by which drugs are released. The simplest and very effective approach is “blend” electrospinning wherein both the polymer and the selected drug molecule are dissolved in a single solution resulting in homogenous fibers. This requires that the polymer and the drug molecules be soluble in the same solvent, typically organic solvents. In the case of hydrophilic drug molecules incorporated in fibers, homogenous fibers would lead to an undesirable fast release in wet environments. The formation of core-sheath fibers by “coaxial” electrospinning using a nested nozzle provides added versatility by allowing for the incorporation of separate components (with complementary functions) in the core and sheath of the fiber structure. This concept can be further extended to “triaxial” electrospinning which inserts an intermediate layer between core and sheath. Another approach for incorporating normally incompatible drugs is emulsion electrospinning, where two immiscible liquids are mixed forming a dispersion of small droplets of one liquid with drugs in the second liquid (e.g., oil-in-water, water-in-oil), allowing effective encapsulation of drugs with a single fiber system.

Results Multiple mechanisms can be involved in the process of releasing the incorporated functional molecules once the fiber membrane is placed in a liquid medium. This includes molecular diffusion through the fiber matrix or surface pores, polymer swelling, and polymer degradation via enzymatic and/or hydrolytic processes. They can be described by common kinetic models, including zero-order release (constant release rate), diffusion-controlled kinetics such as the Higuchi model, and more generalized Korsmeyer–Peppas model for complex mechanisms. In combination with the fiber structure, the dominant release mechanism determines the resulting drug release profile: burst release (short term) or sustained (controlled time period) release. The use of polymers that are responsive to specific stimuli (such as temperature, pH, enzymes) can result in selected time release once the trigger is present.

Several relevant examples of drug-loaded fiber membranes will be briefly reviewed, including incorporation of hypoxia inhibiting drugs (ACF) and nanoparticles (CuO) in core-sheath fiber membranes for the treatment of brain tumor, incorporation of CaO₂ for controlled generation of O₂ during the transplant of pancreatic islets for the treatment of Type 1 diabetes.

Conclusions Key challenges associated with drug release from nanofiber membranes include limited loading capacity, incomplete release of encapsulated drugs, drug stability during electrospinning, uniform drug incorporation within the fiber and over the membrane area, control of the drug release profile as needed for specific applications.

While there are many potential benefits of drug release from electrospun fiber membranes – high surface area, high porosity, controlled release kinetics, flexibility (selection of polymers, loading of functional molecules), many important clinical considerations such as biocompatibility, in vivo efficacy, degradation, immune response, regulations, etc. remain to be fully addressed.

Key words coaxial electrospinning, drug loading, core-sheath fibers, controlled release

40 - FABRICATION AND CHARACTERIZATION OF MUSSEL FOOT PROTEIN-LOADED PULLULAN/GELLAN GUM NANOFIBERS FOR ENHANCED OCULAR DRUG DELIVERY APPLICATIONS

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Background/Rationale The eye is an important organ in the human body that can be negatively impacted by bacterial, viral, and fungal infections. As a result, establishing an effective and simple treatment has always been a relevant topic. Tear fluid film clearance and physical force exerted by eyelids during blinking are the primary challenges that limit the bioavailability of conventional delivery methods, such as eye droplets (only 5% uptake). To prevent rapid clearance, in situ gelling droplets based on Gellan gum (GG) were developed to overcome tear fluid clearance; however, because they are produced in droplet form, a significant number of droplets are eliminated during the blinking process. One approach is to combine the gelling characteristic of GG with the large surface area of nanofibers. The in situ gelling nanofibers absorb tear fluid and quickly form a thin hydrogel film on the ocular surface following application. This lowers the drug dosage, resulting in fewer side effects, while the solid form of nanofibers allows for easier handling and a longer shelf life. Moreover, the incorporation of 3,4-dihydroxyphenylalanine (DOPA) containing mussel foot protein 3 (mMefp-3) from the blue mussel can improve drug retention and enhance bioavailability.

Materials and Methods In this research, nongelling (Pullulan) and in situ gelling (Pullulan/GG) nanofibers were fabricated using single needle electrospinning, and then Mefp-3 and mMefp-3 (modified, containing peptidyl-DOPA) protein were loaded into Pullulan and Pullulan/GG nanofibers. In the case of mMefp-3 loaded Pullulan/GG, a coaxial electrospinning technique was necessary due to strong interactions between protein and polymer molecules. The nanofibers were labeled with fluorescein dye as the drug model. The morphology of the nanofiber was investigated using fluorescent, light, and scanning electron microscopy. The rheological properties were tested using a Kinexus rheometer in shear rate ramp mode at 25 °C and viscoelastic mode at 37 °C in water and simulated tear fluid (STF) media. The drug residence time was measured in a porcine eye model with a custom-made eye geometry simulator, and the fluorescent intensity was recorded with the Maestro device. The cell viability test was performed on 3T3 and NHDF fibroblast cell lines for 24 hours via the Resazurin assay. The biocompatibility for epithelial cells was studied on tissue-specific corneal epithelial constructs. Then the number of viable cells was measured using the CellTiter-Glo assay.

Results According to the morphological data, the fluorescent dye is evenly distributed throughout all electrospun samples except for Mefp-3/Pullulan/GG nanofibers, which exhibited bead-shaped microstructures, and the fluorescent dye was concentrated inside the beads. The lower hydrophilicity of Mefp-3 and its potential to agglomerate under the tested conditions may have led to this nonhomogeneous structure. The average nanofiber diameters were in the range of 200–300 nm and followed a Gaussian distribution curve. The viscosity graphs showed that loading mMefp-3 into the Pullulan/GG causes a much greater rise in viscosity than Pullulan. This finding suggests that GG and the protein build a strong interaction. The viscoelastic measurement in the aqueous medium showed that in situ gelling fibers followed the liquid behavior, while mMefp-3/Pullulan/GG followed a gel-like behavior ($\tan\delta < 1$). After being treated with STF, all the GG-containing samples underwent the gel phase. The drug residence time studies demonstrated that the in situ gelling system can extend the residence time, and the addition of mMefp-3 protein may further increase performance. Mathematical modeling showed that in situ gelling systems exhibit zero-order clearance kinetics, whereas non-gelling nanofibers exhibit first-order clearance kinetics. When the mMefp-3 was added, the kinetic constant (k_0) decreased from 0.107 to 0.082. This phenomenon happens due to the mucoadhesive characteristic of the mMefp-3 protein, which can maintain the thin hydrogel film on the ocular tissue surface. No significant difference was observed in Fibroblast (NHDF and 3T3) and epithelial cell viability test between testing groups, supporting the high biocompatibility of the protein-loaded nanofibers.

Conclusions Overall, the developed in situ gelling nanofiber system demonstrates a promising approach for enhancing ocular drug delivery by overcoming rapid clearance. The incorporation of mucoadhesive mMefp-3 protein further improves the drug residence time, highlighting the positive effect of DOPA. Furthermore, the

proposed electrospun layers were highly biocompatible. These findings highlight the potential of protein-functionalized nanofibers as an effective and patient-friendly alternative to conventional eye drop formulations.

Key words In-situ gelling, coaxial electrospinning, mussel foot protein, Ocular drug delivery, Clearance kinetics.

41 - CONTROLLED RELEASE OF OXYGEN FROM CORE-SHEATH FIBER MEMBRANES FOR SUSTAINED VIABILITY OF PANCREATIC ISLET CELLS

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Background/Rationale Individuals who suffer from type 1 diabetes (T1D) require continuous exogenous insulin injection or islet transplantation due to loss of pancreatic beta cells. Current treatments are effective but prone to side effects, such as hypoglycemia, insulin pump failures, ulcers, etc. While insulin-producing islet transplantation can be a potential cure replacing current diabetic treatments, maintaining sufficient initial oxygen level and promoting blood vessel formation are major challenges for the survival of newly transplanted islets. Newly transplanted cells require oxygen since they are not yet attached to the body's vascular system. Although oxygen can be delivered via diffusion, it will be insufficient in many cases. In order to provide the appropriate oxygen level after transplantation and to accelerate vascularization for transplanted cells, a two-fold approach is investigated that combines providing an initial source of oxygen using calcium peroxide (CaO₂ - CPO) and promoting vascularization through the release of VEGF in the transplant area. CPO reacts with water to produce oxygen, as well as hydrogen peroxide. Due to the possible cytotoxicity of hydrogen peroxide in islets, the enzyme catalase is added to decompose hydrogen peroxide into water and oxygen, further increasing oxygen generation with lower cytotoxicity to islets.

Materials and Methods Coaxial electrospinning of core-sheath fiber membranes produces a versatile platform for drug delivery with controlled release kinetics of encapsulated molecules. The delivery vehicle is based on a membrane formed from core-sheath polymer fibers, which incorporated CPO and the lysozyme, a model protein for VEGF, in the PCL/PVP fiber core and the catalase in the PEO fiber sheath. SEM observation showed uniform fiber formation in a diameter of ~2 μ m. The core-sheath structure and the presence of CPO in coaxially electrospun membrane samples were confirmed using TEM and EDS analysis, respectively.

Results Core-sheath fiber membranes formed using coaxial electrospinning that contain CPO embedded in the fiber core provide a source of oxygen by diffusion from the fibers over periods of multiple (>14) days. CPO containing membranes provide biphasic oxygen release kinetic with 54-75 μ g/day for the first 5 days followed by ~8.9 to 11.1 μ g/day up to 14 days.

Embedding enzyme catalase in the fiber sheath as catalyst significantly reduces production of cytotoxic hydrogen peroxide (H₂O₂) by ~40% and increases overall amount of oxygen released up to ~30% after 4 days of release. To evaluate the potential of promoting vascularization capability, preliminary investigations with the incorporation of lysozyme as a model protein in fiber core for eventual growth factor incorporation have yielded promising sustained release of lysozyme up to 10 days.

To evaluate effectiveness of the coaxial fiber delivery system for oxygen delivery, in-vitro efficacy was measured using a spheroid model with rat insulinoma cells, INS-1 832/2. Studying oxygen availability in 3-dimensional spheroids is crucial because it more closely replicates oxygen consumption by pancreatic islets. In hypoxic conditions, oxygen gradients within islets cause core necrosis, with oxygen being significantly lower in the core than the surface. For groups without oxygen release, immediate necrosis formation was observed after 1 day of incubation in hypoxic environment. CPO-containing PCL/PVP-PEO core-sheath fiber membranes presented enhanced viability of > 90 % at day 5 for metabolically active pancreatic beta cell model (INS-1) spheroids in a hypoxic environment, while non-CPO control cases yielded no surviving cells at day 5.

Conclusions Study presents a coaxially electrospun core-sheath nanofiber system that enables sustained oxygen generation and controlled protein release to support islet transplantation. CPO incorporation provided prolonged oxygen delivery, while catalase reduced cytotoxic hydrogen peroxide with enhanced oxygen availability. This maintained > 90% viability of INS-1 pancreatic β -cell spheroids under hypoxic condition for > 5 days, while controls showed rapid necrosis within 1 day. Sustained release of model protein up to 10 days provides potential for co-delivery of VEGF. Overall, this platform offers a promising strategy to overcome early hypoxia and improve pancreatic cell survival in T1D transplantation therapy.

Key words coaxial electrospinning, core-sheath fibers, calcium peroxide, oxygen release, pancreatic islets

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43 - CONTROLLED DUAL-PHASE NANOFIBER DRUG DELIVERY SYSTEMS USING EMULSION-BASED ELECTROSPINNING

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Background/Rationale Glioblastoma multiforme (GBM) is an aggressive and highly recurrent brain tumor with poor prognosis. Despite surgical resection followed by radio- and systemic chemo- therapies, infiltrated residual tumor cells often cannot be treated effectively due to limited drug penetration across the blood–brain barrier. [1] To address this challenge, dual-phase therapeutic strategy is highly desirable, consisting of an intensive initial drug release to eliminate remaining tumor cells immediately after tumor resection, followed by a sustained, lower-dose release to suppress tumor recurrence in long-term period. Localized therapy capable of providing controlled initial and long-term release within the tumor microenvironment are critical for improving therapeutic outcomes. Precise control of nanofiber structure (homogeneous, core-sheath, emulsion, etc.) and composition enables a programmed initial quick release followed by consistent long-term delivery. [2] This dual-phase strategy is relevant for many other applications, including wound healing, infection control, tissue engineering, antimicrobial textiles, agricultural products, etc.

Materials and Methods Conventional electrospinning uses a single homogeneous solution dissolving both polymer and drug. The resulting fiber results in initial burst release, especially when hydrophilic drugs are incorporated. On the other hand, electrospun fibers with an emulsified solution can provide consistent zero-order release kinetic for an extended period. Emulsion solutions are prepared by dissolving ACF drug in water for water-phase solution, while oil-phase solution contained 7% polycaprolactone (PCL), 5% Span-80 surfactant, and 1.5% BCNU drug were dissolved in chloroform (CF). Once homogeneous solutions were prepared, water-phase solution is slowly added to the vigorously stirred oil-phase solution using homogenizer to form stable water-in-oil emulsions. Prepared emulsions were fed at constant flow rate (0.4-1 ml/h) into the nozzle, and the electrospinning process is initiated by applying high voltage (18-20kV) between nozzle and collector. To improve drug loading capacity and mechanical stability, thin electrospun membranes were densified by using a fold-and-press approach. [3] Densified membranes were cut into ~ 3 (W) x 3 (L) x 1 (T) mm pieces by using a CO2 laser.

Results Core-sheath fibers produced by coaxial electrospinning provide enhanced versatility for drug delivery. However, initial burst release can still occur when hydrophilic drugs are utilized. Once water penetrates to the exposed core due to breakage of coaxial fibers, other connected core sections are affected, accelerating the release rate from most fibers. To ensure sustained release kinetics of hydrophilic drugs, we have utilized emulsion electrospinning, which results in a core-sheath fiber-like encapsulating structure with discontinuous pockets of hydrophilic therapeutics, thus limiting excessive burst release upon hydration. Hydrophobic BCNU and hydrophilic ACF drugs were loaded in oil-phase and water-phase, respectively. Hydrophilic ACF drugs were released in zero-order kinetics up to 30 days followed by reduced release rates up to 60 days. Higher ACF concentrations loaded in nanofibers lead to faster release rates and larger total release amounts without initial burst release. Even at 15% ACF loaded nanofibers, initial burst release was prevented. For hydrophobic BCNU loaded in outer fiber matrix, the release shows diffusion limited kinetics with relatively higher initial release rate followed by gradual release up to 60 days.

Dual-phase delivery was evaluated using the hydrophilic ACF drug. To obtain our targeted dual-phase release kinetics from one NanoMesh device, both homogeneous and emulsion fiber membranes were folded into a single device. Simply by adjusting the weight ratio of homogeneous and emulsion fiber membranes in NanoMesh, we easily adjusted the level of initial quick release and the consistent release kinetics.

Conclusions Emulsion electrospun nanofibers enabled sustained dual-drug release for up to 60 days while minimizing initial burst release for hydrophilic ACF. Electrospun nanofiber systems can be engineered to achieve programmable dual-phase drug release kinetics, combining adjustable initial rapid release with sustained long-term delivery. By integrating homogeneous and emulsion-based nanofibers within a single NanoMesh platform, release kinetics can be precisely tuned. Further control of dual-phase release kinetics can be improved by incorporating coaxial fibers into NanoMesh devices.

Key words Emulsion electrospinning, Glioblastoma, Localized therapy, Dual-phase delivery, Controlled release

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45 - SYNTHESIS AND SWELLING PROPERTIES OF HYDROGEL FIBER MEMBRANES

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Background/Rationale Gel fiber based membranes have a unique structure mimicking the structure of native soft tissues. As such, they can be used as materials for cell cultivation and in tissue regeneration. However, there is a constant need for new methods for the preparations of such materials, since there are no general strategies for their synthesis. The use of water soluble polymers in the synthesis of implants using electrospinning is inappropriate because of their fast dissolution in biological fluids. By utilizing reactive electrospinning, chemically crosslinked gel fibers can be synthesized, which, without enzymatic or chemical degradation, will not dissolve in physiological conditions. Polysuccinimide (PSI) is the anhydrous form of poly(aspartic acid) (PASP), which is a biodegradable and biocompatible artificial polypeptide. PSI can transform into poly(aspartic acid) above pH 7.4 and also in the body (2). Other advantage of this polymer system is that PSI can be easily modified with primary amines and thus a wide variety of PSI and poly(aspartic acids) can be synthesized.

Materials and Methods Based on this flexibility, different techniques were developed to make crosslinks between the PSI chains inside the fibers: after placing free thiol groups as side groups on the polymer, thiol oxidation crosslinking by air during electrospinning (1,2); immersion of electrospun PSI fiber mats into a diamine crosslinker solution to post-electrospinning crosslink the fibers (PASPDA) (2); using coaxial electrospinning, where the crosslinker was in the core and the PSI solution was in the shell (3); and using non-equilibrium low pressure air plasma in allylamine-modified polysuccinimide fibers (4). Swelling properties of PASPDAB membranes were tested by first cutting cylinders of uniform sizes from the premade PSI fiber membranes, then crosslinking them with 1,4-diaminobutane (DAB) solution and hydrolyzing them to obtain PASPDAB membranes. Equilibrium size of the macroscopic samples were measured in the range of pH 3 to 8. Swelling kinetics was also measured during swelling from pH 3 state to pH 8 state. Microscopic changes due to pH changes, namely the fiber diameters were investigated using scanning electron- and fluorescent microscopies.

Results All methods yielded hydrogel fibers that did not dissolve upon submerging them in their solvents, thus crosslinking of polymer chains inside the fibers happened. Microscopic fibrous structures were confirmed by SEM. PASPDAB hydrogel fiber membranes showed pH dependent swelling properties: in pH 3 they shrank and in pH 8 they swelled. Similar size changes were observable under the fluorescent microscope thus the macroscopical size change was caused by the swelling of the individual fibers.

Conclusions The presented synthetic strategies are not exclusive to PSI, but if the chemistry allows it, they can be extended to other polymer systems as well. The pH dependent swelling properties of PASPDAB samples may be exploited in advanced drug delivery systems.

Key words electrospinning; hydrogel fiber; poly(aspartic acid); swelling properties

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46 - CELL GUIDING MULTICOMPONENT NANOYARN TENDON SCAFFOLDS WITH TUNABLE MORPHOLOGY AND FLEXIBILITY

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Background/Rationale Tendon injuries are highly prevalent, with millions of grafting procedures performed annually. Current treatments, including autografts and allografts, suffer from limitations such as donor scarcity, immune rejection, and additional surgical burden. Tissue engineering offers a promising alternative, where scaffolds play a crucial role in supporting cell growth and tissue regeneration. However, conventional electrospun nanofibrous scaffolds often fail to fully replicate the hierarchical fibrillar and tubular structure of native tendon extracellular matrix (ECM), limiting their regenerative potential. Therefore, there is a need for advanced scaffold designs that better mimic tendon architecture while providing suitable mechanical properties and cell-guiding capabilities.

Materials and Methods Multicomponent nanoyarn scaffolds were fabricated using yarn electrospinning. Poly(ϵ -caprolactone) (PCL) was used as the primary structural polymer, while poly(2-ethyl-2-oxazoline) (PEtOx) served as a sacrificial component to introduce additional porosity. A design of experiments (DoE) approach was applied to optimize processing parameters (e.g., flow rate, polymer concentration, take-up speed, and cone rotation) and control nanoyarn diameter and twist angle.

Nanoyarns were first produced via yarn electrospinning, then bundled and coated with a nanofibrous PCL shell through yarn electrospinning as well to form tubular scaffolds. Subsequent dissolution of PEtOx created controlled macro- and microporosity. Morphological characterization was performed using scanning electron microscopy, while mechanical properties were assessed through cyclic bending tests.

Biological evaluation included indirect and direct in vitro assays using mouse fibroblasts, equine dermal fibroblasts, and equine tendon cells to assess cytotoxicity, cytocompatibility, proliferation, and cell alignment.

Results The DoE approach enabled precise tuning of nanoyarn morphology, achieving diameters within the range of native tendon fascicles (~220–470 μ m) and controllable twist angles. Incorporation and removal of PEtOx successfully introduced macropores in the scaffold and enabled production of hybrid nanoyarns with porosities up to ~82% while maintaining structural integrity.

Mechanical testing demonstrated that scaffold flexibility could be tailored through morphology and porosity. All scaffolds exhibited similar bending fatigue behavior, with an initial reduction in bending force followed by stabilization.

Biological assays confirmed excellent cytocompatibility, with cell viabilities exceeding 95%. Cells adhered, proliferated, and exhibited elongated morphologies aligned with the nanoyarn direction. Importantly, cell orientation closely followed the scaffold twist angle, demonstrating effective cell-guiding capability.

Conclusions This study presents a novel and scalable approach to fabricate multicomponent nanoyarn scaffolds that closely mimic the structural and mechanical properties of native tendons. The combination of yarn electrospinning and sacrificial polymer strategies enables precise control over morphology, porosity, and flexibility.

The scaffolds demonstrate excellent cytocompatibility and the ability to guide cell alignment, which is critical for functional tendon regeneration. These findings highlight the strong potential of multicomponent nanoyarn scaffolds for tendon tissue engineering and related applications, such as tendon–bone interface and nerve regeneration.

Key words Tendon tissue engineering; nanoyarn scaffolds; electrospinning; poly(ϵ -caprolactone); poly(2-ethyl-2-oxazoline); porosity tuning; cell guidance; biomaterials; scaffold design; regenerative medicine

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49 - MULTICOMPONENT ELECTROSPUN POLYVINYLPYRROLIDONE NANOCOMPOSITE FIBROUS MEMBRANES CONTAINING SILVER AND PALLADIUM NANOPARTICLES

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Background/Rationale The new era of nanomaterials science requires the design and development of novel materials exhibiting enhanced customizable properties with applicability in high-tech fields such as biomedicine and healthcare. At the same time, electrospinning has emerged as a highly versatile and influential technique for the fabrication of such novel materials including polymer-based nanostructured and multifunctional fibrous membranes. For instance, preventing microbial infection in wounds requires effective wound-healing materials [1]. In addition, colloidal, polymer-capped metallic nanoparticles (NPs) have attracted remarkable attention in the promotion of nanomaterials with antibacterial capabilities [2, 3]. To this end, the present study aims on developing and characterizing hybrid composite electrospun membrane materials for potential use in wound dressing applications.

Materials and Methods Initially, the synthesis and characterization of (a) polyvinylpyrrolidone (PVP)/silver (Ag) [4]; (b) PVP/palladium (Pd) [5]; and (c) PVP/Ag/Pd NP colloidal nanohybrid solutions were conducted. The formation of PVP-based NPs was confirmed by high resolution transmission electron microscopy (HRTEM). Subsequently, the prepared colloidal nanohybrid solutions were subjected to electrospinning in order to produce PVP/Ag, PVP/Pd and PVP/Ag/Pd nanocomposite fibrous membranes. Neat PVP electrospun fibrous membranes were also produced for the comparative examination. All membranes were then exposed to a thermally-controlled treatment that induced crosslinking and structural stability in aqueous environments [4].

Results The resulting fibrous nanocomposites were characterized in respect to their morphology by scanning electron microscopy (SEM), whereas the NP distribution within the fibers was investigated by high-resolution transmission electron microscopy (HRTEM). Moreover, their mechanical properties were assessed through tensile testing. The antimicrobial properties of the aforementioned materials are currently under investigation to further improve the ability of the developed membranes to prevent microbial contamination against gram negative and gram-positive bacteria, that will be beneficial for use in wound healing and other applications.

Conclusions The functionalization of electrospun polymer-based nanofibrous membranes with antimicrobial nanoparticles, such as Ag and Pd, is an attractive and unique strategy with dynamic performance characteristics. This study properly demonstrates the generation of continuous and robust Ag/Pd NP-based PVP fibers exhibiting a high surface area, controlled morphological features and functional capabilities within the experimental design and results analysis.

Key words Nanocomposite electrospun fibers; antibacterial properties, Ag NPs; Pd NPs; polyvinylpyrrolidone.

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54 - COMPARATIVE ANALYSIS OF ELECTROSPUN PCL, PLLA, AND PLCL SCAFFOLDS: SURFACE PROPERTIES AND MORPHOLOGICAL CHARACTERISTICS

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Background/Rationale Tissue engineering is an interdisciplinary field focused on repairing or regenerating damaged tissues and organs using a combination of cells, scaffolds, and bioactive molecules. Scaffolds act as a temporary extracellular matrix, offering structural support for cell attachment, growth, and differentiation[1]. For successful integration and function, the ideal scaffold should be biocompatible, biodegradable, and mechanically compatible with the target tissue[2]. Among synthetic polymers, polycaprolactone (PCL), poly(L-lactic acid) (PLLA), and poly(L-lactide-co-e-caprolactone) (PLCL) are commonly used due to their favorable properties. PCL is known for its slow degradation rate, low glass transition temperature, and high thermal stability, making it suitable for load-bearing applications[3,4]. In contrast, PLLA and PLCL offer tunable mechanical properties and improved flexibility, with PLCL providing better cell adhesion due to its enhanced hydrophilicity[1,5]. This study compares these materials electrospun scaffold properties, focusing on surface morphology and chemistry to guide material selection for improved tissue regeneration.

Materials and Methods PCL, PLLA, and PLCL scaffolds were electrospun using optimal parameters. Subsequently, a series of analyses were carried out, including Scanning Electron Microscopy (SEM), Fourier-Transform Infrared (FTIR) Spectroscopy, X-ray Photoelectron Spectroscopy (XPS), and Differential Scanning Calorimetry (DSC). In addition, the scaffolds' zeta potential, wettability, and mechanical properties were evaluated. Direct cytotoxicity testing and cell morphology analysis with confocal imaging and SEM were also performed to examine their biological and structural performance.

Results The average fiber diameter was $1.1 \pm 0.6 \mu\text{m}$ for PCL, $2.2 \pm 0.5 \mu\text{m}$ for PLLA, and $2.6 \pm 0.2 \mu\text{m}$ for PLCL was observed in SEM. FTIR analyses confirmed the presence of characteristic surface chemical groups. XPS analysis revealed that PLLA had the most intense O–C=O peak, indicating higher carboxylic group presence and improved surface polarity. PCL showed dominant C–C/C–H peaks, and PLCL exhibited intermediate features. Zeta potential results showed that PLLA had the most negative surface charge, followed by PLCL and then PCL. Mechanical testing demonstrated that PLCL had the highest tensile strength ($\sim 5 \text{ MPa}$) and elongation ($\sim 1000\%$), while PLLA showed high stiffness but brittle failure, and PCL presented moderate strength and ductility. Viability assays confirmed higher cell density and survival on PLCL and PLLA. Confocal and SEM images showed better initial attachment, spreading, and proliferation on PLCL and PLLA compared to PCL.

Conclusions In conclusion, PLLA exhibited the highest surface polarity and zeta potential, while PLCL provided the best mechanical flexibility and strength. Both PLCL and PLLA supported enhanced cell adhesion and proliferation. PCL, although biocompatible, showed limited biological response and moderate mechanical properties. Overall, PLCL and PLLA are more promising candidates for tissue engineering applications when comparing PCL.

Key words Keywords: Electrospun scaffold, biodegradable polymers, tissue engineering application.

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59 - PREPARATION AND CHARACTERIZATION OF POLYSUCCINIMIDE–SALT NANOFIBROUS SYSTEMS FOR WOUND HEALING APPLICATIONS

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Background/Rationale Although silver ions are widely applied in antibacterial therapeutics, their environmental impact and potential to induce adverse immune responses have raised increasing concerns. Consequently, their medical use is gradually decreasing, prompting the search for alternative antibacterial ions with improved biocompatibility.

The aim of our research is to develop a bicomponent electrospun polymer scaffold containing zinc and strontium salts embedded within the polymer matrix. The resulting system is intended to function as a novel biocompatible wound dressing that combines effective antibacterial properties with the ability to provide mechanical protection for the wound site.

Materials and Methods The first stage of the study focused on the synthesis of the polysuccinimide (PSI) polymer, followed by the preparation of polymer solutions containing different antibacterial salts dissolved in dimethylformamide (DMF). Electrospinning parameters were systematically optimized to produce both uniaxial and coaxial nanofibrous structures with suitable morphology and stability for biomedical applications. Particular attention was paid to parameters influencing fiber formation, including solution composition, viscosity, applied voltage, feeding rate, and collector distance, in order to obtain homogeneous and defect-free scaffolds. A broad range of experiments was subsequently carried out to evaluate and optimize the physicochemical, mechanical, and biological properties of the developed scaffolds for potential wound dressing applications. The incorporated salts included anhydrous zinc acetate, zinc acetate dihydrate, zinc sulfate monohydrate, zinc chloride, and strontium nitrate, selected for their known antibacterial and bioactive properties.

The structural and chemical characterization of the electrospun materials was performed using Fourier-transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM), enabling the investigation of chemical interactions, fiber morphology, and salt distribution within the polymer matrix. Mechanical performance was assessed under both dry conditions and in physiological saline solution to better simulate the wound environment. Measurements included specific load capacity, tensile strength, elongation at break, and Young's modulus, allowing comparison of scaffold flexibility and durability with conventionally used wound dressing materials.

In addition, release studies were conducted to determine whether the incorporated metal salts could be effectively released from the nanofibrous matrix over time and maintain their potential antibacterial activity. Biological evaluation included cytotoxicity testing on human tumor and fibroblast cells in order to assess the biocompatibility of the developed systems. Since wound dressings are intended for direct and prolonged contact with living tissue, evaluating cellular responses was essential to determine the safety and applicability of the scaffolds.

Results The results demonstrated that the electrospun fibrous structures were capable of successfully incorporating antibacterial salts into the polymer matrix while maintaining stable nanofibrous morphology. The presence of the salts significantly influenced the mechanical behavior of the scaffolds, generally increasing their rigidity and structural stability. At the same time, mechanical testing in saline solution revealed that the developed scaffolds exhibited greater elongation and flexibility compared to conventional medical gauze, suggesting improved adaptability to dynamic wound surfaces.

Furthermore, the scaffolds showed notable antibacterial activity against the investigated bacterial strains, indicating that the incorporated salts retained their functional antimicrobial properties after electrospinning and during release from the matrix. Cytotoxicity studies confirmed that the materials were non-toxic toward human tumor and fibroblast cells, demonstrating favorable biocompatibility and supporting their suitability for biomedical use.

Conclusions Overall, the comprehensive physicochemical, mechanical, antibacterial, and biological evaluations indicate that the developed polysuccinimide–salt nanofibrous scaffolds represent promising candidates for advanced wound dressing applications. Their combination of mechanical protection, flexibility, antibacterial functionality, and cytocompatibility suggests considerable potential for future biomedical and wound healing applications.

Key words polysuccinimide, wound dressing, electrospinning, antibacterial activity

68 - BIOBASED COMPOSITES FOR DENTAL APPLICATIONS: THE FIRST STEPS TOWARDS IN SITU GUIDED TISSUE REGENERATION MEMBRANE MANUFACTURING

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Background/Rationale Periodontitis is an inflammatory disease, characterised by progressive gum and alveolar bone loss, affecting nearly one billion people worldwide. Guided tissue regeneration (GTR), the most common periodontal regeneration method, utilises a barrier membrane to prevent epithelial migration and promote bone regrowth [1]. However, GTR outcomes are highly dependent on surgical precision, the pre-fabricated membranes rarely match the complex geometry of individual defects, and their placement often requires large incisions.

To address these limitations, this project proposes in situ fabrication of GTR materials into periodontal defects via handheld electrospinning. By enabling real-time deposition of fibres, with the long-term goal of integrating core-shell structures, this approach aims to simplify the procedure and enhance regenerative outcomes. This study evaluated the morphological and mechanical impacts of transitioning from the traditional desktop to handheld manufacturing, establishing the viability of handheld electrospinning for personalised periodontal therapy.

Materials and Methods Polycaprolactone (Mw= 80kDa, Thermo Fisher Scientific, UK) was dissolved in a 7:3 binary mixture of glacial acetic acid (>98%, Sigma-Aldrich UK) and acetone (VWR) to prepare 20% (w/v) solutions. For the desktop system, the solution was dispensed using a syringe pump (AL-1000, World Precision Instruments, Sarasota, FL), while the handheld device (Corryn Biotechnologies, UK) utilised its integrated delivery system. In both cases, solutions were fed through a 22-gauge blunt needle at a constant flow rate of 3 mL/h with a 20 cm tip-to-collector distance. Desktop membranes were electrospun at 25 kV, while handheld membranes at 15 kV (device limitation). These electrospinning parameters were established as optimal following Design of Experiments (DoE) methodology.

Results PCL was successfully electrospun using both handheld and desktop devices. SEM analysis showed comparable fibre diameters: desktop fibres averaging $1.39 \pm 1.15 \mu\text{m}$, while handheld fibres $1.56 \pm 1.33 \mu\text{m}$, both within the suitable range for cell attachment [2]. Capillary flow porometry confirmed that both devices remained well below the target cell occlusive threshold ($<30 \mu\text{m}$ [3]), yielding mean pore sizes of $5.4 \pm 0.4 \mu\text{m}$ (handheld) and $8.5 \pm 0.9 \mu\text{m}$ (desktop). Mechanical testing demonstrated comparable tensile properties, with tensile strength of $1.28 \pm 0.2 \text{ MPa}$ and $1.17 \pm 0.33 \text{ MPa}$ and tensile modulus of $4.95 \pm 1.05 \text{ MPa}$ and $7.55 \pm 3.13 \text{ MPa}$, for handheld and desktop devices, respectively. While the obtained Young's modulus corresponds to the gingival range (3-37 MPa [4]), the tensile strength needs further reinforcement to match native tissue (3.81 MPa [4]).

Conclusions This study demonstrates that handheld electrospinning effectively replicates the morphological and mechanical properties of desktop-manufactured GTR materials, validating its potential to simplify clinical workflows. Future evaluations will focus on the biological performance of these membranes, degradation kinetics and barrier function.

Ongoing work aims to miniaturising the applicator for intraoral use and integrating coaxial technology into the handheld platform. This will enable the in situ fabrication of core-shell fibres, utilising a structural PCL core encapsulated by a sodium alginate shell to enhance surface bioactivity and provide tuneable regenerative environments.

Key words handheld electrospinning, guided tissue regeneration, in situ fabrication, barrier membrane

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72 - INFLUENCE OF FIBER DIAMETER ON CURCUMIN RELEASE FROM ELECTROSPUN POLYCAPROLACTONE NONWOVENS

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Background/Rationale Electrospun drug-eluting scaffolds are promising systems for local drug delivery because the release behavior of incorporated compounds can be influenced by structural properties of the fibrous matrix. In addition, the high specific surface area enables a faster drug elution, compared to non-fibrous membranes. In particular, fiber diameter is expected to affect diffusion pathways and therefore drug release kinetics. The aim of this study was to investigate whether the release kinetics of curcumin from electrospun polycaprolactone (PCL) nonwovens are influenced by fiber diameter. Mechanical characterization was included as a supplementary parameter to assess whether structural variations also affect the tensile behavior of the materials.

Materials and Methods Electrospun nonwovens were fabricated from medical-grade PCL dissolved in a 3:1 mixture of chloroform and methanol. Spinning was performed on an aluminum roller collector (diameter 3 cm) at a working distance of 20 cm under ambient conditions of approximately 23 °C and 27.5–30% relative humidity. Different flow rates and voltage settings were applied to generate nonwovens with different fiber morphologies.

Based on these processing parameters, curcumin-loaded PCL nonwovens are electrospun under corresponding conditions. These samples are analyzed with regard to fiber diameter ($n > 30$), drug release behavior ($n = 3$), and tensile properties ($n = 5$). Curcumin release is quantified by UV/Vis spectroscopy over a period of 14 days in order to assess whether differences in fiber diameter influence the release kinetics.

Results Electrospinning under the selected process conditions enabled the reproducible fabrication of PCL nonwovens with distinct fiber diameters in the lower micrometer range. By variation of the flow rate, mean fiber diameters of approximately $2.37 \pm 0.44 \mu\text{m}$, $3.416 \pm 0.52 \mu\text{m}$, and $4.41 \pm 0.94 \mu\text{m}$ were generated. The produced nonwovens showed thicknesses in the range of approximately 101 to 166 μm .

Using the same electrospinning conditions, curcumin-loaded PCL nonwovens are subsequently produced and investigated with respect to fiber diameter, tensile properties, and curcumin release behavior. Drug release is monitored over 14 days by UV/Vis spectroscopy in order to evaluate the influence of fiber diameter on release kinetics.

It is hypothesized that fiber diameter will influence the release kinetics of curcumin: larger fibers are expected to provide longer diffusion pathways and a reduced specific surface area, which may attenuate the initial burst release and result in a more sustained release profile. However, given the relatively narrow range of fiber diameters investigated, it cannot be excluded that the observed differences will be too small to produce a clearly detectable effect on release behavior.

In addition, the incorporation of curcumin may affect the mechanical behavior of the nonwovens and could increase their stiffness. Curcumin may also influence the fiber diameter itself, for example by altering solution properties such as electrical conductivity, which can affect the electrospinning process and thus the resulting fiber morphology.

Conclusions A reproducible electrospinning strategy was established for generating medical-grade PCL nonwovens with defined differences in fiber diameter. These scaffold systems provide a suitable basis for studying morphology-dependent release of curcumin from drug-eluting electrospun materials. Mechanical testing serves as a complementary method of characterization, while the primary focus lies on understanding the relationship between fiber diameter and drug release kinetics.

Key words Electrospinning, Nonwoven, Drug elution, local drug delivery, PCL, Curcumin, Fiber diameter

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76 - HUMAN AUTOLOGOUS TISSUE-ENGINEERED VASCULAR GRAFT FABRICATED USING HYBRID THREE-DIMENSIONAL PRINTING AND ELECTROSPINNING TECHNIQUES

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Background/Rationale Cardiovascular diseases are among the leading causes of morbidity and mortality worldwide, and the development of effective and durable strategies for vascular repair and replacement represents a critical unmet clinical need. Some of them frequently require surgical vascular reconstruction, procedures that have available different kinds of materials with distinct advantages and limitations.

Synthetic patches, including polytetrafluoroethylene (PTFE), Gore-Tex, and Dacron, provide effective short-term results but lack the ability to grow or remodel, leading to restenosis, infection and aneurysm formation (Sundaraman et al., 2021). An alternative approach involves the use of donor biologic grafts, such as homografts and xenografts, which offer better integration but are prone to immune reactions, inflammation, and calcification. Autologous grafts, harvested from the patient's own tissue, offer advantageous immunological characteristics. Nonetheless, they are subject to certain limitations, including limited availability following repeated surgical procedures, size restrictions—especially concerning vessels of smaller diameters—and an increased likelihood of restenosis.

Although there are currently available synthetic and biological vascular grafts, they remain limited by thrombogenicity, infection, lack of growth potential and suboptimal long-term integration. Tissue-engineered vascular grafts (TEVGs) based on autologous cells combine biocompatibility, growth-capable cells, controlled porosity, antimicrobial traits, and mechanical strength for suturing and blood flow, making them a promising alternative to address these challenges (Lang, Materials Today Bio, 2024).

Materials and Methods A scaffold was fabricated using fused deposition modeling of poly (ϵ -caprolactone)(PCL) to provide mechanical strength and geometry, followed by electrospinning of a composite PCL-collagen layer incorporating vancomycin and gentamicin to enhance biocompatibility and reduce infection risk. Adipose-derived human autologous mesenchymal stem cells (MSCs) were expanded and differentiated into a vascular smooth muscle-like cells (dVSMCs) monolayer. Constructs were seeded with the dVSMCs monolayer and implanted as vascular patches in a porcine model. After four weeks, grafts were explanted for macroscopic, histological and immunohistochemical analyses. In-vitro assays assessed cytocompatibility and antibacterial activity.

Results All implants were patent at explantation. Macroscopic evaluation demonstrated integration with native tissue. Histology and immunohistochemistry revealed organized neotissue exhibiting morphological features consistent with the three arterial wall layers. The antibiotic-loaded electrospun layer maintained MSC viability while significantly reducing biofilm formation in vitro.

Conclusions This hybrid 3D printed and electrospun TEVG seeded with autologous human MSC-derived dVSMCs promotes early tri-layered arterial tissue formation in a porcine model. Incorporation of collagen and antibiotics enhances biocompatibility and antimicrobial properties, supporting the potential of this strategy for durable vascular reconstruction.

Key words Electrospinning; Vascular graft; poly (ϵ -caprolactone); collagen; tissue-engineering.

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81 - FROM ELECTROSPUN MICROCHANNELS TO TRANSLATIONAL BIOMIMETIC SCAFFOLDS: PROCESS OPTIMIZATION AND CHARACTERIZATION OF SELF-ASSEMBLING PEPTIDE-BASED CONSTRUCTS

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Background/Rationale Electrospinning is a versatile manufacturing technology for producing fibrous biomaterial scaffolds with high surface area, controlled architecture, and extracellular matrix-like morphology. In regenerative medicine, scaffold performance depends on material properties, process stability, fibre reproducibility, construct handling, and translational feasibility. Self-assembling peptides (SAPs) are promising bioactive materials because their molecular sequences can be designed to incorporate functional motifs and tissue-specific biological signals. However, SAPs remain difficult to electrospin because of formulation instability, limited mechanical robustness, and high sensitivity to processing conditions. This work presents our standard electrospun microchannel platform as a model system linking process optimization, scaffold characterization, biological relevance, and GMP-oriented translation.

Materials and Methods A process-focused electrospinning strategy was developed using SAP-based formulations. The fabrication process was investigated from a manufacturing perspective, with emphasis on the electrospinning apparatus, controllable parameters, and practical challenges associated with SAP-containing systems. Key parameters included formulation composition, solution behaviour, flow rate, applied voltage, needle-to-collector distance, collector configuration, and post-processing conditions. Their effects on fibre formation, scaffold morphology, construct handling, and microchannel reproducibility were evaluated. The standard microchannel format was used as the primary demonstrator, while the overall process logic was considered applicable to flat fibrous scaffolds, and alternative scaffold architectures. Representative in vitro and in vivo outcomes were included to contextualize the biological relevance of the system.

Results The optimized workflow enabled reproducible fabrication of standard electrospun microchannels with improved process control. Their architecture provided a defined scaffold format for biological investigation while retaining flexibility for adaptation to different SAP systems. Parameter optimization improved control over fibre formation, scaffold organization, and construct handling. The use of SAPs introduced processing challenges, mainly related to formulation stability, mechanical robustness, and consistency during electrospinning. These were addressed through systematic optimization and, when necessary, polymer blending. This combination helped balance mechanical performance with biological activity: the polymer component maintained scaffold integrity, while the peptide component provided bioactive functionality. The platform is relevant for both in vitro and in vivo applications, especially where scaffold architecture, cell guidance, and tissue interaction are critical. Beyond tubular microchannels, the same principles can be extended to flat fibrous scaffolds and other biomimetic constructs. By adjusting peptide formulation, and electrospinning parameters, the approach can be tailored to different target cells and tissues, including neural tissue, cartilage, and bone.

Conclusions This work presents SAP-based electrospinning as both a material challenge and a manufacturing opportunity. Using standard microchannels as a model platform, it shows that reproducible constructs require coordinated consideration of formulation design, machine parameters, collector strategy, post-processing, and scaffold characterization. By linking process control with GMP-oriented considerations, this adaptable framework may support the translation of biomimetic scaffolds for regenerative medicine and advanced therapy applications.

Key words self-assembling peptides; microchannels; biomimetic scaffolds; process optimization; GMP translation;

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84 - MULTIFUNCTIONAL ELECTROSPUN POLYSUCCINIMIDE SCAFFOLDS COMBINING ZNO AND MAGNETITE NANOPARTICLES FOR BIOMEDICAL APPLICATIONS

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Background/Rationale Chronic infected wounds nowadays remain a serious clinical problem, and the rising prevalence of multidrug-resistant (MDR) bacteria makes them increasingly difficult to manage with conventional antibiotics. This has driven interest in wound dressings that go beyond passive coverage: combining antibacterial activity, mechanical support, biodegradability, and imaging capability in one material. Polysuccinimide (PSI) is a biocompatible, biodegradable polymer that hydrolyzes to poly(aspartic acid) under physiological conditions, with well-documented cell adhesion properties and tunable degradation [1]. Electrospun PSI produces nanofibrous scaffolds with high surface-area-to-volume ratios and extracellular matrix-like morphology, making them a reasonable base material for tissue engineering and wound care. Zinc oxide nanoparticles (ZnONPs) are known for broad-spectrum antibacterial activity. They generate reactive oxygen species (ROS), disrupt bacterial membranes, and release Zn²⁺ ions, and remain effective against several MDR strains [2]. Magnetite nanoparticles (MNPs) are well-established magnetic resonance imaging (MRI) contrast agents and have shown antimicrobial activity of their own through similar ROS-mediated mechanisms [3]. Based on our previous work, ZnONP-loaded scaffolds showed significant antibacterial activity, while MNP-loaded scaffolds provided MRI contrast. The aim of this work was to incorporate both nanoparticle types into a single PSI scaffold, and to explore whether coaxial electrospinning could offer functional advantages over simple blending.

Materials and Methods MNPs were synthesized by co-precipitation and ZnONPs in an organic medium. Nanoparticle size and morphology were confirmed by dynamic light scattering (DLS) and transmission electron microscopy (TEM) prior to electrospinning. Both types of nanoparticles were mixed in a PSI solution, dimethylformamide (DMF) was used as a solvent. A dual-nanoparticle blend scaffold was first prepared by single-needle electrospinning. Coaxial electrospinning then produced five core/shell configurations: MNP-shell/ZnO NP-core, ZnO NP-shell/MNP-core, PSI-shell/MNP-core, PSI-shell/ZnO NP-core, and PSI-shell/blend-core. The scaffolds were characterized by scanning electron microscopy (SEM) with energy-dispersive X-ray (EDX) mapping and uniaxial tensile testing.

Results SEM showed uniform fiber morphology across all configurations, and EDX confirmed homogeneous nanoparticle distribution within the fibers. Tensile testing revealed that coaxial and blended scaffolds of identical composition behaved differently — not only in mechanical parameters such as Young's modulus, elongation at break, and tensile strength, but also in the characteristic shape of their stress-strain curves. This is most likely attributable to the spatial arrangement of nanoparticles within the fiber rather than to composition itself. Nanoparticle addition can reinforce scaffold mechanics, though excessive loading leads to weakening.

Conclusions Dual-nanoparticle PSI scaffolds incorporating both ZnONPs and MNPs show genuine promise as multifunctional wound dressings, combining antibacterial protection, biodegradability, and MRI contrast in one platform. Coaxial spinning adds a spatial design dimension that simple blending cannot provide, as evidenced by the mechanical differences observed between architecturally distinct but compositionally identical samples. Cytotoxicity, dissolution behavior, and hyperthermia potential are the next steps toward any practical application.

Key words electrospinning, antibacterial, zinc oxide, nanoparticles, magnetite

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100 - MULTIFUNCTIONAL ELECTROSPUN PEO NANOFIBROUS MEMBRANES VIA PHOTO-INDUCED FUNCTIONALIZATION FOR ADVANCED WOUND HEALING

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Background/Rationale Electrospun nanofibrous membranes are highly attractive for wound healing applications due to their high surface area, interconnected porosity, and tunable architecture, which mimic the extracellular matrix and promote cell interaction and tissue regeneration. In this context, tailoring membrane functionality is essential to address the multiple requirements of the healing process, including structural stability, antibacterial activity, biofilm prevention, and controlled bioactivity.

Photo-induced processes represent a powerful strategy for the design of multifunctional electrospun biomaterials, enabling precise control over network formation, morphology, mechanical properties, and aqueous stability under mild processing conditions [1]. In addition to photo-crosslinking, photochemical approaches such as photo-grafting and photoreduction allow the incorporation of bioactive functionalities directly within the fibrous structure [2,3]. These strategies provide versatile pathways to introduce antibacterial agents and therapeutic molecules while preserving the nanofibrous morphology.

In this work, complementary light-driven processes were combined to fabricate multifunctional electrospun poly(ethylene oxide) (PEO)-based membranes with enhanced stability, antibacterial activity, and pro-regenerative properties for advanced wound healing applications.

Materials and Methods Electrospun nanofibrous membranes based on water-soluble poly(ethylene oxide) (PEO) were fabricated and subsequently stabilized through UV-induced photo-crosslinking. Additional photochemical functionalization strategies were employed to tailor membrane properties and introduce bioactive functionalities.

Photoreduction processes allowed the in situ formation of silver nanoparticles (AgNPs) directly inside the nanofibrous matrix from a silver precursor, while photo-grafting reactions enabled the incorporation of methacrylated eugenol within the fibrous network. The resulting membranes were characterized by Field Emission Scanning Electron Microscopy (FE-SEM), Fourier Transform-Infrared (FT-IR) spectroscopy, UV-Vis spectroscopy, and complementary physicochemical analyses. Cytocompatibility, antibacterial activity against *S. epidermidis* and *E. coli*, anti-biofilm behavior, and pro-regenerative performance were evaluated through in vitro 2D and 3D skin models.

Results UV-induced photo-crosslinking successfully stabilized the electrospun membranes while preserving their fibrous morphology and porous architecture. The photocrosslinked systems exhibited improved structural integrity and enhanced aqueous stability under physiological conditions compared with non-crosslinked counterparts.

Photoreduction enabled the in situ formation of well-dispersed Ag nanoparticles within the nanofibrous structure without the need for additional reducing agents. The resulting hybrid membranes combined the high surface area of electrospun fibers with the antibacterial activity of AgNPs, generating multifunctional systems with potential for infection prevention and tissue regeneration [3].

Photo-grafting reactions enabled the homogeneous incorporation of methacrylated eugenol into the polymer matrix while maintaining nanoscale fiber morphology. Functionalized membranes exhibited antibacterial and antioxidant properties, demonstrating the effectiveness of light-driven chemical modification for bioactive surface tailoring [2].

Different concentrations of bioactive components were investigated, and optimized formulations produced uniform, defect-free fibers with average diameters below 340 nm. Physicochemical characterization demonstrated that the scaffolds possessed suitable flexibility, hydrophilicity, permeability, and mechanical robustness for wound dressing applications.

Biological evaluations confirmed that the functionalized scaffolds were cytocompatible and non-toxic while exhibiting significant antibacterial and anti-biofilm activity. In vitro wound-healing assays using human mesenchymal stromal cells showed an 85% reduction in wound width after 24 h in a 2D model. Consistently, in a 3D reconstructed human epidermis model, the functionalized membranes accelerated wound closure by approximately twofold compared with undoped PEO scaffolds.

Importantly, this work provides a structure–function comparison between native eugenol and its methacrylated derivative incorporated into photo-crosslinked electrospun PEO scaffolds, elucidating how chemical modification influences the balance between antimicrobial activity and regenerative performance.

Conclusions This work demonstrates the versatility of combining electrospinning with complementary photo-induced processes for the fabrication of multifunctional nanofibrous biomaterials for wound healing applications. UV-driven photo-crosslinking, photo-grafting, and photoreduction enabled simultaneous stabilization and functionalization of electrospun PEO membranes while preserving their nanostructured morphology.

The developed systems exhibited enhanced aqueous stability together with antibacterial, anti-biofilm, and pro-regenerative properties, highlighting the strong relationship between chemical modification, network architecture, and biological performance. Overall, the results establish light-driven functionalization as an effective strategy for structure–property tailoring of electrospun biomaterials and demonstrate the potential of the developed PEO nanofibrous membranes as scalable platforms for next-generation multifunctional wound dressings.

Key words Photo-induced reactions; wound healing; photo-crosslinking; eugenol; silver nanoparticles.

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105 - UNTAPPED BIOMEDICAL POTENTIAL OF GREEN ELECTROSPUN POLYMERS

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Background/Rationale Green electrospinning is achieved with non-toxic, non-flammable, renewable feedstock polymers, additives, and solvents. This aims not only to make the process more environmentally sustainable, but also suitable for on site biomedical applications.

Materials and Methods In this context, we demonstrate the untapped electrospinning potential of different biopolymers using a battery-operated portable electrospinning device as candidate wound dressings for in situ deposition. For this, ethanol-water soluble biopolymers were screened.

Results Our results show uniform nanofiber mats with diameters under 500nm for hydroxypropyl cellulose, ethyl cellulose, gelatin, and zein. Preliminary data shows that the polymers retain their chemical structure, while showing reduced cytotoxicity, and potential sustained release of drugs (e.g. Tetracycline hydrochloride and acetaminophen). The caveat, however, is their mechanical properties, still one order of magnitude lower than commercial ethanol soluble polyamides. This could be circumvented by the crosslinking of electrospun mats via different chemistry routes.

Conclusions We expect the green electrospun materials to work as appropriate wound dressings due to their biobased origins, biocompatibility, capacity to transport exudates.

Key words Green electrospinning, biopolymers, wound-dressings.

129 - IMPACT OF ELECTROSPINNING ON THE EFFICACY OF IMMUNOMODULATORY ADDITIVES

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Background/Rationale Manuka honey (MH) is a monofloral honey derived from the nectar of the *Leptospermum scoparium* plant in New Zealand. It has gained popularity in the medical field due to its unique bactericidal and anti-inflammatory properties. Historically, it has been used topically on wounds as its low water content creates an osmotic gradient that flushes bacteria, debris, and damaged tissue out of the wound. It also contains methylglyoxal, a potent antibiotic that has demonstrated efficacy in treating multiple strains of antibiotic-resistant bacteria. Additionally, MH contains several flavonoids and phenols which contribute to its anti-inflammatory properties. Methyl syringate (MS) was identified as the component that most significantly contributes to its anti-inflammatory effects in neutrophils, as it significantly reduced intracellular reactive oxygen species and neutrophil extracellular trap (NET) release in vitro. Whole MH demonstrated similar results in neutrophils stimulated with PMA. However, results vary when incorporated into electrospun templates. In traditional electrospinning (TES), MH significantly reduced NET release when incorporated into the solvent at 0.1% v/v, however, it increased NET release at 10% v/v. In near-field electrospinning (NFES), which utilizes a lower applied voltage to produce precisely aligned fibers, 0.1% and 1% did not significantly reduce NET release, nor did 10% significantly increase NET release. It was hypothesized that the applied voltage may be causing glucose degradation into methylglyoxal, which can cause cellular damage at high concentrations. Additionally, 1,1,1,3,3,3-hexafluoro-2-propanol (HFP), the solvent used in the previous experiments has also been used to extract hydroxymethylfurfural (HMF) from fructose, a sugar comprising nearly one-third of MH. Low-dose HMF has antioxidant and anti-inflammatory effects, though safe levels of HMF have yet to be defined. However, excessive exposure to HMF has caused mutagenic, genotoxic, and organotoxic effects in vitro and in vivo. It was hypothesized that the applied voltage and solvent used during the electrospinning process may alter the effectiveness of MH and its components' immunomodulatory effects in neutrophils.

Materials and Methods To evaluate the effect of applied voltage, MH was diluted in phosphate buffered saline (PBS) at 10% v/v and electrospayed at either 1.6 kV at a rate of 18 μ L/h to simulate NFES or 12 kV at 4 mL/h to simulate TES. To evaluate the effect of solvent on MH, MH was dissolved in HFP at 10% v/v. It was sonicated for 4 hours and allowed to continue mixing overnight. The solutions were transferred to 1 mL syringes and allowed to evaporate with a flow rate of either 18 μ L/h or 4 mL/h. After the HFP was evaporated, the MH was resuspended in PBS at 10% v/v. To evaluate the combined effect of the applied voltage and solvent, this step was repeated with the addition of 1.6 kV applied to the 18 μ L/h flow rate and 12 kV applied to the 4 mL/h flow rate during evaporation. MS was initially suspended in dimethyl sulfoxide at a concentration of 188.5 mM. Then the same methods performed with MH were performed with MS at 6.5 mM. All solutions were sterile filtered using a 0.2 μ m filter and stored at 4°C until use.

Neutrophils were isolated from whole human blood and seeded in a 96-well plate at 100,000 cells/well and stimulated with 100 nM of PMA. MH solutions were diluted to a final well concentration of 0.6% v/v for NFES simulated samples and 1.5% v/v for TES simulated samples corresponding to MH elution from these templates eluted in previous studies. MS was diluted to 1300 μ M and 600 μ M for both NFES and TES to evaluate performance. NET release was quantified via myeloperoxidase assay.

Results Preliminary results indicate that the electrospinning process does not have a significant effect on the effectiveness of whole MH or MS. There was no significant difference in any of the experimental groups; neither the HFP treatments nor the applied voltages caused a change in NET release.

Conclusions This suggests that other factors, such as template architecture or pathways of NET induction, may be responsible for the differences in NET release between MH incorporated templates and PMA stimulated NETs. Replicate studies are needed to confirm these results, and additional studies are underway to understand the effectiveness of MH in template induced NET release.

Key words Manuka honey, methyl syringate, neutrophil extracellular traps

137 - BIOACTIVE ZWITTERIONIC SILICA-QUERCETIN ELECTROSPUN NANOFIBERS FOR MULTIFUNCTIONAL BIOMEDICAL APPLICATIONS

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Background/Rationale In the design of advanced biomaterial systems, the integration of inorganic nanostructures into polymer matrices offers a powerful strategy to simultaneously enhance structural stability and biological functionality. Within this framework, silica-based nanostructures have emerged as a versatile platform due to their high chemical stability, tunable surface properties, and broad functionalization capacity. In particular, their surface chemistry can be readily engineered to regulate interactions with biological environments, enabling the development of bioactive interfaces. However, certain limitations still exist in achieving enhanced biological performance. To address this, silica nanoparticles (SiO₂ NPs) were modified with a zwitterionic polymer to impart antifouling and hydration properties, and further functionalized with quercetin (Que) to introduce antioxidant bioactivity. The resulting hybrid nanoparticles were subsequently incorporated into a poly(vinyl alcohol)/poly(acrylic acid) (PVA–PAA) electrospun nanofiber, yielding a multifunctional wound dressing platform with enhanced biological performance.

Materials and Methods SiO₂ NPs were synthesized via the sol–gel method, followed by surface grafting of a zwitterionic polymer through radical polymerization of dimethyl-(3-sulfopropyl) ammonium hydroxide (Zw), initiated by 2,2'-Azobis(2-methylpropionitrile) (AIBN). Que was subsequently loaded onto the nanoparticles via physical adsorption. A PVA–PAA solution was then prepared, and quercetin-loaded zwitterionic grafted SiO₂ NPs (Zw-SiO₂@Que) were incorporated into the matrix at varying ratios. Nanofibrous mats were fabricated by electrospinning under an applied voltage of 16 kV, a tip-to-collector distance of 14 cm, and a flow rate of 1.8 mL h⁻¹. Thermal annealing was subsequently applied to all electrospun nanofibrous samples at 135 °C for 120 min. The obtained nanofibrous mats were characterized by SEM, TEM, FTIR, XRD, and TGA. Furthermore, swelling behavior, hydrolytic degradation, antibacterial and antioxidant activities, cell viability, anti-inflammatory gene expression, and wound-healing assays were performed.

Results Characterization results confirmed successful grafting of Zw and loading of Que, while preserving the spherical morphology of the SiO₂ NPs. The electrospun nanofibers exhibited a homogeneous, continuous, and bead-free morphology. Increasing nanoparticle content led to notable improvements in thermal stability, water uptake capacity, and overall structural integrity. The developed system demonstrated strong antibacterial activity, with complete inhibition observed particularly in pre-annealed samples. Antioxidant analyses revealed a high radical-scavenging capacity. Cell viability remained above 85%, indicating good biocompatibility. Gene expression analysis showed downregulation of pro-inflammatory markers (IL-6, TNF-α, and IL-1β) and upregulation of anti-inflammatory markers (IL-10 and TGF-β). Furthermore, scratch assay results demonstrated significantly enhanced fibroblast migration, suggesting improved wound healing potential.

Conclusions In conclusion, PVA–PAA nanofibers containing quercetin-loaded zwitterionic silica nanoparticles provided a multifunctional platform combining antibacterial, antioxidant, and anti-inflammatory properties, thereby supporting wound healing. These findings demonstrate that the developed system is a strong candidate for advanced wound-dressing and tissue-engineering applications.

Key words Silica nanoparticles; zwitterionic polymer; quercetin; electrospinning; antibacterial activity; antioxidant biomaterials.

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139 - MULTIFUNCTIONAL ELECTROSPUN METHYLENE BLUE@PAN/CYSTOSEIRA BARBATA NANOFIBERS FOR PHOTODYNAMICALLY ENHANCED WOUND HEALING

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Background/Rationale Chronic wound healing remains a significant clinical challenge due to prolonged inflammation, microbial contamination, and impaired tissue regeneration¹. Persistent bacterial colonization and biofilm formation can further delay tissue repair and reduce the effectiveness of conventional wound treatment strategies². Moreover, the increasing prevalence of antimicrobial resistance has increased the demand for alternative therapeutic approaches. Accordingly, substantial attention has been devoted to developing advanced wound-dressing systems that simultaneously prevent infection and support tissue regeneration³. Among the various biomaterial platforms investigated, electrospun nanofibers have emerged as promising candidates due to their high surface area, porous architecture, and structural similarity to the extracellular matrix, all of which are favorable for cell adhesion and tissue repair⁴. Furthermore, integrating antimicrobial photodynamic therapy (aPDT) into wound dressing materials offers an attractive alternative to conventional antimicrobial treatments, as bacteria are less likely to develop resistance to the highly reactive singlet oxygen species generated during photodynamic processes⁵. Therefore, multifunctional electrospun polyacrylonitrile (PAN) nanofibers containing *Cystoseira barbata* and methylene blue (MB) were developed in this study for photodynamic-enhanced wound-healing applications. Owing to its bioactive properties, *C. barbata* was incorporated to enhance the biocompatibility and regenerative potential of the nanofibrous system, while MB was employed as a photosensitizer to generate antimicrobial photodynamic activity upon light irradiation⁶.

Materials and Methods Electrospinning solutions consisting of 10 wt% PAN dissolved in dimethylformamide (DMF) were prepared, and a fixed amount of *C. barbata* was uniformly incorporated into each formulation. Subsequently, MB was added at varying concentrations (0.58–9.28 wt%) relative to the total polymer composition. Electrospun nanofibers were fabricated under optimized conditions of 16 kV applied voltage, 16 cm tip-to-collector distance, and 1.00 mL/h feed rate. The obtained nanofibers were comprehensively characterized using SEM, EDX, FTIR, contact angle analysis, TGA, and tensile testing. Additionally, loading efficiency, release behavior, swelling capacity, and hydrolytic degradation profiles were investigated to assess their suitability for wound-healing applications. Antibacterial and antibiofilm activities were evaluated against *Escherichia coli* and *Staphylococcus aureus* under light-activated conditions, while cytocompatibility and wound-healing potential were assessed using L929 fibroblasts via CCK-8 and scratch assays.

Results The developed nanofibers exhibited uniform, bead-free, and interconnected fibrous morphologies, indicating the successful fabrication of stable electrospun structures after the incorporation of *C. barbata* and MB. FTIR analysis confirmed the characteristic functional groups of PAN, MB, and *C. barbata*, while contact angle measurements revealed enhanced surface hydrophilicity compared to pristine PAN nanofibers. In addition, the nanofibers exhibited suitable physicochemical and mechanical properties for wound dressing applications. Release studies showed a pH-responsive MB release profile, with the highest release observed under physiological conditions, suggesting sustained and localized therapeutic delivery. Antibacterial photodynamic experiments demonstrated significant reductions in the viability of both *E. coli* and *S. aureus*, with more than 3-log bacterial reduction achieved after 30 min of light irradiation and complete bacterial elimination observed after 60 min of treatment. Considering the inherently higher resistance of biofilms, a 60-minute application period was further evaluated, revealing higher efficacy against *S. aureus* compared to *E. coli*, although total eradication was not achieved in either strain under these conditions. Furthermore, in vitro scratch assays revealed enhanced fibroblast migration and accelerated wound closure in the *C. barbata*-containing groups, with the combined MB/*C. barbata* formulation exhibiting the most pronounced regenerative response.

Conclusions The developed multifunctional nanofibers demonstrated promising physicochemical, antibacterial, and regenerative performance, highlighting their potential as advanced wound healing materials.

Key words Antimicrobial, *Cystoseira barbata*, Electrospun Nanofibers, Photodynamic Therapy, Wound Healing

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148 - ELECTROSPUN PVA-BASED PATCHES WITH PLANT EXTRACTS AND “GREEN”-SYNTHESIZED NANOPARTICLES FOR WOUND CARE APPLICATIONS

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Background/Rationale Background

Advanced wound care and atopic dermatitis management require dressings that combine infection control, breathability, moisture regulation, and gentle removal. Electrospun poly(vinyl alcohol) [PVA]-based nanofibers provide highly porous, high-surface-area structures, but their rapid dissolution in aqueous environments limits their practical application. Studies presented here integrate complementary PVA-based electrospun patch strategies to obtain stable, functional dressings loaded with plant-derived therapeutics, “green”-synthesized silver nanoparticles, and other natural agents.

Materials and Methods Materials and Methods

Two PVA-based systems were developed via solution electrospinning. PVA/PVP/pectin nanofibers were loaded with Hawthorn Extract and Dragon’s Blood, and stabilized by glutaraldehyde vapor crosslinking. A fully green formulation was prepared from 15% w/v PVA dissolved in natural lemon juice and thermally crosslinked via citric esterification, with “green”-synthesized silver nanoparticles incorporated at targeted dosages. The patches were then characterized by water solubility and degradation tests, FTIR, SEM, tensile testing, DSC/TGA, swelling, contact angle, and WVTR analyses, release profiling, antioxidant activity, antimicrobial/antifungal assays, indirect cytotoxicity tests, and in vivo human skin hydration/conformity evaluations.

Results Results

All stabilization routes prevented rapid dissolution of PVA nanofibers and produced water-stable porous networks. FTIR confirmed acetal formation after glutaraldehyde treatment, and ester bond formation after lemon-juice thermal curing. Lemon-juice curing at 140°C for 90 min yielded the most stable “green” crosslinked PVA network, preserving fibrous morphology and minimizing mass loss after prolonged immersion. SEM confirmed the formation of continuous, bead-free nanofibers after silver nanoparticle incorporation, while the plant extract-loaded patches retained flexible, conformable structures. Biological testing demonstrated complete inhibition of dermatitis-associated pathogens, such as *C. albicans*, in the most active formulations, along with high fibroblast viability. In vivo measurements showed semi-occlusive behavior, sustained hydration for 6 h, transparency during application, good joint conformity without cracking, and atraumatic, residue-free removal.

Conclusions Conclusions

Strategic matching of crosslinking chemistry with active payloads enables PVA-based electrospun nanofibers to be transformed into stable multifunctional patches. The combined antimicrobial and antifungal activity, moisture management, biocompatibility, mechanical flexibility, and on-skin performance indicate strong potential for advanced wound care and the management of atopic dermatitis.

Key words Keywords: Poly(vinyl alcohol) (PVA), electrospinning, crosslinking, patches, wound dressing, atopic dermatitis, green synthesis, silver nanoparticles

149 - ELECTROSPUN PIEZOELECTRIC FIBERS TO ADVANCE NEXT-GENERATION SELF-POWERED COCHLEAR IMPLANTS

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Background/Rationale Sensorineural hearing loss (SNHL) is mainly associated with irreversible damage to sensory hair cells in the cochlea and represents one of the most widespread sensory impairments worldwide. Its consequences extend beyond hearing deprivation, affecting language development, cognitive performance and psychosocial well-being. Current cochlear implants restore auditory perception by delivering electrical stimulation through multichannel electrode arrays. However, their performance is still constrained by the limited spatial resolution and dependence on complex external electronic components. In this framework, nano-engineered biomaterial interfaces able to convert acoustic-mechanical cues into localized electrical signals may provide a promising route toward more biomimetic and self-powered cochlear stimulation [1]. This study presents a multifunctional platform based on electrospun piezoelectric fibers designed as next-generation cochlear interfaces to move beyond bulk piezoelectric membranes, whose sensitivity and tissue conformability remain limited, by engineering electromechanical functionality at the fiber level.

Materials and Methods Poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) and polyacrylonitrile (PAN), including side-by-side Janus configurations, were processed by electrospinning using hexafluoroisopropanol solutions. Ultrafine Janus fibers were fabricated by eccentric bi-fluid electrospinning process, which enabled a bifacial asymmetric architecture coupled within the same fiber. The resulting structure behaves as an intrinsic unimorph system, with no passive interlayers, potentially enhancing electromechanical coupling while maintaining the flexibility, low thickness and acoustic impedance required for cochlear interface.

To improve the interaction of electrospun fibers with cochlear tissues, surface functionalization with polydopamine (PDA) was investigated. Three functionalization strategies were designed to overcome the intrinsic hydrophobicity and limited cell-adhesive properties of PVDF-HFP and PAN fibers: direct PDA deposition, preceded or not by NaOH and oxygen plasma pretreatments. PDA deposition was quantified by bicinchoninic acid (BCA) assay, while ATR-FTIR spectroscopy and water contact angle (WCA) measurements were used to assess surface chemical modification and wettability. Preliminary slippering tests were performed on laminin-coated glass slides to evaluate fiber adhesion.

Otocompatibility was assessed in vitro using OC-k3 cells by metabolic assay and fluoresce imaging to evaluate cell viability, cell adhesion and distribution on the fibrous substrates, using treated and untreated electrospun fibers. To facilitate fiber insertion and positioning, a biodegradable alginate-based hydrogel microcarrier was developed and tested within 3D-printed artificial cochleae. The carrier was also designed as a local delivery system for neuroprotective, otoprotective and anti-inflammatory molecules, including curcumin, dexamethasone and brain-derived neurotrophic factor. The otocompatibility of the selected molecules and their combinations was evaluated using SH-SY5Y neural cells, while release profiles and hydrogel biodegradation were investigated in vitro.

Results Scanning electron microscopy confirmed the formation of continuous, well-defined electrospun fibrous meshes with controlled morphology and diameter distribution. Average fiber diameters were approximately 0.3 μm for PVDF-HFP, 0.6 μm for PAN and 2.0 μm for Janus fibers. Piezoresponse force microscopy (PFM) mapping confirmed spatially resolved electromechanical asymmetry in the Janus fibers, directly correlated to the side-by-side structure. Direct measurements of the Janus fiber meshes showed 14 mV voltage output and 1 $\mu\text{W}/\text{cm}^2$ power generation.

ATR-FTIR spectroscopy confirmed the introduction of functional groups on the fiber surface, while WCA measurements demonstrated increased hydrophilicity in all treated samples. Preliminary slippering tests supported the improved adhesion of functionalized piezoelectric fibers, suggesting their potential for enhanced anchoring to the basilar membrane of the cochlea. In vitro biological assessment using OC-k3 cells revealed no cytotoxic effects for both treated and untreated electrospun fibers. Fluorescent staining confirmed cell adhesion and distribution on the fibrous substrates.

The hydrogel microcarrier enabled the incorporation of bioactive molecules while preserving otocompatibility. In vitro assays on SH-SY5Y cells assessed a cytocompatible dose for the selected molecules and their combinations. Release studies showed an initial burst followed by sustained delivery, with curcumin released over approximately 2 weeks and dexamethasone over 1 week. Hydrogel degradation in simulated perilymph

biofluid followed apparent first-order kinetics, supporting its potential role as a temporary carrier for minimally invasive fiber placement.

Conclusions This work demonstrates an integrated strategy combining Janus fibers, bioadhesive surface functionalization and biodegradable drug-releasing hydrogel carrier. By including improved tissue adhesion and localized pharmacological support, the proposed platform offers a promising step toward advancing biomimetic cochlear interfaces for SNHL treatment.

Key words Electrospinning, cochlear implants, otocompatibility, piezoelectric polymers, surface functionalization, drug release.

References Acknowledgements

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152 - CLINICAL TRANSLATION OF ELECTROSPUN VASCULAR GRAFTS: FROM LABORATORY TECHNOLOGY TO SCALABLE REGENERATIVE IMPLANTS

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Background/Rationale Electrospinning has emerged as a powerful platform technology for the development of regenerative medical devices due to its ability to create highly porous fibrous structures that support endogenous tissue restoration. While numerous electrospun concepts have demonstrated promising preclinical performance, successful clinical translation remains challenging because of the need to achieve reproducible product performance, robust manufacturing processes, and scalable production under stringent medical device quality requirements.

Materials and Methods Xeltis has pioneered the clinical development of electrospun bioresorbable vascular implants for cardiovascular applications, especially small-caliber (4- 6 mm) vascular grafts 1–3, advancing the technology from early research through preclinical validation, industrial manufacturing, and clinical evaluation, resulting in CE (Conformité Européenne) mark registration for the first product, an access graft for dialysis patients. Clinical development of coronary and peripheral applications is currently ongoing. This translational pathway required manufacturing processes capable of maintaining product consistency despite the inherent complexity and sensitivity of electrospinning processes.

Results This abstract discusses key considerations in the clinical translation of electrospun vascular grafts, including process robustness, scale-up strategies, quality monitoring, and the implementation of manufacturing controls suitable for regulated medical device production. Particular attention is given to the role of product-performance-based quality frameworks that enable reliable manufacturing across different production conditions while maintaining clinically relevant functional characteristics.

Conclusions The progress achieved over the past decade illustrates how electrospinning evolved from an academic fabrication technique to an industrially viable manufacturing platform for advanced regenerative medical devices.

Key words Vascular grafts, regenerative implants, clinical translation, manufacturing scalability, robustness

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162 - COMPARISON BETWEEN DNA-NA-TREATED ELECTROSPUN MEMBRANES, HYDROGELS AND BIOLOGICAL SCAFFOLDS FOR REGENERATIVE MEDICINE APPLICATION

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Background/Rationale Chronic wounds represent a tough clinical challenge as conventional treatments often fail to achieve complete and functional tissue regeneration. In this context, the development of innovative biomaterials and bioactive, biomimetic scaffolds has become essential to promote re-epithelialization, cell proliferation and skin regeneration. Skin integrity is closely related to both physical health and psychological medicine. Among the advanced strategies currently investigated, polymer-based biomaterials have shown significant potential due to their ability to accelerate healing processes and provide structural and biochemical support to damaged tissues. In particular, nanostructured membranes, electrospun nanofiber patches and functionalized hydrogels have emerged as promising platforms for tissue regeneration application.

Materials and Methods This study investigated three types of scaffolds: decellularized extracellular matrix (dECM) derived from pork cartilage; electrospun polymeric membranes based on two blends, poly(vinyl alcohol) (PVA) and poly(ethylene oxide)/chitosan (PEO/Chitosan); functionalized aerogels made of sodium alginate. Chitosan, a natural polysaccharide characterized by high biocompatibility, biodegradability, and excellent performance in biological environments, was selected as the main polymer for membrane and nanoparticle fabrication. Polymeric chitosan nanoparticles were engineered for the controlled release of PDRN-Na, a purified sturgeon-derived DNA fragment belonging to the polynucleotide class and widely used to promote tissue repair and collagen synthesis. Sodium alginate-derived aerogels were also developed to combine the absorbent and hemostatic properties of alginate with the high porosity and structural stability of aerogel systems.

All scaffolds were mechanically and morphologically characterized by scanning electron microscopy (SEM), thermally stabilized and functionalized with different concentrations of DNA-Na/PDRN-Na. Biological evaluation was performed in vitro using immortalized human keratinocytes (HaCaT) and MCF-7 epithelial cells as wound healing models. Degradation studies, controlled release analyses, cytotoxicity assays, metabolic activity tests (MTT), proliferation assays (CFSE), and RNA extraction/quantification were carried out to comparatively assess scaffold biocompatibility, cell viability, proliferation response and cell–material interactions.

Results The results highlighted distinct performances among the investigated scaffolds. Decellularized extracellular matrix (dECM) exhibited significant intrinsic bioactivity in terms of cell viability, although it did not induce a clear proliferative enhancement and showed sensitivity to high concentrations of sodium DNA, which reduced its effectiveness. Poly(vinyl alcohol) (PVA) proved to be a highly biocompatible and biologically neutral material, with proliferation increases attributable solely to the presence of sodium DNA rather than to scaffold-related effects. Among the tested materials, the PEO/chitosan membrane emerged as the most promising platform, combining high intrinsic bioactivity with a positive interaction with intermediate sodium DNA concentrations, resulting in enhanced cell viability and proliferation.

Morphological characterization of nanofibrous membranes revealed a well-interconnected and homogeneous porous architecture that promoted nanoparticle integration, confirming the reliability of the fabrication process. Although drug encapsulation efficiency was lower than expected, the system showed potential for further optimization through improved loading strategies and nanoparticle surface modifications. In addition, the membranes demonstrated excellent resistance to degradation under simulated physiological conditions, supporting their suitability for in vivo applications. Aerogel-based scaffolds displayed favorable structural and mechanical properties, including a highly three-dimensional architecture and soft consistency, making them attractive candidates for biomedical use. However, limited nanoparticle loading within the internal cavities currently restricts their effectiveness as delivery systems, suggesting the need for targeted engineering approaches to improve functionality. Importantly, both scaffold types showed no cytotoxic effects, while unloaded and drug-loaded nanoparticles exhibited excellent biocompatibility in Live/Dead assays, providing a strong foundation for future tissue engineering and drug delivery applications.

Conclusions Overall, this study demonstrates that the physicochemical properties of scaffold materials play a crucial role in modulating the bioactive effects of sodium DNA and influencing the performance of nanoparticle-based delivery systems. Although limitations related to encapsulation efficiency and release control were identified, the investigated scaffolds showed promising biological and structural properties,

supporting their potential as platforms for tissue engineering and regenerative medicine applications. Future research should focus on optimizing nanoparticle loading and release processes, refining nanoparticle surface properties, improving loading strategies for aerogel-based systems and evaluating long-term biological responses under more physiologically relevant conditions, including 3D and preclinical in vivo models.

Key words Wound healing, electrospinning, nanoparticles, chitosan, biological tests

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167 - ENGINEERING NANOFIBROUS BIOMATERIALS WITH ENHANCED BIO-INTERFACE PROPERTIES

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Background/Rationale The bio-interface serves as the interaction boundary between biomaterials and host tissues [1]. The fabrication of well-designed bio-interfaces can construct a favorable microenvironment by regulating mechanical cues and biological signals. Nanofibrous biomaterials provide a multifunctional platform for bio-interface engineering due to their extracellular matrix-mimicking structure and tunable surface chemistry [2]. Various fiber-based materials with tailored bio-interfaces have been developed to achieve multiple functions, including mechanical stimulation, anti-adhesion performance, and microenvironment modulation. The fibrous sponges could provide compression for promoting hemostasis [3]. The hydrated fibrous patches showed favorable anti-adhesion behavior [4]. The hydrogel embedded with photothermal short fibers exhibited antibacterial and anti-inflammatory effects to regulate the microenvironment [5]. The engineered nanofibrous biomaterials with enhanced bio-interface properties hold great potential for tissue repair.

Materials and Methods The flexible bioactive glass nanofibers were prepared via sol-gel electrospinning. The fibers were homogenized with poly(vinyl alcohol) (PVA) and then freeze-dried to construct self-expanding nanofibrous cryogels (BGNCs). A Janus nanofibrous patch (J-NFP) was fabricated by sequential electrospinning. The CeO₂ nanoparticles (CeNPs) were embedded into one side of the nanofibrous patch. While zwitterionic poly(sulfobetaine methacrylate) brushes were grafted on the opposite side via surface-initiated atom transfer radical polymerization, creating a superlubricated skin. For microenvironment regulation, PLGA short fibers loaded with gold nanorods (AuNRs) and diclofenac sodium (DS) were incorporated into gelatin methacryloyl (GelMA) hydrogel pre-immobilized with stromal cell-derived factor 1 α (SDF-1 α), forming a sprayable photothermal fiber-embedded hydrogel system for on-demand antibacterial and anti-inflammatory modulation.

Results The self-expanding BGNCs exhibited ultrafast fluid-triggered expansion and excellent underwater resilience, which contributed to efficient hemostasis in rabbit liver and femoral artery injury models. The Janus patch featured a superlubricated surface, resulting in significant reduction in protein, platelet, and cell adhesion. In addition, CeNPs endowed the system with reactive oxygen species (ROS) scavenging capability and suppressed expression of pro-inflammatory cytokines, effectively preventing postoperative adhesions in rat skin and intrauterine injury models. The sprayable photothermal hydrogel enabled NIR-triggered antibacterial activity and on-demand DS release, while sustained release of SDF-1 α facilitated recruitment of endogenous stem cells, accelerating infected wound healing with downregulated inflammatory pathways confirmed by RNA-seq.

Conclusions Various nanofibrous platforms with engineered bio-interfaces were developed for diverse applications, including a self-expanding fibrous sponge for compressive hemostasis, a superlubricated Janus patch with anti-adhesion and ROS scavenging capabilities, and a photothermal fiber-embedded hydrogel for microenvironment modulation. Collectively, these results demonstrated that the nanofibrous biomaterials with enhanced bio-interface properties offered versatile and powerful strategies, exhibiting great potential in tissue repair applications.

Key words Bio-interface, nanofibrous biomaterials, tissue repair

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180 - ELECTROSPUN NANOFIBER-BASED CONDUCTIVE HYDROGEL BIOPLATFORMS FOR BRAIN-MACHINE INTERFACES

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Background/Rationale Electrical stimulation of the nervous system through implantable electrodes represents an established therapeutic strategy for the treatment of a broad spectrum of neurological disorders. Neural prosthetic technologies have emerged as powerful tools for restoring, modulating, or replacing impaired neural functions by establishing a functional interface between electronic devices and the central or peripheral nervous system. Depending on the clinical application, these devices are implanted within the brain, spinal cord, optic nerve, cochlea, or peripheral nerves, where they enable the bidirectional transmission of electrical information through the recording of endogenous bioelectrical signals and the delivery of precisely controlled electrical stimulation. The long-term functionality of these systems critically depends on the performance of implantable neural probes, which must maintain stable electrical properties while preserving intimate and reliable integration with the surrounding biological tissue.

Despite remarkable technological advances, the long-term clinical efficacy of implantable neural interfaces remains substantially limited by the foreign-body response triggered following implantation. Mechanical trauma associated with probe insertion initiates a complex cascade of inflammatory and immunological events that culminates in glial scar formation, neuronal degeneration, and progressive encapsulation of the implant. These biological processes increase the electrical impedance at the tissue-electrode interface, compromise signal fidelity, and progressively reduce stimulation efficiency, ultimately leading to device failure and the need for surgical replacement. Consequently, the development of neural interfaces capable of mitigating chronic inflammatory responses while maintaining stable electrochemical performance constitutes one of the foremost challenges in the field of neuroengineering.

To address these limitations, significant research efforts have been devoted to the development of conductive polymeric materials capable of simultaneously fulfilling the electrical, mechanical, and biological requirements of chronic neural interfaces. Among these, intrinsically conductive polymers (ICPs) have attracted considerable attention owing to their unique combination of electronic conductivity, chemical versatility, and polymeric processability. Nevertheless, although ICPs exhibit lower elastic moduli than conventional metallic electrodes, their mechanical compliance remains insufficient to adequately match the exceptionally soft nature of neural tissues, particularly within the central nervous system. This persistent mechanical mismatch contributes to chronic tissue irritation and compromises long-term implant performance.

Materials and Methods In this context, conducting polymer hydrogels (CPHs) have emerged as a promising class of multifunctional biomaterials that integrate the electronic conductivity of conjugated polymers with the hydrated three-dimensional architecture and mechanical compliance of hydrogel networks. The resulting hybrid materials closely replicate the physicochemical characteristics of native neural tissue while providing efficient charge transport, thereby offering a compelling strategy to reduce interfacial mechanical mismatch, attenuate foreign-body reactions, and improve the long-term stability and functionality of implantable bioelectronic devices.

Results This presentation will provide a comprehensive overview of the evolution of CPHs, from their fundamental design principles to the latest advances in neural bioelectronics and brain-machine interfaces. Particular emphasis will be devoted to recent contributions from the Pierini Research Group concerning the development of electrically conductive biointerfaces fabricated via electrospinning. These presented studies demonstrate innovative materials design strategies aimed at engineering biomimetic neural interfaces with enhanced electrochemical performance, mechanical compliance, and biological integration.

Conclusions The scientific concepts, technological approaches, and final applications presented will be of interest to researchers working in electrospun nanostructured systems, electrically conductive biomaterials, functional hydrogels, conjugated polymers, biomembranes, tissue engineering, and implantable bioelectronic devices, with a special focus on brain-machine interfaces.

Key words Conducting polymer hydrogels (CPHs); Neural interfaces; Neural bioelectronics; Brain-machine interfaces; Electrospinning; Intrinsically conductive polymers (ICPs); Conductive biomaterials; Functional hydrogels; Tissue engineering; Implantable bioelectronic devices.

181 - ELECTROSPUN MEDICAL DEVICES - FUNCTIONAL VERSATILITY AND SCALABLE MANUFACTURING

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Electrospinning enables precise control of nanofiber architecture—porosity, mechanical properties, and surface chemistry—unlocking solutions across diverse medical applications. Current electrospun products span wound dressings with accelerated resorption, bone and soft tissue scaffolds with high biomineralization, and sutureless stent coverings with superior durability and sealing performance. Each application exploits the unique tunable properties of electrospun fiber networks.

Despite this versatility, translating electrospinning to commercial manufacturing at scale remains challenging. Traditional batch-based approaches require multiple manual steps, limiting throughput and product consistency. This presentation outlines the functional breadth of electrospun medical devices, the manufacturing barriers to scalability, and how Vivolta's MediSpin™ platform enables integrated automation solutions for commercially viable production without sacrificing precision or product complexity.

Key words Electrospinning · Nanofibers · Medical devices · Scaffolds · Wound dressings · Stent coverings · Biomineralization · Scalability · Automation · Manufacturing · Throughput · Product consistency ·

4 04.ENERGY, ELECTROCATALYSIS & SUSTAINABLE MATERIALS

11 - MODULAR DESIGN OF BIOMIMETIC ELECTROSPUN KERATIN COMPOSITES FOR TUNABLE GASEOUS SORPTION INSPIRED BY REPTILE EGGSHELLS

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Background/Rationale Biomimicry, the replication of natural structures, is an emerging strategy in materials engineering for developing advanced functional materials. Reptile eggshells serve as compelling models for tunable bioinspired material design due to their diversity in forms and functions. Unlike the relatively uniform structure of avian eggshells, reptile eggshells display a wide range of configurations driven by the wide range of breeding conditions and environmental pressures encountered across reptilian species. A limited set of building components in reptile eggshells results in an interesting variety of material properties such as sorption properties, mechanical performance, antimicrobial protection, water repellency, and UV absorption. Their ability to regulate gaseous sorption is particularly noteworthy, ranging from prominent levels in squamate eggshells to being almost negligible in most crocodile eggshells. Translating these modular design principles into bio-based materials could provide sustainable alternatives to conventional synthetic sorptive materials, particularly for applications requiring tunable moisture management.

Materials and Methods Inspired by the modular architecture of reptile eggshells, four key biomimetic components were reconstructed: (1) electrospun keratin nanofibrous membranes resembling the fibrous shell membrane, (2) an egg protein matrix replicating the proteinaceous eggshell matrix, (3) calcium carbonate (CaCO₃) particles introducing mineralization, and (4) a paraffin coating representing the lipid-rich cuticle layer. Keratin was extracted from wool via sulfitolysis and processed into nanofibrous membranes using solvent electrospinning. The organic matrix and lipid components were applied via dip-coating, while CaCO₃ was deposited as a modular surface layer in controlled weight ratios.

The structural and chemical fidelity of the biomimetic composites was evaluated using Scanning Electron Microscopy (SEM) and Fourier-Transform Infrared Spectroscopy (FTIR), with direct comparison to representative reptile eggshells. Water vapor sorption behavior was quantified using Dynamic Vapor Sorption (DVS) analysis. By systematically varying the concentration and combination of individual modules, the contribution of each component to overall sorption behavior was assessed.

Results SEM and FTIR analyses confirmed that the biomimetic composites successfully replicate the modular composition of reptile eggshells at both structural and chemical levels. DVS measurements demonstrated that the CaCO₃ component is the dominant factor governing vapor sorption, with increasing mineral content leading to a pronounced reduction in moisture uptake. By varying the CaCO₃ content from 10% to 90%, the full spectrum of sorption behavior observed in natural reptile eggshells was reproduced, ranging from highly absorptive to strongly barrier-like responses.

In composites with low mineral content, incorporation of the organic matrix significantly influenced sorption behavior by modifying pore structure and diffusion pathways, while the lipid-inspired paraffin coating further reduced moisture uptake. Importantly, the combined effects of these modules enabled fine-tuning of vapor sorption beyond what could be achieved by mineral content alone. The resulting biomimetic composites exhibited sorption profiles closely matching those of natural eggshells such as *Pantherophis guttatus* (high absorption) and *Caiman crocodilus* (low absorption), validating the effectiveness of the modular design strategy.

Conclusions This work demonstrates that the modular design principles of reptile eggshells can be successfully translated into fully bio-based keratin composites with tunable vapor sorption properties. The results confirm that while CaCO₃ content primarily controls overall moisture barrier performance, the organic matrix and lipid components play a crucial role in fine-tuning sorption behavior in weakly calcified systems. By decoupling and recombining individual functional modules, a wide and continuous range of sorption responses can be achieved without replicating the exact microstructure of the biological template.

The developed biomimetic platform offers a sustainable and adaptable route toward advanced materials for applications requiring controlled moisture management, including wound dressings, tissue engineering

scaffolds, filtration membranes, and sustainable packaging. More broadly, this study highlights the potential of modular biomimetic design as a versatile framework for engineering multifunctional, bio-inspired materials.

Key words Modular biomimetic composites / Protein nanofibers / Keratin electrospinning / Tunable vapor sorption / Reptile eggshells

12 - ELECTROSPINNING FOR ENERGY APPLICATIONS

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Background/Rationale To meet the demands of energy-hungry consumers, the growing use of renewable energy sources, and energy-intensive industries (e.g., AI data centers), new and improved energy storage and conversion devices must be developed and commercialized. Battery systems with high capacities, long cycle life, and fast charging rates represent one approach. Similarly, fuel cells can provide clean, efficient, and reliable power across transportation, stationary, and industrial sectors to reduce greenhouse gas emissions and our dependency on fossil fuels. Redox flow batteries can balance the intermittent nature of renewable energy sources, offering scalable, long-duration energy storage where power (stack size) is decoupled from capacity (tank volume). These applications and their associated challenges have motivated researchers to examine new chemistries and new electrode and membrane/separator materials for high-performance devices. Equally important is the identification of new electrode architectures and membrane morphologies that will take full advantage of material properties. This is especially timely because nanomaterials, such as quantum dots, nanowires, core-shell catalysts, and carbon nanotubes, are being incorporated into next-generation electrodes and membranes with ever-increasing frequency.

Often, material properties observed on a nano-scale are not seen in macro-devices. Macroscopic structures of mutually incompatible polymers and mixtures of nanoparticles with a polymer binder must be better designed to exploit and control such features as macro- and micro-porosity, particle or polymer domain interconnectivity, and interfacial surface area availability. Additionally, new fabrication methods must be developed that can easily produce such structures in large, high-speed roll-to-roll manufacturing lines. Intelligently designed nanofiber electrospinning schemes can address many of these critical challenges. As a commercial fabrication method, electrospinning is scalable and robust for the creation of non-woven mats of sub-micron-diameter polymer and polymer/particle fibers. Thus, fibers with a high particle loading, multifiber constructs, and hybrid fiber/particle structures can be optimized for a specific energy-related device/process and then manufactured at scale.

Materials and Methods In this talk, the use of nanofiber electrospinning for battery and fuel cell electrode fabrication and for bipolar membrane design and manufacturing will be discussed, with a focus on: (1) Battery electrodes (Si/C fiber anodes for Li-ion batteries and fiber mat hydrogen electrodes with Pt/C catalyst for H₂/Br₂ redox flow batteries) [1,2], (2) fiber mat electrodes for H₂/air fuel cells (Pt/C, Pt-alloy/C, and platinum-group-metal-free catalyst electrodes) [3,4], and (3) bipolar membrane with a nanofiber 3D junction layer [5,6].

Results Experimental methods for making the electrodes/membranes will be described along with unique aspects of the fiber morphology that impact observed properties and device performance, e.g., internal nanoporosity or fiber surface hydrophobicity.

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Conclusions Additionally, the critically important subjects of scale-up and incorporating electrospinning into roll-to-roll manufacturing schemes will be addressed, where, for example, fuel cell electrodes are made using a conventional coating/spraying process with inks that contain preformed fibers.

Key words nanofiber mat electrodes, bipolar membranes, particle/fiber hybrid electrodes and membranes.

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14 - WHEN ELECTROSPINNING MEETS ART: SMART AND SUSTAINABLE ELECTROSPUN MATERIALS FOR CULTURAL HERITAGE CONSERVATION

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Background/Rationale In the field of restoration, there is a growing demand for eco-friendly methodologies that ensure safety for both operators and the environment. This talk will discuss the use of electrospun nonwovens as sustainable carriers for cleaning agents for restoration practices and their superior effectiveness compared to traditional cleaning methods.

Materials and Methods The performance of the ES mats has been evaluated in the removal of different classes of coatings, including aged terpenic resins and highly crosslinked alkyd varnishes applied to simulate vandalism on street art artifacts.

Results Electrospun nonwovens, thanks to their micro- and nano-porous structure, enable a controlled solvent delivery and an effective interaction with the superficial coatings to be removed [1-3].

In our first work [1], we developed a sandwich-like composite for painting cleaning consisting of an organogel core - (poly(3-hydroxybutyrate) and γ -valerolactone as green solvent - protected by two external layers of electrospun polyamide nonwovens made of sub-micrometric fibers. The electrospun layers act as mechanical reinforcement, significantly improving the handling and bending resistance of the organogel, which is otherwise prone to fragmentation. Moreover, the electrospun layers slow down the diffusion of the solvent, enabling a controlled superficial action that removes the varnish while safeguarding the integrity of the underlying painting layer.

A simplified cleaning system was then developed based on polyamide electrospun nonwovens saturated with dimethyl carbonate as a green solvent [2]. The nonwoven acts simultaneously as a reservoir for the solvent and as an adsorbent for the swollen varnish. This allows the unwanted layer to be removed via a "peel-off" effect, eliminating the need for invasive mechanical action, thereby reducing stress on the underlying paint layers. Interestingly, the cleaning effectiveness depends on the microporosity of the mat; smaller pore sizes enhance the capillary rise of the dissolved varnish into the fibrous structure.

To enhance the removal of highly insoluble and resistant paint layers, such as alkyd spray paints used in vandalism or street art, electrospun nonwovens have been functionalized with photoactive agents [3]. Here, pullulan nonwoven incorporating melanin nanoparticles extracted from cuttlefish ink was used. Upon illumination with a LED source, this material generates localized and controlled photothermal heating. The synergistic action of controlled heat and a properly selected solvent promotes swelling and softening of the target coating, allowing for rapid and precise removal confined only to the irradiated area.

A key advantage of using electrospun systems for art restoration lies in their efficiency and sustainability. The system operates effectively using only a fraction of the maximum solvent absorption capacity of the nonwoven, significantly reducing solvent consumption and application time. Moreover, the materials retain their structural and functional integrity after multiple cleaning cycles, demonstrating reusability and reduced waste generation. Tests have shown that electrospun nonwovens remain effective and unaltered after at least three cycles, underscoring their potential for long-term, sustainable conservation strategies.

Conclusions Overall, the proposed strategy demonstrates that electrospun nonwoven materials represent a versatile, efficient, and environmentally responsible solution for the conservation of cultural heritage. By reducing solvent use, limiting mechanical intervention, enabling reusability, and ensuring high selectivity, this approach contributes to the development of green and sustainable preservation methodologies.

Key words art conservation, smart systems, biobased materials, photothermal effect

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22 - ELECTROSPINNING: A WINDOW OF OPPORTUNITIES FOR MEMBRANES

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Background/Rationale Sustainability in membranes requires flexibility in membrane preparation: The flexibility to control membrane preparation parameters to tailor membrane properties and performance.

Materials and Methods Electrospinning offers a window of opportunities to do so: its easy scalability and flexibility make it highly attractive for large-scale industrial membrane production and numerous applications [1].

Results Using functional polymers or additives in a wire electrospinning process, allows direct use of electrospun mats as membrane adsorbers in e.g. medical applications. Membrane adsorbers rely on convection for molecules to reach selective binding sites and combine high-throughput membrane filtration with the high selectivity of adsorption chromatography. Our results with electrospun sulfonated poly (ether ether keton) mats show a static adsorption of 72 mg lysozyme/g. With pore sizes nearly fifty times larger than the size of lysozyme, electrospun membrane adsorbers enable unhindered transport. The dynamic adsorption capacity reaches a stable value after three cycles being 59.3 mg lysozyme/g at 10% breakthrough independent of flow rate. This confirms dominant convective transport and almost full utilization of binding sites. Adsorption occurs through both reversible electrostatic and irreversible hydrophobic interactions, with stable performance after three cycles. Increasing sulfonation degree increases functional group density and smaller fiber diameters (90 vs 166 nm) increase the number of accessible adsorptive groups but do not proportionally enhance lysozyme adsorption due to steric and diffusional limitations, although the normalized adsorption per surface area does increase [2].

Alternatively, porous electrospun polysulfone mats can be coated with a dense selective toplayer using interfacial polymerization with standard industrial recipes, making a composite, salt-selective membrane for low pressure applications such as forward osmosis for dewatering of diluted industrial streams. Forward osmosis uses the osmotic pressure difference over a membrane to remove water of highly fouling streams in e.g. the food and beverage industry. Our work shows high water fluxes of 13 l/m².h due to the decreasing driving force upon concentration decreasing to 4.6 l/m².h while concentrating apple juice, manure and whey. Overall high concentration factors of 2.1 (apple juice), 2.5 (manure), and 1.75 (whey) are obtained. Exceptionally low reverse salt transport is observed (ten times lower than commercial membranes). The highly porous electrospun support structure reduces internal concentration polarization while maintaining product quality [3].

Also, multiple different porous mats can be stacked followed by hot-pressing resulting in dense ion exchange membranes for energy storage in flow batteries. Because multiple separate layers are combined in such an array, local functionalities and properties in these membranes can be tuned. The experimental approach allows systematic variation of the cation exchange layer (CEL), the interfacial layer (IL), and the anion exchange layer (AEL) thickness and morphology independently. A phytic acid/Fe³⁺ complex is introduced as water dissociation catalyst. Electrochemical impedance spectroscopy reveals that water dissociation resistance dominates total BPM resistance, indicating that interfacial catalysis and morphology

Conclusions As follow up we currently expand on this using co-electrospinning of three different solutions simultaneously in our unique three-line needle spinner. In this way, robust intermingling of e.g. anion and cation exchanges materials with catalysts can be obtained in one single step, making integrally robust bipolar membranes for e.g. electrodialysis or flow battery applications.

Key words Nanofiber membranes; interlayer morphology; membrane separation processes.

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28 - ELECTROSPUN POLYMER FIBER YARNS FOR FOG WATER COLLECTION

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Background/Rationale Limited access to clean water is a major global challenge, making fog water harvesting a promising alternative in regions where conventional water sources are scarce or unavailable. Nature provides highly efficient models for this process, including the Namib desert beetle, which captures water droplets using surfaces with contrasting wettability, and spider webs, on which water droplets from fog can condense [1]. Electrospinning enables the fabrication of highly porous fibrous materials that can imitate the geometry and selected surface features of spider silk threads. When electrospun fibers are twisted into continuous yarns, they can form an effective drainage pathway that reduces water accumulation within the structure and accelerates droplet runoff. Previous studies have shown that the balance between water capture and rapid drainage can be improved by combining hydrophilic and hydrophobic domains in fibrous systems [2,3]. Therefore, the aim of this study was to fabricate hydrophobic-hydrophilic electrospun polymer yarns and evaluate their potential as an efficient fog water collection system.

Materials and Methods Yarns were prepared from thermoplastic polyurethane (TPU), used as the hydrophobic component and polyamide 6 (PA6) was selected as the hydrophilic component. The electrospun fibers were twisted into continuous yarns that can capture, transport, and release water droplets. These were arranged vertically in a harp-like configuration to promote droplet coalescence and gravity-driven drainage. Fog harvesting performance was compared between hybrid TPU-PA6 and purely hydrophobic TPU samples. Wetting behavior was assessed through contact angle measurements, with emphasis on hysteresis, which governs droplet mobility and removal.

Results The hybrid TPU-PA6 yarns showed superior fog water collection compared with purely hydrophobic TPU yarns. They exhibited lower contact angle hysteresis, indicating enhanced droplet mobility and more efficient drainage. The presence of hydrophilic PA6 fibers improved initial droplet capture and promoted early-stage growth, while the hydrophobic TPU component facilitated droplet transport and prevented water accumulation that could block the structure. This synergistic combination of contrasting wettability enabled more effective droplet growth, coalescence, and removal along the vertically aligned yarns.

Conclusions Overall, these results demonstrate that integrating hydrophilic and hydrophobic polymers is a promising strategy for designing efficient, bioinspired fog water collectors.

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Key words fog water harvesting; electrospinning; yarns; hydrophilic-hydrophobic fibers; biomimetic materials

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29 - $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$ NANOFIBERS FOR SOLID-STATE ELECTROLYTES: OPTIMIZING ELECTROSPINNING SOLUTIONS TO ACHIEVE SMOOTH, SIZE-CONTROLLED FIBERS

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Background Solid-state electrolytes (SSEs) represent a critical advancement toward safer Li-ion batteries with higher energy density. Nanocomposite SSEs combine inorganic and organic materials to simultaneously achieve high ionic conductivity and robust mechanical integrity [1]. $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$ (LLZO) nanofibers (NFs) can be used to manufacture nanocomposite SSEs and are fabricated via electrospinning of a precursor-laden solution, followed by calcination to decompose the carrier polymer and crystallize the garnet phase [2]. Fiber diameter, morphology, and macroscopic arrangement collectively govern the ultimate properties of the resulting nanocomposites; in particular, thinner NFs have been shown to yield improved ionic conductivity [3]. Nevertheless, a systematic understanding of how solution composition and electrospinning parameters can be co-optimized to produce smooth, well-controlled LLZO NFs remains lacking. To address this gap, this work investigates the effects of polymer concentration, precursor concentration, and ethanol as a co-solvent with N,N-dimethylformamide (DMF) on fiber quality and dimensional control.

Materials and Methods Polyvinylpyrrolidone (PVP) ($M_w = 1,300,000$), LiNO_3 (99.9%), $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ (99.999%), zirconium(IV) propoxide ($\text{Zr}(\text{OCH}_2\text{CH}_2\text{CH}_3)_4$, 70 wt% in 1-propanol), DMF (99.8%), and acetic acid (99.7%) were sourced from Merck, while ethanol (96%) was obtained from Kiilto.

Precursor solutions of LiNO_3 and $\text{La}(\text{NO}_3)_3$ in DMF were prepared inside an argon-flushed glovebox to minimize moisture exposure. Stoichiometric amounts (15 mol% excess Li) of precursor solutions were added to a solution of PVP dissolved in acetic acid and DMF. The mixture was stirred for at least 17 hours. The concentrations of solid components are reported as wt% relative to the combined mass of that specific component and the solvents.

Solution electrical conductivity was measured using a Radiometer MeterLab CDM210 conductivity meter. Electrospinning was carried out at $23 \pm 1^\circ\text{C}$ and $35 \pm 2\%$ RH using a Doxa Microfluidics Professional Lab Device equipped with a 20G needle and flat collector. Unless otherwise stated, the tip-to-collector distance, applied voltage, and flow rate were fixed at 15 cm, 10 kV, and 0.2 mL/h, respectively. After drying for at least 20 hours, fiber diameter and morphology were characterized by scanning electron microscopy (SEM) using a Zeiss EVO MA 15. The diameters of 100 NFs were measured across three representative images.

Results At fixed total precursor (10 wt%) and acetic acid (10 vol%) concentrations, smooth, bead-free NFs with an average diameter of 234 nm were obtained when PVP concentration was 14 wt%. Lower PVP concentrations yielded thinner but beaded fibers as the viscosity was insufficient to suppress the Rayleigh-Plateau instability responsible for bead formation. Notably, in the absence of precursor salts, 14 wt% PVP in DMF produced predominantly bead-on-a-string morphology. This is attributed to the pronounced increase in solution conductivity upon addition of the precursors (from 7 $\mu\text{S}/\text{cm}$ to 3670 $\mu\text{S}/\text{cm}$), which enhances the electrostatic jet-stretching force sufficiently to overcome the surface-tension-driven bead formation.

This force balance was further manipulated by either adding 40 vol% ethanol or increasing the precursor concentration from 10 to 20 wt%. Both yielded bead-free precursor fibers at reduced PVP concentration of 12 wt%. This was accompanied by a small increase in diameter, which was further increased upon raising the applied voltage to 15 kV. This is attributed to increased viscosity as a result of greater solids content, and instability of the Taylor cone due to lower surface tension. The observation of insufficiently solidified fibers for the high precursor concentration experiment and 15 kV applied voltage, suggests that this combination produced excessively rapid jet acceleration, preventing adequate fiber stretching and solvent evaporation.

Conclusions The effects of polymer and precursor concentration, and ethanol as a co-solvent on the electrospinning of LLZO nanofibers were investigated. Increased electrical conductivity by adjusting the precursor concentration and reduced surface tension by ethanol addition effectively suppressed bead formation. These results lay the groundwork for optimizing solution composition and fabrication of smooth, thin LLZO NFs suitable for application in SSEs.

Key words Battery materials, solid-state electrolytes, inorganic nanofibers

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44 - ENERGY-EFFICIENT ALCOHOL RECOVERY VIA HYDROPHOBIC ORGANOSILICA NANOFIBER MEMBRANES AND SALTING-OUT DEMIXING

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Background/Rationale Efficient separation of alcohols from aqueous streams is a critical challenge in process intensification across (bio)chemical industries. In particular, emerging technologies such as CO₂ hydrogenation to ethanol require rapid and energy-efficient alcohol recovery under harsh conditions, including elevated temperatures. Conventional separation methods such as distillation, adsorption, and pervaporation are effective but remain energy- or cost-intensive, especially for short-chain alcohols that are fully miscible with water and form strong hydrogen-bonding networks. Inorganic membrane-based liquid–liquid separation offers an attractive low-energy alternative, yet its application to alcohol/water systems remains limited by two key challenges (1): (i) poor long-term wettability stability of inorganic silica-based membranes, which tend to become hydrophilic over time, and (ii) its effectivity has only been shown for immiscible heterogeneous azeotrope mixtures, hence it is unclear how the membranes will perform for fully miscible alcohol/water systems. This work addresses these challenges by developing long-term hydrophobic organosilica nanofiber membranes and combining gravity-driven separation with salt-induced phase demixing. (2)

Materials and Methods Hydrophobic organosilica nanofiber membranes were fabricated via electrospinning of sol–gel-derived silica systems using two functionalization strategies: (i) a one-step pre-functionalization by incorporating dimethyldiethoxysilane (DMDES) into a tetraethoxysilane (TEOS)-based sol–gel synthesis, and (ii) post-functionalization of electrospun TEOS membranes with chloro-octyldimethylsilane (Cl-OdMS). Membranes were characterized using SEM, ATR-FTIR for chemical composition, static water contact angle measurements for wettability stability, and thermogravimetric analysis to assess thermal resistance. Gravity-driven separation experiments were conducted using binary and ternary alcohol/water mixtures (ethanol, n-propanol, n-butanol, n-pentanol) with and without added salts at different concentrations (NaCl, NaBr, K₂HPO₄, K₂CO₃). Phase purities were quantified by ¹H NMR spectroscopy, and ternary phase diagrams were experimentally constructed to map salt-induced binodal expansions.

Results Both pre-functionalized TEOS/DMDES and post-functionalized TEOS/OdMS membranes exhibited high porosity, micrometer-scale pore sizes, and stable nanofiber morphologies. Crucially, both membrane types showed long-term hydrophobic stability, maintaining water contact angles exceeding 110° for over three months when stored at controlled humidity or even when submerged in water, significantly outperforming unmodified silica membranes. The membranes also demonstrated excellent robustness against high temperatures (up to 673 K) and strongly alkaline conditions (pH up to 13.3). In gravity-driven separation experiments, the hydrophobic organosilica membranes acted as affinity-based phase separators rather than selective barriers, yielding phase purities corresponding to the binodal limits of the liquid–liquid equilibrium. Without salt addition, effective separation was limited to intrinsically immiscible systems (n-butanol/water and n-pentanol/water). By exploiting the salting-out effect, the immiscibility window was substantially expanded. Among the tested salts, K₂CO₃ proved most effective, inducing phase separation even in fully miscible ethanol/water and n-propanol/water systems and achieving alcohol-rich phase purities up to ~75% for ethanol and ≥83% for longer-chain alcohols. Approximately 97% of the added salt remained in the water-rich phase, minimizing contamination of the alcohol product. The approach was successfully extended to ternary alcohol/ethanol/water systems, enabling experimental construction of binodal solubility curves and demonstrating broad applicability.

Conclusions This study demonstrates a simple, energy-efficient, and robust strategy for alcohol/water separation by combining long-term hydrophobic organosilica nanofiber membranes with salt-induced phase demixing. The one-step pre-functionalized TEOS/DMDES membranes provide a scalable and cost-effective alternative to post-functionalized systems while maintaining comparable separation performance, thermal stability, and chemical resistance. Although the membranes function as phase separators rather than selective barriers, the salting-out approach enables separation of otherwise fully miscible systems, making this platform particularly attractive for process intensification scenarios such as ethanol recovery from CO₂ hydrogenation and other aqueous reaction streams.

Key words Organosilica nanofiber membranes; hydrophobic membranes; gravity-driven separation; alcohol/water separation; salting-out; process intensification.

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52 - SOUND INSULATION BY MEANS OF BIO-BASED MULTILAYER HYBRID COMPOSITES BASED ON ELECTROSPUN FIBERS AND NATURAL SPONGES

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Background/Rationale A major environmental problem to which humans are exposed nowadays is noise pollution mainly caused by rapid development and urbanization. This can result in various issues affecting both the mental and physical health of people when they are regularly exposed to such environments. Porous fibrous materials are widely used for sound absorption due to their ability to effectively dissipate acoustic energy [1]. However, traditional synthetic fibrous materials, including mineral wool and glass fibers, have raised concerns regarding their environmental impact and potential health risks during their fabrication and handling. To address this issue, recent studies are now focusing on the development of more sustainable materials, mainly based on natural fibers and sponges, due to their low toxicity, renewability and biodegradability. However, such materials usually exhibit limited acoustic performance, especially at the lower frequency range [2].

Moreover, electrospun fibers are characterized by high surface area and tunable microstructures, in addition to their enhanced porosity and airflow resistance. Hence, a combination of electrospun fibers with natural fibrous materials into hybrid multilayer systems is proposed in this study, to further improve the sound adsorption properties, while preserving key characteristics such as cost efficiency, biodegradability and reduced environmental impact [3], [4].

Materials and Methods To achieve improved sound absorption capabilities, especially at lower frequencies, blended polyvinylpyrrolidone (PVP)/cellulose acetate (CA) electrospun fibers were fabricated and used along with naturally derived sponges of *Luffa Cylindrica* (LC) to produce multilayer hybrid composites. The materials were characterized with respect to their morphology and sound absorption properties, by means of Scanning Electron Microscopy (SEM) and the Standing Wave Ratio (SWR) method implemented within an impedance tube, respectively.

Results The results show that the incorporation of CA/PVP microfibers significantly enhances the acoustic performance of the LC-based composites. At first, samples consisting of pure LC exhibited the lowest sound absorption, confirming that electrospun layers significantly improve the acoustic properties. Moreover, the combination of thick LC layers (with larger pores and coarser surface) and thin PVP/CA fibrous layers has proven to be advantageous for broadband sound absorption. Furthermore, compared to systems using only CA, it was shown that the addition of PVP shifted absorption toward lower frequencies by increasing airflow resistivity and viscous damping. Finally, experimental data suggest that a multilayer structure with alternating LC and microfibrillar electrospun layers exhibit superior performance, as they present improved sound dissipation and scattering than simpler structures where PVP/CA layers were only used on the outer surfaces of the composites.

Conclusions This work focuses on the fabrication of multilayered hybrid composites, formed by combining electrospun fibers with porous, natural sponges (i.e. LC) for the fabrication of sustainable acoustic materials. This multilayer arrangement enables the control of structural and acoustic properties, addressing the limitations of natural fibers and conventional sound absorbing materials. Such systems are suitable for applications in building acoustics as well as traffic and urban noise control.

Key words Sound absorption, natural fibers, electrospun fibers, multilayered composites

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55 - MORPHOLOGY-TAILORED ELECTROSPUN POLYBENZIMIDAZOLE SUPPORTS FOR PLATINUM NANOCATALYSTS IN TOTAL CATALYTIC OXIDATION

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Background/Rationale Volatile organic compounds (VOCs) are hazardous air pollutants that require efficient abatement technologies. Catalytic oxidation is one of the most promising approaches because it enables the decomposition of VOCs into less harmful products at relatively low temperatures. However, catalyst performance strongly depends on the accessibility of active sites and on the interaction between the active phase and the support. Electrospun nanofibrous mats offer highly porous, open structures that can suppress internal diffusion limitations and improve reactant access to catalytic sites. This study investigates how different electrospinning strategies influence the morphology of polybenzimidazole (PBI) nanofibrous supports, platinum dispersion and catalytic performance in VOC oxidation.

Materials and Methods Polybenzimidazole nanofibrous mats (catalyst supports) were prepared by three electrospinning approaches: classical real solution electrospinning, colloid electrospinning and suspension electrospinning. Platinum nanoparticles were deposited onto the electrospun supports by wet impregnation using platinum acetylacetonate as the precursor, followed by calcination in air at 300 °C. The resulting catalysts were characterized by nitrogen physisorption, scanning electron microscopy, scanning transmission electron microscopy, X-ray diffraction, X-ray photoelectron spectroscopy and microwave plasma atomic emission spectroscopy. Catalytic activity was evaluated in the gas-phase total oxidation of ethanol, acetone and toluene using a fixed-bed reactor, with 1060 volumetric ppm of the individual VOC in air and repeated light-off experiments. Catalyst performance was compared using the temperature at which 10% conversion was achieved and turnover frequency.

Results The electrospinning route strongly affected the morphology of the polybenzimidazole supports. Colloid electrospinning produced nanofibers with polybenzimidazole nanoparticles located on the nanofiber surface, suspension electrospinning generated larger planar formations originating from suspended particles and real solution electrospinning with a targeted low viscosity resulted in bead-containing nanofibers. These morphological differences influenced platinum nanoparticle dispersion. Fresh catalysts showed the mean platinum particle sizes of approximately 9.0, 10.4, and 10.7 nanometres, depending on the support morphology. Catalytic activity increased markedly when the mean platinum particle size changed from about 9 to 11 nanometres, especially for acetone and toluene oxidation. The most active catalyst, based on the suspension-electrospun support, reached substantially lower temperatures for 10% conversion than the other samples. During consecutive light-off experiments, platinum nanoparticle sintering and agglomerate formation were observed. Rather than deactivating the catalysts, this restructuring contributed to higher catalytic activity, probably due to the formation of catalytically favorable platinum ensembles and local hotspots at active sites. After reaction, the catalysts also showed increased specific surface area, most notably for the most active sample.

Conclusions The study demonstrates that the morphology of electrospun polybenzimidazole nanofibrous supports can be tailored by choosing the appropriate electrospinning route and that this morphology directly affects platinum dispersion and volatile organic compound oxidation performance. The high porosity of the nanofibrous mats allows easy access of reactants to platinum active sites and minimizes diffusion limitations. The results demonstrate that electrospinning is a versatile tool for the design of nanostructured catalytic supports and show that controlled support morphology and platinum nanoparticle size are key parameters for improving the catalytic oxidation of VOCs.

Key words Electrospinning; Polybenzimidazole; Nanofibrous catalyst support; Platinum nanoparticles; Volatile organic compound oxidation

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56 - CATALYTIC PERFORMANCE OF MGO ELECTROSPUN NANOFIBERS IN LIQUID PHASE GUERBET COUPLING OF BUTANOL

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Background/Rationale The Guerbet reaction is considered the most promising catalytic route for the synthesis of higher alcohols. Branched alcohols are the most significant oxygenated organic compounds due to their remarkable physicochemical attributes, widely used in fuels, solvents, and chemical intermediates at the industrial level. This cascade process enables the coupling of primary alcohols (1-butanol) into β -branched dimer alcohols (2-ethylhexanol) with excellent atom efficiency. Homogeneous noble metal catalysts exhibit high selectivity but suffer from high cost and difficult separation of the catalyst from the reaction mixture, motivating the search for alternative catalytic materials.

MgO-based electrospun nanofibrous heterogeneous catalysts have emerged as promising alternatives to conventional homogeneous catalysts due to their high surface-to-volume ratio, structural tunability, and low mass transfer resistance reduction. Different electrospinning parameters enable precise control over microstructural and morphological properties, such as fiber diameter, porosity and surface texture, which are crucial for catalytic performance (activity & selectivity).

Materials and Methods MgO nanofibers were prepared by the electrospinning method using magnesium acetate tetrahydrate, polyvinylpyrrolidone (PVP), N, N-dimethylformamide (DMF) and MgO powder having surface area more than 300 m²/g. Perfectly fine mats of nanofibers were obtained by electrospinning a fine, transparent, homogeneous solution. The resulting nanofibers were calcined at 500°C, 600°C and 700°C for 2 h in a muffle furnace in static air.

The electrospinning was performed by a device (Cersum s.r.o., Czech Republic) consists of a steel syringe electrode and a stainless-steel plate acting as the collecting electrode. The tip-to-collector distance is 200–240 mm, and it can function at a DC voltage of up to 80 kV. The ambient temperature was kept between 20 and 25 °C, while the relative humidity was between 25-40 %. The catalytic experiments were carried out in a pressurized (up to 60 bar) batch catalytic reactor (Buchi AG, Switzerland). The effective volume of the chemical reactor is 0.25 liters.

Results The prepared catalysts were characterized by X-ray diffraction (XRD), by using a Bruker D8 Advance Eco diffractometer (Bruker Corporation, USA) equipped with Cu K α radiation (λ = 1.54056 Å); nitrogen physisorption was conducted at cryogenic conditions (77 K) using an automated volumetric gas adsorption apparatus, the Quantachrome Autosorb iQ-C-XR (Anton Paar QuantaTec, USA); scanning electron microscopy (SEM) was carried out (TESCAN Vega III, Czech Republic); TEM analyses were conducted using a FEI Tecnai F20 S/TEM microscope (FEI Company, USA) equipped with an X-TWIN lens and a high-brightness field emission gun (FEG) operated at 200 kV and surface elemental analysis were conducting by using Kratos ESCA 3400 X-ray photoelectron spectroscopy (XPS) (Shimadzu Corporation, Japan). Catalytic activity and selectivity were evaluated in a batch reactor in the liquid phase.

SEM analysis confirmed the formation of MgO nanofibers with retained fibrous morphology after calcination. nitrogen physisorption measurements revealed that suspension-derived MgO samples significantly improved textural properties, with an enhanced specific surface area. These structural and textural properties elucidate improved active sites accessibility and potential enhancement in catalytic selectivity in Guerbet reaction.

Conclusions The preliminary findings demonstrate that electrospinning is an effective approach for the fabrication of MgO nanofibrous heterogeneous catalysts with tunable morphology and enhanced textural properties. The high surface to volume ration and porous framework of MgO highlights their potential for selective Guerbet coupling towards higher alcohol fuels production.

Key words Electrospinning; Guerbet coupling; Higher Guerbet alcohols; MgO catalyst; Electrospun nanofibrous catalyst

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64 - ELECTROSPUN FREE-STANDING LIGNIN-BASED CARBON FIBRE CATHODES FOR LITHIUM-SULFUR BATTERIES

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Background/Rationale This research explores free-standing sustainable carbon fibre cathodes for lithium sulfur batteries (LSB). Li-S chemistry is particularly attractive due to its high theoretical specific capacity (1675 mAh/g), significantly higher than that of conventional lithium-ion batteries (300 mAh/g). The electrodes in my research are fabricated through electrospinning lignin, a by-product of the paper industry. The resulting fibres function as the sulfur host, providing both conductivity and polar sites (such as oxygen and sulfur sites) to improve capacity/polysulfide retention. The free-standing architecture eliminates the need for a current collector, binder, and conductive additives, which are all inactive mass and improves the specific energy density.

Materials and Methods This research replaces the conventional petroleum-derived carbon precursor, polyacrylonitrile (PAN), with lignin – a waste by-product of the paper industry – providing a more sustainable and cheaper alternative, while also upcycling lignin. Fabrication of the fibres is performed through electrospinning in an ambient environment, without toxic chemicals, demonstrating a safe, low-barrier-of-entry manufacturing process. The lignin fibres are then pyrolysed to yield a conductive carbon fibre mat. Sodium thiosulfate is also incorporated into the precursor solution as a pore-activating agent to tailor the fibre porosity. The resulting carbon fibre mats are directly used as cathodes in LSB.

Results This research examines the influence of sodium thiosulfate content and carbonisation temperature on fibre porosity and surface chemistry. Increasing porosity reduces inactive mass and restricts polysulfide diffusion, while changing carbonisation temperature varies the structural properties and surface chemistry.

Li-S coin cells made with these fibre mats demonstrate competitive capacity compared to conventional commercial cathodes, especially when evaluating the specific capacity of the cell against the weight of the whole cathode. The material was characterised through gas adsorption, Raman spectroscopy, XRD, SEM, XPS, and electrochemical testing, confirming that an increased porosity and surface chemistry lead to improved battery performance.

Conclusions This work demonstrates a scalable and sustainable approach to cathode fabrication, decreasing the weight and volume of the cell. Making this work attractive for lightweight applications such as drones and electric aviation.

Key words Lignin-derived carbon fibres, Lithium-sulfur battery, Free-standing cathodes

70 - ELECTROSPUN MOF MEMBRANES FOR THE REMOVAL OF DYES FROM BLEACHING WASTEWATER IN A CHEMICAL TEXTILE RECYCLING PROCESS

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Background/Rationale Textile industry is one of the most polluting industries, producing an immense number of toxic discharges into nature [1]. Textile dyes are often soluble in water and their presence in wastewater is for now inevitable. To address this issue, researchers have tried different methods of dye retention and adsorption offers the highest efficiency at a lowest price, compared to chemical and biochemical methods. Metal-organic frameworks (MOFs) are adsorption materials used for many applications due to their high specific surface area [2]. However, when MOFs are used for water treatment on an industrial scale, their form of dispersed fine powders can cause aggregation and clogging of tubing and overall difficulty of handling. Therefore, there has been growing demand for the incorporation of MOF, particularly nanofibers produced by electrospinning [3]. This research focusses on integration of one of common MOFs, MIL-101(Fe), into electrospun nanofibers (ENF) of polyamide 11 (PA11). We electrospun PA11 and synthesized MIL@PA11 to compare the adsorption capacity of pristine MIL-101(Fe) and MIL-101(Fe)-loaded PA11 ENF.

Materials and Methods MIL-101(Fe) was synthesized by solvothermal method using FeCl₃ 6H₂O and Terephthalic acid as precursors in DMF at 120°C. The MIL-101(Fe) powder was characterized by FTIR spectroscopy, XPS, SEM and BET surface area.

For electrospinning experiments, Polyamide 11 was dissolved in formic acid (FA) and dichloromethane (DCM) in different ratios, at 50°C for at least 3 hours. To determine the optimal electrospinning conditions, Taguchi method was applied to design the experiments of four parameters at three levels: FA/DCM solvent ratio (2/8, 5/5, 8/2), PA11 concentration (8%, 12%, 15%), TCD (10, 15, 20 cm), and voltage (10, 15, 20 kV).

Results The MIL-101(Fe) particles are smooth and exhibit a uniform hexagonal structure. The nitrogen adsorption isotherm of MIL-101(Fe) is compatible with the type I isotherm, which is characteristic of microporous materials [4]. The BET surface area was 662 m² g⁻¹. The XRD and FTIR characteristic peaks indicate the successful preparation of MIL-101(Fe) [5, 6]. It was observed that conditions for stable Taylor cone and, therefore, homogeneous nanofibers were FA/DCM 5/5 ratio, PA11-8%, TCD 10 cm and voltage 15 kV, and these parameters were kept for electrospinning of MOF-loaded ENFM. Surfactant additional has improved the adsorption effectiveness of the ENFM. Adsorption capacity of MIL@PA11/T20-2.5% membrane was two times higher than that of MIL@PA11 (131.6 and 55.6 mg/g, respectively), in which the adsorption is only possible on the surface of membrane and not in its bulk. With addition of surfactant, the adsorption capacity first increases, because surfactant allows the ENFM to be immersed into the dye solution, and the MIL-101(Fe) particles in membrane bulk can be exposed to dye molecules. However, higher amount of surfactant (2.5%), it starts hindering the exposure of MIL-101(Fe) in the ENF and therefore hinders the overall adsorption.

Conclusions Polyamide 11 electrospinning process was optimized. The MIL-101(Fe) was successfully synthesized and incorporated in PA11 solution to produce MIL@PA11 ENFM. Addition of a surfactant improves adsorption of ENFM due to the increased permeability of membrane. More research is needed on incorporating MOF onto the nanofiber surface of PA11, and not only into the bulk of the fiber.

Key words Metal-organic frameworks, electrospun nanofibers, adsorption, textile wastewater

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79 - METAL DOPED ELECTROSPUN CARBON NANOFIBERS AS CATHODES FOR SCALABLE HYDROGEN PRODUCTION (ENDURION)

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Background/Rationale Electrospinning has emerged as one of the most versatile and scalable techniques for producing nanostructured materials with finely tunable morphology, composition, and surface chemistry.[1] Its ability to generate continuous fibers with diameters ranging from the micrometer down to the nanometer scale has positioned it as a powerful platform for designing advanced electrode materials. In particular, electrospun carbon nanofibers (CNFs) have attracted significant attention due to their high surface area, interconnected porosity, mechanical robustness, and excellent electrical conductivity after carbonization.[2] These features make them ideal candidates for electrocatalytic applications, where efficient charge transport and abundant accessible active sites are essential.

Within the broader context of sustainable energy technologies, the hydrogen evolution reaction (HER) remains a cornerstone for clean hydrogen production via water electrolysis.[3] However, the widespread deployment of electrolyzers is still constrained by the reliance on platinum-group metals (PGMs), which, despite their outstanding catalytic activity, suffer from scarcity, high cost, and supply-chain vulnerability. This has motivated an intensive search for non-critical raw material (non-CRM) alternatives capable of delivering competitive HER performance while enabling large-scale, economically viable implementation.

Electrospinning offers a unique pathway to integrate non-CRM catalytic species, such as transition-metal nanoparticles, heteroatom dopants, or metal-free active sites, directly into a conductive carbon fiber matrix with nanoscale precision. The resulting hybrid CNFs can exhibit synergistic effects between the carbon framework and the embedded catalytic centers, enhancing intrinsic activity, stability, and mass-transport characteristics.[4,5] Moreover, the compatibility of the method with continuous production and its adaptability to diverse precursor chemistries make it particularly attractive for developing next-generation HER electrodes.

Materials and Methods The present work in ENDURION project focuses on the design and fabrication of electrospun CNF films from PAN/DMF solutions containing dissolved non-CRM metal precursors of Ni and Mo. After thermal treatment, the CNF films doped with Mo₂C and Ni particles have been fully characterized by means of varied techniques (isothermal N₂ adsorption, X-ray diffraction (XRD), electric conductivity, etc.) to assess their potential as free-standing electrodes for HER. The electrochemical performance has been evaluated in a three-electrode custom-made electrode support by linear sweep voltammetries and chronoamperometries, determining the overpotentials needed to reach current densities of up to 800 mA·cm⁻².

Results Results have shown that the generated particles on CNFs are homogeneously distributed. XRD analysis and electron diffraction have been used to determine the crystalline nature of the generated particles after the corresponding thermal treatments. Electron microscopy has allowed us to observe that while the obtained Mo-based nanoparticles are very small, around 10 nm, Ni-based particles range from nanometric to submicron sizes. The fibers also showed high porosity, with specific surface areas (SA) in the range of 100-900 m²·g⁻¹, and high electrical conductivity (50-1100 S·m⁻¹). The catalyst loading has also been tuned, reaching values of up to 1.5 mg·cm⁻². Subsequent electrochemical characterization of these CNF films has shown that some of the characterized parameters, such as catalyst loading, has an impact on the observed overpotential for HER at different current densities, reaching values as low as 300-350 mV at 100 mA·cm⁻².

Conclusions In conclusion, by leveraging the structural and compositional control inherent to electrospinning, this study aims to advance sustainable catalyst development and contribute to the broader transition toward CRM-free hydrogen technologies.

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Key words electrospun carbon nanofibers, hydrogen evolution reaction, non-CRM catalysts, electrochemistry

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87 - LUMINESCENT FIBROUS MATS FOR CONTROLLED COLOR CONVERSION OF LED LIGHT

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Background/Rationale Down-shifting of light frequency is frequently used in lighting systems, such as LEDs, to efficiently change the color of emitted light. Typically, InGAN and GaN LEDs emitting light in the blue region of the electromagnetic spectrum are combined with yellowish-green phosphorescent materials to provide both additional emission and LED light scattering, creating the impression of white light [1]. Beyond lighting applications, this effect is also considered useful for improving photovoltaic efficiency by converting unused parts of the spectrum into photons that can participate in the photovoltaic effect [2]. The vast majority of research conducted for the aforementioned applications focuses on inorganic phosphorescent materials such as lanthanides. While such materials offer many advantages, they also struggle with some important weaknesses. Main drawbacks are: availability (supply chains drawbacks), long emission lifetimes (limiting potential data transfer), and narrow emission lines (frequently matching not absorption spectra), etc. Therefore, there is a need to investigate the organic-based technologies regarding the mentioned applications, and electrospun fibers supporting efficient light emission and scattering seem to perfectly fit this role.

Materials and Methods Here, we focus our research on the fabrication of down-converting fiber mats for use in tandem with LEDs operating at ~450 nm for lighting applications. In particular, we investigate PMMA fiber nonwovens doped with the luminescent dye DCM to answer the question: how do electrospinning processing parameters affect the color of the emitted light, and can we control it? To do so, we prepare fiber mats with varying amounts of DCM dye and spin times. The output emissions are investigated using a fiber-coupled Czerny-Turner pocket spectrometer, which enables the determination of the emission spectrum over a wide wavelength range. That, in turn, enables the determination of CIE1931 coordinates and the assessment of adjustments to fabrication parameters to obtain the desired emission color. Moreover, the DCM dye is known to be an efficient component of laser materials. Therefore, the capability of PMMA fibers doped with DCM dye to generate laser light was also determined.

Results In our research, we show that both the thickness of the fiber mat and the DCM dye concentration can significantly influence the resulting color of tandem device emission. For example, the mat thickness determines how high the ratio of DCM dye emission intensity to LED emission intensity will be. That enables the almost linear change in position on the CIE diagram from the left to the right side with respect to the mat's thickness. On the other hand, the dye concentration, due to emission self-absorption, shifts the entire "trajectory" downward, enabling wide color tuning using only a single component material. Finally, we show that the same material can be easily processed into a material capable of generating laser light via random lasing, with a controllable spatial intensity distribution relative to the fiber mat morphology.

Conclusions To conclude, we show that electrospinning process parameters can be adjusted to tune the performance of an LED device with a fibrous luminescent coating, enabling a wide color-tuning range using a single component material. This demonstrates the potential use of the electrospinning technique in materials processing for devices used in lightning applications. The main advantage is its simplicity, allowing one to obtain various emission parameters without the need to change the luminescent material. However, the topic is, to the best of our knowledge, not well explored; thus, it may require more investigation and interest.

Key words down-shifting, down-conversion, LED, color tuning, lighting applications, random laser

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96 - SUSTAINABLE CARBON FIBRES FOR ZERO-EXCESS LITHIUM METAL BATTERIES

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Background/Rationale Full electrification of the transport sector demands batteries with higher energy density and reduced reliance on critical raw materials for sustainable and secure battery production. While lithium-ion batteries (LIBs) have driven much of the progress so far, their continued dominance risks straining natural resources and limiting uptake in weight-sensitive sectors. Zero-excess lithium metal batteries (ZELMBs) offer a promising alternative, replacing the graphite anode with a bare current collector onto which Li metal is directly plated during operation, eliminating inactive anode material and boosting energy density [1].

However, poor Li plating and stripping reversibility severely limits cycle life. On commercial copper foil surfaces, Li deposits non-uniformly due to high nucleation barriers and local current hotspots. This non-uniform deposition evolves into morphological instabilities, such as needle-like dendrites or mossy Li, which disrupt the solid electrolyte interphase (SEI), promoting electrolyte decomposition and Li loss [2].

Three-dimensional current collectors can improve deposition uniformity by distributing charge over a larger surface area, reducing local current density peaks, and accommodating volume changes. Carbon nanofibers (CFs) are particularly attractive, combining high conductivity, low density, and low-cost precursors [3], among which lignin is a promising candidate. Lignin is a renewable biopolymer, rich in O-containing functional groups within aromatic networks, [4]. Upon carbonization, it forms O-rich, turbostratic carbon structures with abundant microporosity and defect sites [5], and these features can be tuned to regulate Li nucleation behaviour and improve plating and stripping reversibility.

Materials and Methods Electrospinning solutions were prepared by dissolving PEO in aqueous NaOH, followed by the addition of organosolv lignin, and electrospun into fibrous mats (~100 µm thick). Mats were cut into strips, sandwiched between carbon felt, and carbonised under N₂ at 700 °C, 1000 °C, or 1300 °C (CF700, CF1000, and CF1300) for 2 h at 1 °C min⁻¹ to obtain CFs with distinct structural and chemical properties.

Structural and chemical characterisation, including defect content, graphitic order, heteroatom concentration, and pore size distribution, was performed using Raman spectroscopy, X-ray diffraction (XRD) small-angle X-ray scattering (SAXS), gas adsorption and X-ray photoelectron spectroscopy (XPS). Electrochemical performance was evaluated in coin cells assembled in an Ar-filled glovebox using 1 M lithium bis(trifluoromethanesulfonyl)imide (LiTFSI) in 1:1 (v/v) dioxolane (DOL)/dimethoxyethane (DME) with 5 wt% LiNO₃, with Li nucleation overpotential and plating/stripping reversibility as key metrics. Together, these measurements were designed to establish structure-property-performance relationships and identify the key CF characteristics governing optimal electrochemical behaviour.

Results Characterisation at 700 °C, 1000 °C, and 1300 °C revealed clear trends of increasing structural order, decreasing defect content and N/O concentrations, and the loss of certain defect types. These changes were accompanied by substantial pore evolution, with a marked increase in pore size with carbonization temperature and broadening of the pore size distribution between 1000 °C and 1300 °C.

Compared to Cu foil, CF1000 exhibits a significantly reduced nucleation overpotential, whereas CF1300 shows an increased nucleation overpotential. A strong inverse correlation between nucleation overpotential and the pre-nucleation capacity was observed across all CF samples, suggesting that greater Li accommodation within the carbon structure lowers the effective nucleation barrier. Pre-nucleation storage is governed by defect chemistry and local curvature of the carbon structure, which together dictate Li⁺ adsorption and the formation of early-stage Li clusters.

CF1000 also demonstrated the strongest long-term performance, achieving ~99.0% coulombic efficiency over 200 cycles and symmetric cell lifetimes exceeding 3000 hours.

Conclusions In this work, we demonstrate that lignin-derived electrospun CFs can serve as functional free-standing current collectors for ZELMBs. Carbonisation temperature provides a practical handle for tuning CF structure and electrochemical performance, with carbonization at 1000 °C identified as optimal. Pores of ~1.0–1.4 nm enhance pre-nucleation Li capacity by providing favourable environments for Li cluster

formation, and a strong negative correlation between pre-nucleation Li capacity and nucleation overpotential reflects the improved nucleation kinetics of pre-lithiated fibres.

Key words zero-excess, lithium metal batteries, electrospinning, carbon fibre current collectors

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99 - MULTICOLOR AND WHITE RANDOM LASING IN PHOTONIC SOFT-MATTER SYSTEMS

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Background/Rationale Random lasing (RL) has emerged as a versatile and cost-effective alternative to conventional lasers. It relies on multiple light scattering rather than a traditional optical cavity, making it a highly flexible photonic platform for laser displays and Light-Fidelity [1]. To construct such devices, scattering gain media are required, which can successfully include liquid crystals (LCs) [2], microcrystals, quantum dots[3], and others. One of the major challenges in modern photonics is the realization of broadly tunable multicolor and white lasing from a single device. However, achieving pure white emission that satisfies international standards such as D50, D65, or D75 remains difficult, mainly due to Förster resonance energy transfer (FRET) among red, green, and blue (RGB) chromophores, which often leads to unbalanced emission spectra. Previous studies on organic and hybrid systems typically report deviations from white-light standards on the order of 10–20%. In this work, we demonstrate how standard-compliant white emission can be achieved using spatially separated RGB dyes. This presentation focuses on the role of LCs as well as hierarchically designed electrospun polymer fiber mats with a gradient distribution of RGB dyes. This architecture physically separates the gain media, suppresses FRET, and enables controlled multicolor and white RL.

Materials and Methods The fiber mats were fabricated from polymethyl methacrylate (PMMA) doped with three laser dyes: DCM(R), Coumarin6(G), and Perylene(B). Electrospinning was used to prepare single-, double-, and triple-layer fiber mats (SLFM, DLFM, and TLFM). This system was compared with an LC host mixture, in which sequential phase transitions were observed with increasing temperature, including ferroelectric nematic (NF) and twist-bend nematic (NTBF) phases. For the LC system, perylene was replaced by stilbene420 as the blue-emitting component. Characterization of all systems included morphological analysis using fluorescence microscopy and/or confocal microscopy, and/or scanning electron microscopy (SEM). Optical performance was first evaluated through fluorescence measurements. RL experiments were then performed using a 405 nm nanosecond pump laser (Nd:YAG system with optical parametric oscillator, OPO). FRET suppression was confirmed using fluorescence lifetime imaging microscopy. Speckle-free imaging was evaluated against a coherent reference source, a continuous-wave helium-neon laser.

Results The electrospun fibers exhibited diameters ranging from 1.0 to 2.5 μm , forming smooth structures capable of supporting waveguiding and scattering. FLIM analysis confirmed that the hierarchical architecture strongly suppressed non-radiative FRET due to the physical separation of dyes in distinct fiber regions. In DLFM structures, spatial control of fiber density enabled smooth tuning across a broad color range, including transitions such as sky blue to mint green and red to apple green. The TLFM system achieved high-quality white lasing with excellent spectral fidelity. By adjusting the excitation position along the gradient or changing the pumping direction (DCM-rich side vs. perylene-rich side), the emission could be precisely tuned to match standard illuminants D55, D65, D70, and D75. Deviations from these standards were as low as 0.2%–3%, representing a significant improvement over previously reported systems. Furthermore, the RL emission covered a wide color gamut exceeding sRGB, Adobe RGB, and DCI-P3 standards. Color wheel measurements confirmed that fiber mats enable extensive multicolor tuning, producing highly saturated emission and stable white output. Application-oriented tests showed that RL significantly reduced speckle artifacts, decreasing contrast from $C \approx 0.15$ (for a coherent He–Ne laser) to $C \approx 0.04$. Controlled chromaticity drift during prolonged operation was also observed, suggesting potential use in optical dosimetry. The LC-based system allowed multicolor tuning through temperature-driven phase transitions rather than spatial dye distribution or excitation position. However, while efficient multicolor lasing was achieved, the best white emission reached was closest to the D75 standard.

Conclusions Gradient fiber mats provide a scalable platform for next-generation photonic devices. By suppressing FRET through physical separation of dyes, the system enables reproducible spectral tuning from multicolor emission to high-fidelity white lasing (D65 standard). In contrast, the LC system enables tunability via external stimuli such as temperature and electric fields, allowing mesophase-dependent emission control, although with different white-standard accuracy. Both approaches demonstrate different advantages and complementary properties. Their combination may enable the development of new hybrid photonic systems for applications such as Li-Fi communications, adaptive lighting, and speckle-free laser display technologies.

Key words random lasing, multicolor, tunability, white standards, electrospun fibers, liquid crystals

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102 - COMPARATIVE STUDY OF THREE BIOMASS-DERIVED ORGANOSOLV LIGNINS IN ELECTROSPUN SYSTEMS FOR TUNABLE RELEASE APPLICATIONS

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Background/Rationale The increasing demand for sustainable and efficient delivery systems in agriculture has fostered interest in bio-based materials capable of modulating the release of active compounds. Lignin is particularly attractive in this context because it is an abundant renewable biopolymer whose complex chemical structure depends strongly on both biomass source and extraction process. This structural diversity can influence its interactions with embedded molecules and may therefore be exploited to design tunable delivery systems. This study investigates how organosolv lignins extracted from different waste biomasses affect the release kinetics of curcumin, used as a model bioactive polyphenol, when incorporated into electrospun PLA-based fibrous materials.

Materials and Methods Lignin was extracted through an organosolv process from three agro-industrial and agricultural waste biomasses, namely hazelnut shells, spelt husks and potato plant residues, using an EtOH/H₂O/HCl(Cat) system at 120 °C for 6 h. The structural features of the extracted lignins, labelled as Ln, Lh and Lp, were investigated by NMR spectroscopy. Each lignin fraction was incorporated into PLA-based electrospun mats together with curcumin (Merck), selected as a model polyphenolic compound because of its characteristic UV–Vis absorbance band. PLA/lignin/curcumin blend solutions were prepared in acetone/DMF mixtures at different lignin-to-curcumin ratios, and electrospinning parameters were optimised to obtain continuous nanofibrous architectures. Release experiments were carried out by immersing the samples in PBS (pH 7.4) for 10 days at 25 °C. Eluted aliquots were analysed daily by UV–Vis spectroscopy to assess curcumin release kinetics. SEM, AFM, fluorescence microscopy and water contact angle measurements were used to investigate fibre morphology, lignin/curcumin-rich domain distribution, surface wettability and their relationship with release behaviour.

Results The electrospun mats displayed continuous PLA-based fibrous networks containing lignin/curcumin-rich bead-like domains. Their abundance increased with lignin loading, while their shape and size appeared to depend on the lignin source. This source- and loading-dependent morphology suggests the formation of local depots within the PLA matrix, potentially involved in curcumin diffusion and release control. Daily UV–Vis monitoring of the curcumin absorption band showed distinct release kinetics among the formulations, with differences in both release rate and relative amount released over time. These trends were consistent with the NMR results, which evidenced source-dependent differences in the functional group profile and in the relative distribution of lignin structural units. Such variations may influence lignin polarity, supramolecular organisation and affinity for curcumin, thereby affecting its distribution within the PLA matrix and modulating release kinetics.

Conclusions This study shows that organosolv lignins obtained from different agro-industrial and agricultural waste biomasses can act as structure-dependent modulators of curcumin release from electrospun PLA-based materials. By preserving, at least partially, the native structural features of lignin from each biomass source, the organosolv process provides lignins with distinct chemical functionalities and molecular organisations. These differences affect lignin-curcumin interactions within the fibrous matrix and allow the release profile of the model polyphenol to be tuned. Selecting lignin according to its biomass-derived structure therefore represents a sustainable strategy for designing delivery systems with tailored release behaviour, with potential relevance in agro-food and agricultural applications requiring controlled and prolonged release of functional molecules.

Key words Lignin; Biowaste; PLA nanofibres; Controlled release; Curcumin; Sustainable agriculture

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108 - BIO-DERIVED PHOTOTHERMAL CELLULOSE ACETATE NANOFIBER MATS CONTAINING ETHANOL-SOLUBLE LIGNIN FRACTIONS

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Background/Rationale Photothermal materials efficiently absorb incident light and convert it into thermal energy, enabling applications in photothermal actuation, solar-driven desalination, energy conversion, and biomedical therapy. Conventional photothermal systems often rely on plasmonic localized heating in metallic nanostructures or non-radiative relaxation in semiconductor-based materials. However, their high cost, limited sustainability, and insufficient environmental compatibility remain critical barriers to the clean utilization of solar energy.

To address these limitations, lignin offers a bio-derived alternative owing to its abundance, renewability, and aromatic molecular structure. Lignin is mainly composed of p-hydroxyphenyl, guaiacyl, and syringyl phenylpropane units bearing phenolic hydroxyl, methoxy, and other oxygen-containing functional groups. These aromatic structures enable broad light absorption, while π -conjugated and π - π interacting domains can facilitate non-radiative relaxation through molecular vibration, leading to efficient light-to-heat conversion. In this study, an ethanol-soluble lignin-rich fraction was incorporated into electrospun cellulose acetate nanofibers to construct a bio-derived photothermal nanofiber mat. The lignin fraction serves as an intrinsic photothermal absorber, while the porous electrospun nanofiber network enhances light scattering and retains photogenerated heat near the functional surface.

Materials and Methods Enzymatic hydrolysis lignin (EHL) was fractionated in an ethanol/deionized water mixture (90:10, v/v) under stirring for 6 h to obtain an electrospinnable lignin-rich fraction. The dispersion was centrifuged at 5000 rpm for 30 min, and the collected supernatant was concentrated by rotary evaporation followed by freeze-drying for more than 2 days to obtain the S1 lignin powder. Cellulose acetate (CA, Mw = 50,000) was dissolved at 15 wt% in a DMSO/acetone mixed solvent (1:1, v/v), and S1 powder was added at different S1:CA mass ratios. The resulting solutions were electrospun using a drum collector at 18.5 kV, a tip-to-collector distance of 15 cm, and a flow rate of 550 μ L/h, yielding stable S1 lignin/CA nanofiber mats.

Results The S1/CA nanofiber mat exhibits a uniform fiber morphology with an average diameter of 700 nm. Under 1 sun irradiation, the mat rapidly reached a surface temperature of approximately 40 °C within 10 s, indicating efficient light-to-heat conversion. Furthermore, the photothermal response remained stable after more than 5000 bending cycles, confirming the mechanical robustness and durability of the photothermal nanofiber mat.

Conclusions This study demonstrates a bio-derived photothermal functional mat fabricated by incorporating an ethanol-soluble lignin-rich fraction into electrospun cellulose acetate nanofibers. The resulting S1/CA nanofibrous mat exhibited rapid photothermal heating under 1-sun irradiation and maintained stable performance after repeated bending cycles. These findings suggest that bio-derived lignin fractions can serve as effective intrinsic photothermal absorbers for flexible electrospun nanofiber mat, providing a promising route toward bio-derived and light-responsive thermal management applications.

Key words fractionated lignin nanofiber, photothermal, biopolymer, electrospinning

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112 - ELECTROSPINNING OF SHORT-SIDE CHAIN PERFLUOROSULFONIC ACID IONOMERS: TUNING NANOFIBER DIAMETER THROUGH FORMULATION PARAMETERS

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Background/Rationale Fuel cells are a promising technology for efficient energy conversion. Further performance improvements rely on advanced strategies for integrating functional materials into their architecture. In this context, this work investigates a novel approach to tailor the morphology of electrospun ionomer-based mats, with potential application as electrodes. Classical electrospinning relies on the fine-tuning of formulation parameters to obtain nanofibers by mastering the proper viscoelastic properties. In particular, three distinct concentration regimes (dilute, semi-dilute unentangled, and semi-dilute entangled) can be associated with the final fiber morphology (droplets, beads-on-string, and uniform fibers, respectively)¹. The concentration and molar mass of the polymer as well as polymer-solvent interactions are critical parameters for controlling fiber morphology. Ionomers, like the short-side chain perfluorosulfonic acid Aquivion, contain a hydrophobic main-chain and hydrophilic groups on their sidechains, leading to a solvent-dependent molecular conformation due to their amphiphilic structure². When Aquivion is dispersed in water, the polymer chains are organized as clusters, inhibiting the production of fibers due to the resulting low viscoelasticity, even at polymer concentrations as high as 25wt. %.

Materials and Methods To tune the molecular conformation of Aquivion and promote electrospinning, the addition of green organic solvents and a carrier polymer to the aqueous dispersion was investigated. The physicochemical properties of the formulation were thoroughly characterized. Particular attention was paid to the composition of the green solvent mixture, the ratio between Aquivion and the carrier polymer, and the total polymer concentration in order to identify the different concentration regimes and their influence on mat morphology. The ratio between Aquivion and the carrier polymer ranged from 90 to 180.

Results The average diameter of the Aquivion fibers varied between 200 nm and 1 µm, while maintaining compliance with the principles of green electrospinning. The results demonstrate that increasing the molar mass of the carrier polymer, adjusting the Aquivion concentration, and selecting appropriate solvent mixtures are key parameters for controlling fiber morphology.

Conclusions These findings provide a sustainable strategy for tailoring ionomer-based nanofibers and further expand the potential of green electrospinning approaches for the fabrication of advanced functional materials for fuel cell applications.

Key words Electrospinning; Aquivion; carrier polymer; green solvents; fiber morphology.

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115 - FROM BIOPOLYMERS TO CATALYSTS: ELECTROSPINNING AND PYROLYSIS FOR THE IN-SITU FORMATION OF GOLD NANOPARTICLES ON SUSTAINABLE CARBON FIBERS FROM MALTODEXTRIN

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Background/Rationale Nowadays, the polymer industry still strongly relies on fossil resources, driving the search for sustainable materials for electrospinning applications. Maltodextrins, bio-based and water-soluble products obtained from starch hydrolysis ($DE < 20$), are promising candidates due to their low cost, renewability, and excellent spinnability.[1] In parallel, gold nanoparticles have gained attention as heterogeneous catalysts for biomass valorization, particularly in oxidation reactions of lignin- and cellulose-derived compounds.[2] Carbon-based electrospun fibers represent attractive catalyst supports because of their high surface area and porosity.[3] In this context, this work proposes an innovative one-step electrospinning strategy to fabricate carbon-based fibrous supports decorated with gold nanoparticles, integrating material synthesis and catalyst formation while avoiding the use of solvents and fossil-derived precursors.

Materials and Methods Maltodextrin and citric acid were dissolved in water and mixed with $\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$ to obtain Au loadings between 0.05 and 5 wt%. The resulting solutions were electrospun into nonwoven mats and subsequently pyrolyzed under N_2 at 700 °C. A mild air activation step (350 °C, 15 min) was performed to enhance the accessibility of Au active sites. Fiber morphology and Au nanoparticle size were investigated by SEM, FESEM, and TEM, while crystalline phases, elemental composition, and textural properties were analyzed by XRD, EDS, and N_2 physisorption (BET), respectively. Catalytic activity was evaluated in glycerol oxidation at 50 °C under 3 atm of O_2 using a 0.3 M glycerol solution with a NaOH : glycerol molar ratio of 4:1. The catalyst amount was adjusted to maintain a constant glycerol/Au molar ratio across all samples, and products were quantified by HPLC.

Results Electrospinning of aqueous maltodextrin solutions containing citric acid and $\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$ produced homogeneous nonwoven mats across the entire Au loading range (0.05–5 wt%), indicating that the gold precursor does not affect spinnability under the selected conditions. Pyrolysis at 700 °C under N_2 yielded submicrometric carbon fibers decorated with metallic Au nanoparticles, consistent with in situ reduction of Au(III) during carbonization. FESEM-EDS confirmed that the Au content matched the nominal loading, while XRD showed metallic Au reflections within an amorphous carbon matrix. At low loadings, TEM revealed partial coverage of Au nanoparticles by a thin carbon layer, which may hinder surface accessibility. A mild air activation at 350 °C for 15 min improved Au exposure while preserving fiber morphology and generating local voids around nanoparticles. N_2 physisorption showed similar textural properties for all samples, with an average specific surface area of $411 \pm 86 \text{ m}^2 \text{ g}^{-1}$.

Catalytic tests in glycerol oxidation showed strong dependence on Au loading and nanoparticle size. High loadings (5 and 1 wt%) produced larger Au nanoparticles ($28.0 \pm 23.5 \text{ nm}$ and $25.2 \pm 15.9 \text{ nm}$) with low activity (37 and 61 h^{-1}), whereas lower loadings yielded smaller nanoparticles ($8.2 \pm 4.8 \text{ nm}$ and $7.4 \pm 6.0 \text{ nm}$) and much higher activity (939 and 1700 h^{-1}). This trend agrees with the known structure–activity relationship for Au-catalyzed glycerol oxidation, where smaller nanoparticles are more active. Product distribution was mainly toward glycolic acid, with formic and glyceric acids as minor products.

Conclusions This work demonstrates the potential of electrospinning as a versatile and sustainable approach for the fabrication of functional catalytic materials. Homogeneous maltodextrin-based nonwoven mats were successfully produced over a wide Au loading range, confirming the excellent spinnability of the developed aqueous formulations. Subsequent pyrolysis enabled the direct conversion of the electrospun structures into carbon fibrous supports decorated with Au nanoparticles through an integrated one-step process. The resulting electrospun carbon fibers exhibited suitable textural properties and tunable catalytic performance in glycerol oxidation, highlighting the effectiveness of electrospinning in designing bio-derived catalytic systems for biomass valorization.

Key words Electrospinning, carbon nanofibers, gold nanoparticle catalyst, biomass valorization.

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117 - METAL-FREE ORGANOHALIDE-ENGINEERED ELECTROSPUN PVDF NANOFIBERS FOR HIGH-PERFORMANCE PIEZOELECTRIC ENERGY HARVESTING TOWARD SELF-POWERED IMPLANTABLE DEVICES

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Background/Rationale Piezoelectric nanogenerators (PENGs) are promising power sources for self-powered implantable medical devices because they can convert mechanical stimuli into electricity without repeated battery replacement. However, conventional ceramic piezoelectrics often contain heavy-metal components and have rigid mechanical characteristics, limiting their suitability for deformable and biocompatible biomedical systems. Polyvinylidene fluoride (PVDF) is an attractive organic piezoelectric polymer because of its flexibility, processability, and biocompatibility, but its piezoelectric output is strongly limited by insufficient formation and orientation of the polar β -phase. This study addresses this challenge by combining electrospinning-induced chain alignment with metal-free organohalide-assisted heterogeneous crystallization.

Materials and Methods PVDF was dissolved in a DMSO/acetone solvent mixture and blended with a precursor solution of 1,4-diazabicyclo[2.2.2]octane-based organohalide, DABCO–NH4I3. The mixture was electrospun using a rotating drum collector to fabricate one-dimensional nanofiber mats. The as-spun mats were post-heated at 100 °C under inert atmosphere to promote the formation of hexagonal DABCO–NH4I3 crystals within the PVDF matrix. The post-heating time was varied to optimize β -phase crystallization and piezoelectric performance. Morphology and composition were analyzed using SEM, TEM/STEM, and EDS. Intermolecular interactions and crystal structures were evaluated using XPS, DFT calculations, XRD, FTIR, DSC, and GIWAXS. Local piezoelectric response was measured by PFM, and PENG devices were fabricated by sandwiching the nanofiber mats between aluminum electrodes with polyimide encapsulation. Cytocompatibility was examined using HaCaT cells, CFSE staining, and MTS assays. Energy harvesting was evaluated under compressive tapping, bending, and ultrasound-driven vibration, including a porcine-skin-mimicking implantable configuration.

Results The incorporation of DABCO–NH4I3 produced smooth, bead-free PVDF composite nanofibers and introduced rod-like organohalide crystals within the polymer matrix. XPS and DFT analyses confirmed preferential intermolecular interactions between charged sites in DABCO–NH4I3 and polar PVDF chains, selectively promoting the TTTT β -phase conformation. Structural analyses showed that the optimized composite achieved a β -phase fraction of 93.1% and a crystallinity of 54.87%, with preferred orientation along the one-dimensional fiber axis. As a result, the nanofiber composite exhibited an exceptional piezoelectric coefficient of $d_{33} = -275$ pm/V, corresponding to a 468% enhancement compared with pristine PVDF nanofibers. The resulting PENG generated a maximum output voltage of 75.82 V under compressive loading and a maximum power density of 57.01 μ W/cm². The device also showed good fatigue resistance, with only a 9.8% decrease after repeated mechanical impacts. Under ultrasound stimulation at 28 kHz, a therapeutically relevant frequency, the PENG generated approximately 1.02 V and charged a capacitor to 0.99 V within 100 s. The ultrasound-driven output remained stable for 360 min, corresponding to more than 6.0×10^8 vibration cycles. The all-organic composite also showed favorable cytocompatibility, with HaCaT cell viability exceeding that of pristine PVDF after 3 days.

Conclusions This work demonstrates that metal-free DABCO–NH4I3 organohalide crystals can effectively enhance the piezoelectric performance of electrospun PVDF nanofibers by inducing selective β -phase crystallization and fiber-axis molecular orientation. The combination of high piezoelectric response, mechanical durability, cytocompatibility, and ultrasound-driven energy harvesting suggests that the developed PVDF/DABCO–NH4I3 nanofiber PENG is a promising platform for self-powered implantable and biointegrated medical devices.

Key words Electrospinning; PVDF; DABCO–NH4I3; metal-free organohalide; β -phase crystallization; piezoelectric nanogenerator; implantable medical device; ultrasound energy harvesting

118 - BIOCOMPATIBLE FIBROUS MATS FOR ENERGY HARVESTING AND PERIPHERAL NERVE REPAIR

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Background/Rationale The piezoelectric effect is a phenomenon through which materials can induce charges on their surfaces when they are mechanically stressed, and vice versa, when an electric field applied across the material leads to a mechanical deformation. Piezoelectric materials exhibiting a noncentrosymmetric crystal structure can inter-convert mechanical and electrical energy. Although the piezoelectric effect was first discovered and exploited in inorganic materials, it has also been found in a range of other material classes, including biocompatible polymers such as poly(vinylidene fluoride) and natural polymers [1]. These class of materials, exhibiting mechanical flexibility and easy of processing have been successfully used to fabricate nanofibers by electrospinning and it has been demonstrated that both the confined geometry in the form of filaments and the mutual interaction among adjacent fibers in networks and array enhances the piezoelectric performances [2]. These fibers, in a properly designed device form, capture ambient mechanical energy, including mechanical vibrations, the movement of objects and bodies, impact events, and air and/or fluid flows, and convert them into electrical energy. Such energy can be used to support consumable electronics and components in a wide range of applications. In tissues engineering, the small electrical stimulation generated through the piezoelectric effect can interact with cells, influencing membrane potentials, ion channel activity, protein signaling pathways, and gene expression [4].

Materials and Methods Free-standing membranes and on-substrates fiber meshes based on ordered and disordered assembly of piezoelectric nanofibers were realized by electrospinning. Fibers were assembled in a device architecture for the measurements of their sensing and energy harvesting capabilities. In vitro analyses were performed using rat primary Schwann cells and dissociated dorsal root ganglia neurons cultured on nanofibers. In vivo experiments were performed to test the regenerative capability of free-standing membranes on cavernous nerve lesion in adult male rats.

Results Here, we report on different strategies for achieving outstanding piezoelectric performance in polymer nanofibers, together with in vitro and in vivo studies aimed at promoting peripheral nerve repair and regeneration in rats.

Conclusions Studies demonstrated energy harvesting capabilities of the realized fiber in device architectures, in vitro boosted focal adhesion development of Schwann cells and in vivo promoted response of neuronal and glial cells.

Key words Piezoelectric nanofibers, sensing, energy harvesting devices, peripheral nerve repair, in vivo and in vitro studies

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124 - DEVELOPMENT & OPTIMISATION OF LIGNIN-DERIVED CARBON FIBRES FOR HIGH-PERFORMANCE STRUCTURAL BATTERIES

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Background/Rationale This research explores the development of sustainable and high-performance materials for structural lithium-sulfur (Li-S) batteries using lignin-derived electrospun carbon nanofibres (CNFs). Structural batteries simultaneously provide load-bearing capabilities and energy storage, reducing the overall weight of electric transportation systems.

As the second-most abundant biopolymer on Earth, lignin is a renewable, low-cost alternative to traditional petroleum-derived precursors such as polyacrylonitrile (PAN). Electrospun lignin CNFs offer advantages such as high surface area, tuneable porosity and good conductivity, making them attractive for electrochemical applications. However, their poor mechanical properties limit their use in structural systems. This work focuses on improving the mechanical performance of lignin-based CNFs whilst maintaining desirable electrochemical behaviour. In parallel, the sustainability of the precursor system is being improved to reduce the dependence on non-renewable additives and to optimise solution properties for electrospinning.

Materials and Methods A lignin-based electrospinning solution is prepared to benchmark tensile and electrochemical performance of all samples. This consists of Organosolv lignin dissolved in NaOH (aq) with PEO added as a co-polymer to aid fibre formation. The resulting fibres were then carbonised at high temperatures to produce conductive carbon nanofibres. Following carbonisation, these fibres are washed in deionised water to remove salts and impurities. Electrospun PAN fibres were also prepared and carbonised to compare mechanical and electrochemical properties.

To improve the sustainability of the precursor system, rheology testing was carried out on the electrospinning solutions to investigate the possibility of reducing or eliminating non-renewable plasticising additives. Measurements are carried out over a range of shear rates to better understand the conditions required for successful electrospinning of lignin-rich biopolymer systems.

Several manufacturing strategies were also investigated, such as compressed fibres or aligned fibres to improve mechanical strength. Co-axial fibres have also been investigated for the potential of adding nanomaterial reinforcement (e.g. CNTs or CNCs). Mechanical testing, SEM/TEM and electrochemical characterisation were then used to compare the different fibre structures and manufacturing approaches. Additionally, a modular electrospinner has also been developed, upgrading our current lab set-up to allow for more precise control over electrospinning conditions.

Results Rheology measurements showed that solutions exhibiting more stable behaviour at higher shear rates generally demonstrated improved electrospinnability. Solutions with more consistent viscosity profiles were easier to process into continuous fibres with fewer defects, suggesting that rheological stability plays an important role in fibre formation for lignin-based systems. Although the exact mechanism is not yet fully understood, it is believed that improved chain entanglement and flow stability may contribute to enhanced jet formation during electrospinning.

Coaxial electrospinning was successfully demonstrated as a proof-of-concept approach for producing hollow CNFs. Fibres were manufactured using a sacrificial PEO core, which was later removed during processing. TEM images confirmed the formation of hollow fibre structures.

Electrochemical testing through galvanostatic cycling indicated that fibres with different properties exhibited variations in lithium plating behaviour. This suggests that fibre morphology and structural reinforcement methods may influence electrochemical performance alongside mechanical strength. The results demonstrate the importance of balancing mechanical robustness with electrochemical functionality when developing lignin-derived structural battery materials.

Conclusions Rheological testing proved to be a valuable method for understanding and predicting the electrospinnability of lignin-based precursor solutions. Additionally, the mechanical properties of lignin-derived fibre mats can be significantly influenced by manufacturing approach and fibre architecture. Electrochemical testing indicated that variations in fibre structure and mechanical reinforcement methods can influence lithium plating behaviour during galvanostatic cycling. This highlights the strong relationship between structural design and electrochemical performance in multifunctional battery materials.

The results suggest that lignin-based CNFs are promising candidates for sustainable structural energy storage systems, provided that mechanical limitations can be addressed. Future work will focus on further

optimising fibre architecture, improving mechanical durability and investigating the relationship between microstructure and electrochemical behaviour in full-cell systems.

Key words Lignin-derived carbon nanofibres (CNFs) - Structural batteries - Lithium–sulfur batteries (Li–S) - Sustainable energy storage - Fibre architecture

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134 - PROTEIN-BASED FIBERS FUNCTIONALIZED WITH HYDROPHOBIC DYES BY THE COMBINATION OF MECHANOCHEMISTRY AND ELECTROSPINNING

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Background/Rationale A key advantage of electrospun fibers is their straightforward functionalization, which enhances their utility across numerous applications. This can be achieved both on the fiber's surface (coating, plasma treatment, chemical functionalization) and by adding various additives (nanoparticles, biomolecules, quantum dots, or pharmaceuticals) directly to the polymer or biopolymer solution, which is then used in the fiber fabrication process [1,2]. The wide range of available functionalization methods allows for the selection of the most suitable procedure for the specific material and application. However, in most cases, the choice of additives for the matrix must be compatible in terms of solubility or miscibility. As a result, the range of molecules that can be practically employed is often limited [3]. Our current research focuses on developing luminescent fibers derived from hydrophilic proteins for applications across the broad field of photonics, including lighting systems and optical sensors. The number of commercially available organic dyes with high emission efficiency has been quite limited, restricted primarily to a few hydrophilic dyes that can be applied.

Materials and Methods In the first step, mechanochemical milling of the protein (lysozyme) with a luminescent dye (such as perylene, coumarin C6, or DCM) was performed using a vibrational ball mill. Subsequently, electrospun fibers were fabricated using a horizontal setup (Spinbox by Bioinicia Fluidnatek apparatus) based on protein–dye complexes with the addition of PEO in an aqueous solution. The ratio of protein–dye complexes to PEO was 85:15. The optical properties of the obtained materials were studied using fluorescence confocal microscopy with fluorescence lifetime imaging (TCS SP8 or Stellaris 8, Leica), a UV–Vis absorption spectrometer (Jasco V-670), and a Horiba FluoroMax-4 spectrofluorometer. Morphological studies were performed using s-SNOM nano-FTIR (Neaspec, Attocube), a scanning electron microscope (JSM-6610LVnx, JEOL), a transmission electron microscope (Hitachi H-800), and a Nikon ECLIPSE Ti2-E inverted microscope enabling bright-field, crossed-polarizer, and fluorescence imaging.

Results We developed a novel approach that integrates mechanochemistry with electrospinning, enabling the incorporation of a broad range of hydrophobic organic dyes, largely independent of their molecular structures. Mechanical grinding of proteins with the dye leads to the formation of a water-soluble complex [4], which can subsequently be used as a precursor for electrospinning solutions. Here, we present electrospun lysozyme-based nanofibers functionalized with commercially available dyes, including perylene, Coumarin 6, and DCM. The milled proteins with dyes constitute 85% of the fibers' dry mass, while the remaining 15% comprises polyethylene oxide (PEO). The high proportion of proteins relative to synthetic polymers enhances biocompatibility and aligns with the principles of the circular economy. Moreover, to gain more insight into the nanoscale structure, s-SNOM and nano-FTIR spectroscopy were applied, enabling the analysis of the spatial distribution of the dye within the structure.

Conclusions By combining mechanochemistry with electrospinning, bio-based luminescent materials have been fabricated in accordance with the principles of green chemistry, shifting away from organic solvents toward aqueous solutions. Moreover, both techniques are scalable and cost-effective, thereby enhancing their potential as innovative routes for producing functionalized biopolymer fabrics.

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Key words mechanochemistry, luminescent materials, proteins, biopolymer,

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138 - ENCAPSULATION OF ORGANIC BASIL (*OCIMUM BASILICUM*) ESSENTIAL OILS FOR AGRI-FOOD APPLICATIONS

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Background/Rationale Essential oils (EOs) are a class of substances (typically VOCs) found in aromatic plants that have also been widely studied as biocontrol agents, since some bioactive compounds present in these EOs have shown antioxidant and antimicrobial properties. However, EOs are often unstable and readily evaporate into the air, so they can be easily lost during shelf life and administration. Hence, to preserve the stability and effectiveness of EO treatments, they need to be encapsulated. Several different encapsulation strategies have been developed on purpose to date. Electrospun nanofibres have also been employed to encapsulate EOs. In this study, basil (*Ocimum basilicum*) EOs have been encapsulated within electrospun/electrosprayed architectures to protect and stabilise such bioactive compounds for use in the agri-food sector.

Materials and Methods In this study, the essential basil oil was extracted using a steam distiller. The system consisted of an electrically heated boiler, a stainless-steel still for loading plant material, a water-cooled condenser, and a decanter for phase separation. For each extraction, dry basil biomass was mixed with distilled water. Then, the EO fraction was collected, dried over anhydrous sodium sulfate, and stored at 4°C until analysis.

Regarding encapsulation, two strategies were used: one employing electrospinning alone, and the other combining electrospinning and electrospraying. In the first case (MA), core-shell electrospinning was utilised, where the core contained basil EO dissolved in PCL, while the shell was composed of alkali lignin (AL) dissolved in PLA. In the second case (MB), AL was dissolved in a PVP-PCL blend to generate electrospun nanofibres, while the halved basil EO content, relative to MA, was dissolved in a PCL-AL mixture and electrosprayed to generate spherical particles. Alternatively, a 1.5x EO content, relative to MB, was used in a similar electrodeposited architecture (MC). In the last two fabrics, electrospinning and electrospraying were carried out contemporarily. The EO release capacity of the different frameworks was measured by soaking the various matrices in PBS (pH 7.4) for 10 days at 25 °C. The EO content of sacrificial solutions collected at fixed times over a set period was measured by spectrophotometer, GC-MS, and HPLC-MS. The morphologies of the nanostructured scaffolds were analysed by optical microscopy, stereomicroscopy, scanning electron microscopy, and atomic force microscopy.

Results The GC analysis of basil EO showed that methyl chavicol/estragole was the predominant component, accounting for approximately 66% of the oil, followed by methyl eugenol at approximately 12%. Aromadendrene represented the main minor component, while eucalyptol, linalool and the remaining detected volatiles were present at lower relative abundances. UV-Vis monitoring of the sacrificial solutions collected during immersion in phosphate buffer at pH 7.4 revealed that all matrices exhibited a pronounced initial release, indicating a substantial burst contribution during the first 24 h. However, the release profiles differed markedly depending on the encapsulation architecture. The electrospun/electrosprayed systems, MB and MC, in which basil EO was incorporated into electrosprayed PCL/lignin droplets, showed rapid release followed by a sharp decrease after 48-72 h, suggesting rapid depletion of readily accessible EO domains. Conversely, the core-shell system (MA), containing basil EO in the PCL core and alkali lignin in the PLA shell, displayed the lowest normalised initial burst and a more persistent residual release during the late stages of immersion. This behaviour suggests that the core-shell architecture provided a more effective diffusion barrier and improved temporal modulation of EO delivery. Notably, although MC contained a higher EO loading than MB, corresponding to a 1.5-fold increase, the release response was not proportionally enhanced, indicating that the accessible EO fraction was controlled not only by the initial loading but also by droplet morphology, EO-polymer partitioning and lignin-mediated retention. Such an interplay is supported by the distinct morphological architectures of the various matrices.

Conclusions Overall, the results indicate that the release of basil EO was strongly governed by matrix architecture rather than by EO loading alone, with electrospun/electrosprayed systems showing a dominant burst release and rapid depletion of readily accessible EO domains. Conversely, the core-shell design reduced the initial burst and promoted a more sustained late-stage release, highlighting its greater suitability for temporally modulated EO delivery.

Key words Basil essential oils; encapsulation; release profile; agri-food applications.

142 - ELECTROSPINNING THE VALUE OUT OF BIOWASTE: MULTIFUNCTIONAL MATERIALS FOR METAL RECOVERY AND SUSTAINABLE FOOD PACKAGING

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Background/Rationale The transition toward a circular bioeconomy demands innovative strategies to valorize biowaste into high-value functional materials, decoupling economic growth from resource depletion. Conventional fossil-based plastic packaging is non-degradable and contributes to pollution and food waste, while industrial heavy metals and electronic waste (WEEE) threaten ecosystems and human health but also represent valuable sources of recoverable metals. Electrospinning offers a scalable, green method to transform biowaste-derived compounds into porous nanofibers with high surface area and multifunctional properties.

This study is organized around three strategic pillars: sustainable active food packaging [1–3], precious metal recovery, and heavy metal remediation [4]. It investigates the integration of four biowaste-derived agents, humic substances (HS) from compost, lignin nanoparticles (LNPs) from Kraft lignin (KL), microbial proteins (MPs) from cheese whey, and microbially induced calcite precipitates (CCPs), into biopolymer matrices to develop multifunctional electrospun materials. Indeed, the chemical richness of these biowastes, characterized by phenolic, carboxylic, amino, and hydroxyl functional groups, enables antioxidant, antimicrobial activity, as well as high-capacity metal binding.

Materials and Methods HS extracted from compost and LNPs synthesized from KL via a hybrid anti-solvent/ultrasonication route were incorporated into poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) electrospun fibers and subsequently converted into continuous biopapers through thermal annealing.

For precious metal recovery, KL was blended with cellulose acetate (CA) or polyvinylpyrrolidone (PVP) and electrospun into fibrous adsorbents for Au(III) and Pd(II) capture from simulated WEEE leachates.

Microbial proteins (MPs) recovered from cheese whey were incorporated into CA electrospun fibers, while microbially induced calcium carbonate precipitates (CCPs) were embedded in PVP/hydroxypropyl cellulose (HPC) electrospun mats. Both MP- and CCP-based materials were investigated as sustainable adsorbents for the selective recovery of Pb(II) from aqueous solutions. The resulting materials were characterized by SEM-EDS, TGA, FTIR, XRD, and DLS analyses. Functional properties were evaluated through antioxidant (DPPH), antimicrobial (disk diffusion and ISO 22196), and antifungal assays against relevant bacterial and fungal strains. Adsorption performance toward target metal ions was quantified by UV-Vis spectroscopy, ICP-MS, and MP-AES, and interpreted using kinetic/equilibrium isotherm models.

Results PHBV/HS and PHBV/LNPs biopapers exhibited outstanding antioxidant activity (up to 97% DPPH radical inhibition), broad-spectrum antimicrobial effects against Gram-positive (*S. aureus*, *B. cereus*, *E. faecalis*) and Gram-negative (*E. coli*, *S. typhi*) bacteria, antifungal activity, and excellent UV-blocking capacity across 200–800 nm. Application tests demonstrated that PHBV/HS biopapers extended cherry shelf-life to 14 days at room temperature. Incorporation of LNPs at 3 wt% reduced oxygen permeability up to 10-fold compared to neat PHBV and maintained mechanical properties.

For precious metal recovery from WEEE leachates, CA/KL electrospun fibers exhibited outstanding performance, achieving >90% Au(III) removal at pH 3 and efficient Pd(II) uptake. The lignin-based fibers also promoted the in-situ reduction of adsorbed metal ions to metallic nanoparticles (Au^0 and Pd^0), enabling simultaneous metal capture and recovery.

For heavy metal remediation, CA/MP nanofibers showed a Pb(II) adsorption capacity of 66 mg g⁻¹ and marked selectivity over Zn(II) (14 mg g⁻¹) in binary systems. Adsorption followed the Langmuir isotherm and pseudo-second-order kinetic models, while the materials retained approximately 75% of their initial adsorption capacity after four adsorption–desorption cycles using 0.1 M EDTA. PVP/HPC/CCP membranes achieved near-complete Pb(II) removal (>90%) at environmentally relevant concentrations (0.5–10 ppm) and a maximum adsorption capacity of 220 mg g⁻¹. Their performance was driven by a dissolution–precipitation mechanism leading to the formation of cerussite (PbCO_3) crystals on the fiber surface, as confirmed by XRD and SEM-EDS analyses after adsorption.

Conclusions This work shows that electrospun materials derived from biowaste can be widely applied in active food packaging, heavy metal removal, and recovery of valuable metals. By combining green chemistry, microbial biotechnology, and nanofiber engineering, it supports food preservation, water purification, and circular bioeconomy by turning waste into high-value functional products.

Key words Electrospinning; Biowaste valorization; Active food packaging; Heavy metal remediation; Precious metal recovery

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146 - FROM BIOWASTE TO BIOMIMETIC FUNCTION: ELECTROSPUN NANOSTRUCTURED CONSTRUCTS FOR SUSTAINABLE AGRICULTURE

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Background/Rationale A radical transition is needed in conventional agricultural practices, which are increasingly unsustainable because of the intensive use of pesticides and fertilizers required to maintain high and resilient yields. In this context, nanoagrochemicals are emerging as more eco-friendly alternatives to conventional formulations, with improved efficiency enabled by sustained nutrient release. However, concerns related to long-term environmental accumulation can be mitigated by exploiting bio-based and renewable materials.

Biowaste (BW) represents an abundant, low-cost source of chemical and biological functionality. Among BW-derived components, lignin offers considerable potential as a biostimulant and soil amendment because of its metal-ion chelation capacity and intrinsic redox behaviour, which results into antioxidant and antimicrobial activity. Moreover, combining BW-derived molecules with inorganic nanostructured phases can reduce issues related to compositional heterogeneity, enhance stability, and boost intrinsic bioactive features [1,2]. Hydroxyapatite (HA) is particularly suitable for forming hybrids with lignin (L), as it is a biocompatible source of phosphorus, an essential macronutrient, and has a flexible crystal structure able to host different moieties. Encapsulating hybrid nanostructures into electrospun fibres further enables the fabrication of two- and three-dimensional constructs that mimic soil architecture. This study presents a sustainable multifunctional platform for agricultural applications. Specifically, hybrid BW-apatite nanostructures (HA-L) were synthesised and embedded in electrospun polylactic acid (PLA) fibres to enable their availability and controlled release due to the polymer degradation.

Materials and Methods HA-L nanostructures were synthesised through a wet-chemistry approach. An aqueous solution containing an appropriate amount of sodium lignosulfonate (SSL) and CaCl_2 was added dropwise to an aqueous K_2HPO_4 solution to obtain the Ca/P molar ratio of 1.67 typical of HA. The pH was maintained at 10.5 using NaOH. After 3 h of stirring, the system was subjected to solvothermal treatment at 100 °C for 4 h. The resulting precipitates were separated by centrifugation and washed three times with double-distilled H_2O . Two samples were prepared using different SSL concentrations.

PLA fibres were produced by electrospinning using either conventional or coaxial configurations. Nanocomposite mats were obtained by incorporating HA-L into the fibres. An alternative nanofiller-loading strategy was also investigated: an HA-L water/ethanol dispersion was deposited onto the mats by electrospraying using the same set-up employed for fibre deposition. Antioxidant activity was evaluated using DPPH and Folin assays.

Results X-ray diffraction (XRD) profiles confirmed the formation of the characteristic HA structure even in the presence of SSL. Dynamic light scattering (DLS) showed that SSL significantly contributed to nanoparticle stabilization: the hybrid nanostructures exhibited an average diameter of approximately 80 nm, markedly lower than that of neat HA nanoparticles.

Hybrid HA-L nanoparticles showed relevant antioxidant and antimicrobial activity, which increased sharply with increasing SSL content. In particular, biocidal tests against fungi and typical pests of hazelnut plants highlighted the strong efficacy of the synthesised samples. The hybrids were also effective against human pathogenic Gram(+) and Gram(-) bacteria, including *staphylococcus aureus* and *pseudomonas aeruginosa*, and showing activity comparable to, and in some cases higher than, that of conventional antibiotics.

Both neat and composite mats consisted of submicrometric fibres arranged in a web-like structure with interconnected porosity. This morphology is suitable for mimicking soil structure while providing a high surface area for agrochemical release. Incorporation of the hybrid nanoparticles conferred significant antioxidant and antimicrobial activity and improved water-sorption behaviour. The best-performing systems were those produced by combining electrospinning and electrospraying, owing to the greater availability of the HA-L active components. The samples were also fully biocompatible, exhibiting no toxicity toward plant-beneficial strains.

Conclusions The obtained nanostructured materials exhibit marked antioxidant activity, significant water-sorption capacity, and broad biocidal action against phytopathogenic bacteria and fungi. At the same time, they promote the proliferation of microorganisms beneficial to the soil microbiome. By adopting a holistic sustainability approach, this study demonstrates organo-mineral systems with multifunctional activity and enhanced efficacy for sustainable agriculture.

Key words Lignin; apatite; electrospinning; hybrid nanomaterials; waste-to-wealth; nanoagrochemicals

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150 - ORGANOSOLV LIGNIN-BASED NANOFIBRES WITH MINIMIZED BINDER POLYMER CONTENT

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Background/Rationale We investigate the electrospinning of organosolv lignin (OL), a low-cost natural polymer with superior quality due to its sulphur-free content (Huang et al, 2019; Collins et al, 2019), as an alternative to petroleum-based polymers such as polyacrylonitrile (PAN). Despite growing interest in electrospun OL (Ruiz-Rosas et al., 2010; Poursorkhabi et al., 2016; Ding et al., 2016) further studies are needed to identify dope compositions for a wider range of lignin sources with minimized binder polymer content, as well as to understand the dependence of the size and internal fibre structure of the fibres on the solution composition. In this work we have mapped the electrospinning conditions using OL's using a sustainable solvent (water with a small amount of NaOH) while seeking robust electrospinnability with minimised content of poly(ethylene oxide) (PEO) as binder polymer. The study includes softwood and hardwood OL's, as well as PEO's of different molecular weights.

Materials and Methods Fibers were produced in a purpose-made electrospinning setup using both stationary and rotating collectors, and the stability of the process was mapped in the lignin-binder-solvent ternary phase diagram for about 30 compositions. The Taylor cone and jet motions were imaged using a high-speed camera to understand the fluid dynamic behaviour of the electrospinning. The rheology of the solutions was characterized, and the electrospun fibres were imaged by FESEM for sizing and morphology, and their cross-sections obtained by FIB-FESEM.

Results Robust electrospinning could be maintained indefinitely within a well-defined region in the composition ternary diagram, for lignin weight-fraction below about 15%, and PEO (600 kDa) weight-fraction that could be decreased with increasing lignin content, to a value as low as 4% in the final fibre. These low PEO concentrations are well below the theoretical entanglement number for PEO only. However, the steep dependence of the specific viscosity with the total polymer content shows that the small lignin molecules created connections between the PEO chains, producing a long-range network. Submicron fibre diameters with narrow dispersion were obtained, being systematically smaller for HOL than SOL, possibly due to the smaller MW of the HOL. In addition, internal voids and hollow structures were observed at nearly all compositions. Some fiber surfaces revealed nanostructures with various morphologies identified as Na₂CO₃ by EDX and XRD.

Conclusions The stability parameters were investigated to study the jet rotational motion and determine the minimum amount of binder polymer required to produce nanofibers. It was possible to reduce the concentration of PEO in the fibres below the minimum theoretically required to achieve PEO chain entanglements. This was possible to strong interactions between the short lignin molecules and the PEO long chains, thereby producing a sufficiently entangled network with high lignin content. From the circular cross sections, we conclude that the voids formed as the last solvent evaporated after extensive jet thinning and rigid skin formation.

Key words lignin, organosolv, PEO, entanglements, rheology

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168 - METAL-ORGANIC FRAMEWORK DERIVED HIERARCHICAL CO DECORATED CARBON NANOFIBER INTERLAYER FOR HIGH-PERFORMANCE LITHIUM–SULFUR BATTERIES

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Background/Rationale Lithium–sulfur (Li–S) batteries are considered one of the most promising next-generation battery systems due to their high theoretical energy density and the cost-effectiveness of sulfur. However, their practical application is still hindered by the shuttle effect of soluble lithium polysulfides and sluggish sulfur redox kinetics, which cause poor cycling stability.[1] To address these issues, effective polysulfide confinement and catalytic conversion are essential for achieving high-performance Li–S cells.[2]

Materials and Methods In this work, Electrospun polyacrylonitrile (PAN) nanofibers were used as a fibrous scaffold for the sequential growth of Zn-based ZIF-L and Co-based ZIF-67. ZIF-L nanosheets were first grown on the PAN nanofiber surface, followed by the secondary growth of ZIF-67 to form a hierarchical structure. The obtained composite was then carbonized under a nitrogen atmosphere to produce the metal-organic frameworks (MOF)-derived carbon nanofiber interlayer. The carbonized product obtained from the sequentially grown ZIF-L/ZIF-67 on PAN nanofibers was denoted as Co-NC@CNF.

Results Scanning electron microscope (SEM), transmission electron microscope (TEM), and X-ray photoelectron spectroscopy (XPS) analyses confirmed the formation of a hierarchical carbon nanofiber interlayer after carbonization, demonstrating the successful conversion of the MOF precursors into chemically active and catalytic components. The polyacrylonitrile (PAN) nanofibers were converted into a conductive carbon backbone, while the sequentially grown ZIF-L and ZIF-67 components were transformed into N-doped porous carbon and Co-containing catalytic sites, respectively. Compared with pristine carbon nanofibers, the Co-NC@CNF interlayer exhibited stronger affinity toward lithium polysulfides, as confirmed by polysulfide adsorption tests. This enhanced interaction can be attributed to the polar N-doped carbon matrix and Co-based catalytic sites, which jointly promote polysulfide immobilization and redox conversion.[3] Cyclic voltammetry revealed sharper and more distinct redox peaks with reduced polarization, indicating accelerated conversion between soluble polysulfides and insoluble Li₂S/Li₂S₂. In addition, electrochemical impedance spectroscopy showed a lower charge-transfer resistance, suggesting improved interfacial reaction kinetics. Owing to these combined effects, Li–S cells employing the Co-NC@CNF interlayer delivered a capacity of approximately 700 mAh g⁻¹ at 2 C and retained 88.2% of their capacity after 200 cycles.

Conclusions This work highlights the effectiveness of MOF-derived fibrous interlayers for improving Li–S battery performance. By integrating conductive carbon nanofibers, N-doped carbon, and Co-based catalytic sites, the hierarchical interlayer suppresses polysulfide shuttling, promotes sulfur redox kinetics, and enhances cycling stability. These results suggest that sequential MOF engineering on electrospun nanofibers offers a versatile platform for developing high-performance Li–S batteries.

Key words Li-S battery, Shuttle effect, Electrospinning, Carbon nanofiber, Metal-organic framework

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174 - GREEN SOLVENT ASSISTED FRACTIONATION AND ELECTROSPINNING OF KRAFT LIGNIN AND COAXIAL FIBER DESIGN TOWARDS FLEXIBLE GAS DIFFUSION ELECTRODES FOR ZINC-AIR BATTERIES

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Background/Rationale This work investigates Kraft lignin (KL) as a renewable precursor for electrospun fibers intended as a future platform for Zn-air battery (ZAB) development. The main goal and challenge is not only to obtain electrospinnable lignin, but to establish a stable, scalable process. KL in particular is attractive as a bio-based feedstock material because it is an abundant waste material with highly aromatic structure making it suitable for carbon fiber (CF) production. However, its direct electrospinning is restrained by residual Kraft-process impurities, limited solubility and poor flexibility of resulting fibers. These limitations are crucial for producing self-standing carbon supports serving as electrocatalytically active gas diffusion electrodes (GDE) in oxygen reduction reaction (ORR) and oxygen evolution reaction (OER) for next generation of rechargeable ZABs. This study therefore aimed to improve KL processability and to develop a precursor compatible with subsequent carbonization and catalytic functionalization, while respecting the principles of green and sustainable chemistry.

Materials and Methods A novel single-solvent approach using propylene glycol methyl ether (PGME) was developed for both lignin fractionation and preparation of electrospinning dope solutions. Fractionation was performed by dispersing lignin in PGME (ratio 1:15 m/m), stirring vigorously for min. 6 h at room temperature, filtration, solvent evaporation (with recycling), and drying under high vacuum at 60°C for min. 12 h. Electrospinning of lignin solutions was carried out using Spinbox (Bioinicia), 22G needle for single-phase electrospinning or 0,9 mm OD capillary with 16G needle for coaxial electrospinning. Needle was connected to positive voltage supply and rotating drum covered with Al foil as collector to negative voltage supply. In typical experiment, collecting distance was set to 10 cm and applied voltage was +10 kV to needle and -2 kV to collector. Thermal stabilization and carbonization of fibers were done in tube furnace (Carbolite) in air and N₂ flow (1 dm³/min), respectively. Three-step stabilization (heating rate 0,2-0,5°C/min to 100°C, 150°C and 250°C with 1-3 h holds) was followed by single-step carbonization at 800-1000°C, 5°C/min.

Results The strategy relied on the assumption that insoluble inorganic components could be removed before spinning. A simple PGME extraction route yielded a fully soluble lignin fraction with a yield of 75%, substantially higher than reported for acetone- and ethanol-based fractionation. Concurrently, the ash content was reduced to 0.06%, and the conductivity of a 50 wt% PGME-fractionated KL solution dropped to 10 µS/cm, thereby enabling stable spinning conditions.

PGME-based dopes with concentrations below 40 wt% behaved more like electrospray systems due to insufficient molecular entanglement and viscosity. In contrast, concentrations of 40-50 wt% range enabled electrospinning but promoted needle clogging due to evaporation-induced solidification at the needle tip. This issue was resolved through coaxial electrospinning using a solvent sheath, stabilizing process and eliminating clogging. Uniform fibers with an average diameter of $1,4 \pm 0,2 \mu\text{m}$ were obtained, although brittle because of KL intrinsic properties. Brittleness was addressed by coaxial electrospinning with a polyvinyl butyral (PVB) sheath, producing flexible core-sheath fibers with an average diameter of $1,6 \pm 0,4 \mu\text{m}$. Carbonization trials confirmed that thermal stabilization is essential for preserving lignin-derived fibrous structures, preventing excessive softening/fusion before effective carbonization. The resulting CF formed bundles of 2-5 µm in diameter, while individual fibers had an average diameter of $1,18 \pm 0,24 \mu\text{m}$.

Conclusions This study demonstrates a complete route from KL purification to electrospun precursor fibers with improved processability. A novel PGME-based system was identified that supports both extraction and electrospinning while reducing conductivity and enhancing stability of KL electrospinning. The solvent is well aligned with the principles of green chemistry, serving as non-toxic and easily recyclable alternative. Developed coaxial electrospinning strategy overcame needle clogging, enabling production of fibers with improved elasticity and mechanical strength. Overall, the fibers produced in this work should be regarded as a precursor platform providing a foundation for future optimization of carbonization, catalyst selection and loading, and their eventual application as a self-supporting ORR/OER GDE in ZAB.

Key words lignin electrospinning; coaxial electrospinning; lignin fractionation; carbon fibers; Zn-air batteries;

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177 - ELECTROSPUN CELLULOSE-DERIVED CARBON NANOFIBER MATS AS FREE-STANDING ANODES FOR SODIUM-ION BATTERIES

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Background/Rationale Sodium-ion batteries (SIBs) have emerged as sustainable alternatives to lithium-ion batteries because of the abundance and low cost of sodium resources [1]. However, the larger ionic radius of Na⁺ results in sluggish ion diffusion and significant volume changes during cycling, necessitating the development of advanced electrode materials [2]. Electrospun carbon nanofibers have attracted considerable interest owing to their high electrical conductivity, interconnected porous structure, and mechanical flexibility [3]. Moreover, their free-standing architecture eliminates the need for polymer binders and metallic current collectors, improving ion transport and reducing inactive material within the electrode [4]. In this work, electrospun cellulose-derived nanofibers were carbonized to fabricate conductive carbon nanofiber mats for sodium-ion battery anodes. The structural evolution and carbonization behavior were investigated using scanning electron microscopy (SEM) and Raman spectroscopy.

Materials and Methods Cellulose medium fibers were blended with poly(vinyl alcohol) (PVA) to prepare a homogeneous electrospinning solution. Continuous nonwoven nanofiber mats were fabricated by electrospinning and subsequently carbonized under a nitrogen atmosphere at 900 °C for 2 h to obtain conductive carbon nanofiber mats. The morphology and carbon structure of the resulting fibers were characterized by scanning electron microscopy (SEM) and Raman spectroscopy. The electrochemical performance was evaluated using CR2032 coin cells assembled in an argon-filled glove box. Circular carbon nanofiber electrodes (14 mm diameter) were directly used as free-standing working electrodes without polymer binders or conductive additives. Sodium metal served as the counter electrode, glass fiber was used as the separator, and the electrolyte consisted of 1 M NaPF₆ dissolved in ethylene carbonate (EC)/dimethyl carbonate (DMC) (1:1, v/v). The active material loading was approximately 1.0 mg cm⁻², with an electrode thickness of approximately 0.15 mm.

Results Electrospinning followed by carbonization produced flexible, free-standing carbon nanofiber mats with a well-preserved interconnected fiber structure. The electrochemical measurements demonstrated that the carbon nanofiber electrodes exhibited low internal resistance, indicating efficient electron transport and good electrode/electrolyte contact. Compared with the reference electrode, the carbon nanofiber anode delivered an excellent specific capacity while maintaining excellent structural integrity during cycling. After only a few formation cycles, the Coulombic efficiency rapidly increased to approximately 99%, demonstrating highly reversible sodium-ion storage and stable electrochemical performance.

Conclusions Electrospun cellulose-derived carbon nanofiber mats exhibited good flexibility, low resistance, and enhanced sodium storage performance. Their free-standing architecture and high Coulombic efficiency demonstrate strong potential as sustainable anode materials for next-generation sodium-ion batteries.

Key words Electrospinning; Cellulose nanofibers; Carbon nanofibers; Sodium-ion batteries; Binder-free electrodes; Sustainable energy storage.

5 05.FUNCTIONAL NANOFIBERS FOR SENSING, FILTRATION & SMART TEXTILES

18 - ELECTROSPUN ELECTRICALLY AND THERMALLY CONDUCTIVE FIBERS FOR ENERGY HARVESTING AND STORAGE

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Background/Rationale The rapid evolution of wearable electronics and autonomous systems has intensified the demand for multifunctional textile platforms capable of integrating electrical conductivity, thermal management, and energy harvesting without compromising flexibility, breathability, and mechanical durability. Electrospinning has emerged as a highly versatile and scalable technique for fabricating fibrous materials with tunable morphology, high surface area, and controlled internal structure. However, pristine polymer fibers typically lack the electrical and thermal properties required for advanced applications.[1] This work presents recent advances in engineering electrospun polymer fibers through the incorporation of conductive nanomaterials and functional fillers, enabling synergistic enhancement of electrical and thermal performance for energy harvesting and storage applications.

Materials and Methods A key strategy involves integrating conductive nanomaterials such as carbon nanotubes (CNTs), reduced graphene oxide (rGO), exfoliated graphite (EG), and MXene ($\text{Ti}_3\text{C}_2\text{T}_x$) into or onto electrospun fibers. A two-step fabrication approach using electrophoretic deposition (EPD) of CNTs onto electrospun polyvinylidene fluoride (PVDF) fibers yields highly conductive, porous, and stretchable mats with a resistance of $80 \pm 6 \, \Omega$ and elongation up to $\sim 600\%$. Importantly, this process preserves fiber morphology and water vapor permeability, enabling multifunctional sensing capabilities such as pressure, motion, respiration, and temperature detection while maintaining user comfort.[2] These results demonstrate an effective route to introduce conductivity without compromising the intrinsic advantages of fibrous textiles. To further enhance energy harvesting performance, rGO incorporation into PVDF fibers is shown to significantly increase the electroactive β -phase content (up to 81%) and crystallinity, resulting in improved piezoelectric and triboelectric responses.[3] The optimized composites achieve high power densities and stable performance under coupled mechanical and thermal stimuli, highlighting their potential in self-powered electronic systems. Processing parameters, including solvent selection and filler concentration, play a critical role in tailoring the microstructure and functional output of these nanocomposites.[4]

Results Thermal management is another critical aspect addressed through the incorporation of thermally conductive fillers. The addition of exfoliated graphite into electrospun polystyrene (PS) fibers enhances both mechanical properties and heat transport. These composites exhibit significantly improved thermal response under infrared irradiation, with temperature increases far exceeding those of pristine polymers, demonstrating their capability for efficient heat dissipation and energy recovery.[5] In parallel, phase-change electrospun systems based on PS–polyethylene glycol (PEG) demonstrate the ability to store and release thermal energy, combining high latent heat capacity with excellent breathability and structural stability. Such materials enable effective thermal buffering and insulation, contributing to energy-efficient wearable systems.[6] Developing multifunctional materials that combine efficient heat conduction, energy harvesting, sensing capability, and flexibility is crucial for next-generation portable and wearable electronics. In this context, MXene ($\text{Ti}_3\text{C}_2\text{T}_x$)-integrated electrospun fibers represent a significant advancement. Polyacrylonitrile (PAN)–MXene nanofibers and yarns fabricated via scalable electrospinning exhibit markedly enhanced thermal conductivity at both single-fiber and macroscopic levels. Infrared thermography reveals an increase in surface temperature of approximately $22 \, ^\circ\text{C}$ compared to pristine systems, while rapid photothermal response enables temperatures up to $60 \, ^\circ\text{C}$ under infrared irradiation. Additionally, MXene incorporation modifies the surface potential of fibers, enhancing their triboelectric characteristics and enabling higher energy output. These composite yarns also demonstrate reliable tactile sensing with high sensitivity, highlighting their multifunctionality.[7]

Conclusions Over the past decade, improving polymer thermal conductivity has become essential for thermal management. Electrospinning enables chain alignment and controlled filler dispersion, enhancing performance. Despite progress, challenges in scalability and stability remain, while multifunctional systems show promise for self-powered wearable technologies.

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Key words hybrid fibers, conductivity,

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19 - NANOFIBERS IN NEXT-GENERATION CHEMICAL SENSING: PERSPECTIVES AND OPPORTUNITIES

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Background/Rationale This plenary lecture presents a perspective on nanofiber-based architectures as a new platform for next-generation chemical sensing and their pathway toward industrial deployment.

Materials and Methods The talk begins with recent advances in electrospinning technologies, highlighting the controlled fabrication of aligned nanofiber membranes and nanofiber yarns. These advanced one-dimensional architectures provide a scalable foundation for mechanically robust, flexible, and high-surface-area sensing platforms. Building on this structural foundation, three representative sensing strategies will be discussed. First, chemi-resistive gas sensors based on semiconducting metal oxide nanofibers (e.g., SnO₂ and WO₃) will be introduced, with a focus on catalyst functionalization strategies that suppress aggregation and enable uniform dispersion on nanofiber surfaces. Such controlled catalyst integration, combined with strong interfacial coupling in 1D frameworks, significantly enhances gas response and selectivity by promoting targeted surface reactions and efficient charge modulation. Second, a room-temperature photoactivated gas sensing platform will be presented, utilizing visible light sources, including blue and green light-emitting diodes (LEDs).

Results This approach enables low-power operation while maintaining high sensing performance, addressing key limitations of conventional high-temperature gas sensors. Third, the concept is extended to polymer-based colorimetric nanofiber sensors capable of ultrahigh-sensitivity detection of toxic and hazardous gases, including those relevant to semiconductor manufacturing environments. These systems demonstrate the versatility of nanofiber platforms across different sensing mechanisms.

Conclusions Finally, the lecture will offer a forward-looking perspective on integrating nanofiber-based sensing systems with artificial intelligence-driven materials design and automated sensing platforms. This convergence is expected to accelerate the development, optimization, and large-scale deployment of next-generation gas sensing technologies.

24 - ENGINEERING FUNCTIONAL ELECTROSPUN FIBERS FOR A CLEANER ENVIRONMENT

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Background/Rationale Electrospinning is one of the most powerful and versatile fabrication methods used in the production of micro- and nanofibers [1]. This technique enables precise control over fiber morphology, composition and architecture, making it particularly suitable for the development of advanced functional materials. Electrospun fibrous materials are highly attractive across a wide range of applications due to their unique characteristics, including extremely high surface-to-volume ratios, interconnected porosity, tunable mechanical properties and the ability to incorporate multiple functionalities.

Materials and Methods -

Results This presentation provides a general overview of our group's research activities focused on the fabrication of functional electrospun fibrous materials, with particular emphasis on systems specifically engineered for environmental applications, including water remediation [2-5], gas sensing [6], recovery of precious metals from electric and electronic wastes [7], thermal energy storage [8] and sound absorption [9,10].

Key words Electrospinning, environmental applications, fibrous nanocomposites.

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25 - ADAPTIVE NANOFIBERS: ENGINEERING COMFORT THROUGH EMISSIVITY CONTROL

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Background/Rationale Smart textiles that naturally help regulate body temperature offer an eco-friendly way to reduce dependence on energy-intensive heating and cooling systems. One promising approach is to control how much heat a fabric radiates by changing its surface properties, allowing it to switch between heat-retentive (keeping warmth in) and heat-dissipative states (letting heat escape). While some technologies can already achieve this, they often need external power or lose shape when stretched, making them impractical for clothing.

Results We here present a new type of textile being a fully passive and autonomously adaptive dynamic emissivity switch textile (DEST). The textile is based on a thermo- and humidity-responsive electrospun poly(N-isopropyl acrylamide) (PNIPAM) copolymer. To ensure reliable performance in aqueous environments, an allyl-functionalized PNIPAM copolymer was synthesized via post-polymerization amidation of P(NIPAM-co-methyl acrylate) and processed using an eco-friendly water–ethanol electrospinning method. Subsequent photo-initiated thiol–ene crosslinking yielded water-stable, thermoresponsive nanofibers with a transition temperature close to that of human skin. To enable controlled and reversible macropore actuation, a dimensionally stable metamaterial architecture is utilized, designed to prevent out-of-plane distortion. This stability is achieved through a honeycomb-patterned electrospinning collector combined with a precisely engineered mechanical cutting design. A silver coating adds infrared reflectivity, allowing the material to retain radiative heat when the macropores are closed.

Conclusions The result is a textile that can switch between heat-retaining and heat-releasing states without any external energy, offering a comfort range of about 6 °C. This dual responsiveness makes it ideal for clothing that adapts naturally to changing conditions, improving comfort while reducing energy use.

Reference:

Key words PNIPAM Nanofibers, Metamaterial Design, Thermoregulation, Emissivity, Shape-memory Polymer

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27 - HIERARCHICALLY COATED PVDF-CNT FIBER MATS FOR INTEGRATED SENSING AND HUMAN-MACHINE INTERACTION

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Background/Rationale Wearable electronic systems require materials that integrate conductivity with flexibility, durability, and air permeability. Electrospun polymer fibers are promising due to their porous architecture. However, their intrinsic electrical insulation limits their direct use in sensing applications. Surface functionalization using conductive nanomaterials offers a pathway to overcome this limitation while preserving key textile properties.

Materials and Methods In this study, electrospun PVDF fiber mats were modified with carbon nanotubes (CNTs) via electrophoretic deposition (EPD). The process enabled controlled and repeatable coating through multiple deposition cycles, forming conductive pathways on individual fibers. The materials were characterized using scanning electron microscopy, Raman spectroscopy, impedance analysis, and mechanical testing. Breathability was assessed via water vapor transmission rate measurements. Functional performance was evaluated through sensing experiments.

Results The EPD process resulted in uniform CNT coatings distributed along fiber surfaces, with minimal aggregation and preserved porosity. Electrical measurements showed a drastic decrease in resistance with increasing deposition cycles, reaching approximately 80 Ω , indicating the formation of effective percolation networks. Importantly, the mats retained high water vapor permeability ($\sim 1000 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$), confirming that conductivity was achieved without compromising breathability.

Mechanical analysis revealed simultaneous improvement in tensile strength and toughness, with strength doubling compared to pristine PVDF (from 2.2 ± 0.2 to 4.4 ± 0.1 MPa), and toughness increasing more than threefold (from 3.8 ± 0.5 to 12.0 ± 0.3 MJ/m³). The materials exhibited stable and repeatable responses under mechanical deformation.

The PVDF-CNT mats demonstrated multifunctional sensing capabilities, including pressure sensitivity, detection of joint motion, respiratory monitoring, and response to infrared radiation. A proof-of-concept textile keyboard further confirmed their applicability in interactive systems.

Conclusions The combination of electrospinning and electrophoretic deposition provides an effective strategy for creating conductive yet breathable fibrous materials. The resulting PVDF-CNT mats exhibit a unique balance of electrical, mechanical, and functional properties, making them strong candidates for next-generation wearable sensors and smart textiles.

Acknowledgments

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Key words electrospinning; PVDF; carbon nanotubes; wearable sensors; conductive textiles

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57 - ELECTROSPUN PIEZOELECTRIC FIBER YARNS AS A SCALABLE PLATFORM FOR AI-INTEGRATED SELF-POWERED SENSORS

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Background/Rationale Electrospun piezoelectric polymer fibers have emerged as a powerful platform for next-generation sensor technologies owing to their flexibility, high surface-area-to-volume ratio, lightweight nature, and ability to directly convert mechanical stimuli into electrical signals. Their conformability enables seamless integration into textiles and soft systems, making them promising for wearable healthcare, soft robotics, distributed sensing, and intelligent human-machine interfaces. However, translating electrospun fibers into reliable and scalable sensor systems still requires overcoming several challenges, including limited piezoelectric output, mechanical fragility under large deformation, unstable electrode integration, and the lack of systematic structural optimization strategies.

Materials and Methods In this presentation, I will present our integrated design framework for electrospun P(VDF-TrFE)-based piezoelectric fiber yarn systems. The proposed approach connects nanoscale materials engineering, yarn-level structural design, electrode integration, and intelligent signal processing. Intrinsic piezoelectric performance is enhanced through β -phase engineering, while mechanical robustness is improved using laminate-inspired yarn architectures optimized by multi-objective Bayesian learning. In addition, composition-gradient organic electrodes are introduced to enable stable and resilient electrical integration. Stretchable and durable sensor configurations are further realized through coil and knot architectures, and tailored machine learning algorithms are incorporated for intelligent interpretation of self-generated electrical signals.

Results The developed electrospun piezoelectric fiber yarn systems exhibit enhanced piezoelectric output, improved mechanical reliability, and stable self-powered sensing performance under large and repeated deformations. The laminate-inspired architectures provide reinforced mechanical durability without sacrificing sensing functionality, while the composition-gradient organic electrodes maintain robust electrical contact during deformation. Coil and knot configurations further expand the mechanical adaptability of the fiber sensors, enabling stretchable and durable operation in soft and textile-like environments. By integrating machine learning algorithms, these fiber-based platforms demonstrate high-accuracy human activity classification and multimodal mechanical monitoring.

Conclusions This work demonstrates that electrospun P(VDF-TrFE)-based piezoelectric fiber yarns can serve as a scalable platform for AI-integrated self-powered sensors. By combining β -phase engineering, structurally optimized yarn architectures, resilient electrode integration, deformable sensor configurations, and machine learning-based signal analysis, the proposed framework addresses key barriers in translating electrospun fibers into reliable sensor systems. The results suggest a promising pathway toward intelligent, mechanically robust, and scalable self-powered sensing platforms for wearable healthcare, soft robotics, distributed sensing, and human-machine interfaces.

Key words Electrospinning, Piezoelectric, Fibers, Self-powered Sensing

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58 - PHASE BEHAVIOUR AND DYNAMIC PROPERTIES OF LIQUID-CRYSTALLINE MIXTURES CONFINED WITHIN ELECTROSPUN POLY(METHYL METHACRYLATE) COMPOSITE FIBERS

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Background/Rationale The incorporation of liquid crystals (LCs) into electrospun polymer matrices offers a versatile route toward functional fibrous materials with tunable structural and dynamic properties [1,2]. In this study, binary liquid-crystalline mixtures were encapsulated within poly(methyl methacrylate) (PMMA) fibers to investigate how spatial confinement and interfacial interactions influence phase behaviour and molecular mobility.

Materials and Methods Composite fibers were fabricated by electrospinning solutions containing PMMA and a binary LC mixture composed of a mesogenic azo compound [3] and cholesteryl pelargonate. The phase behaviour was characterized using Differential Scanning Calorimetry and Polarized Optical Microscopy. Molecular dynamics and relaxation processes were studied using Broadband Dielectric Spectroscopy (BDS). Structural organization, chemical heterogeneity, and intermolecular interactions were further examined using Fourier Transform Infrared Spectroscopy (FTIR), including Focal Plane Array imaging and Optical Photothermal Infrared Spectroscopy (OPTIR).

Results The study reveals that the spatial confinement within electrospun fibers significantly modifies the LC phase transition behaviour compared to the bulk system. While the bulk mixture exhibits complex crystallization processes, its encapsulation within PMMA fibers stabilizes the glassy Smectic A* phase over an extended temperature range. The BDS analysis revealed a distinct shift in the molecular mobility of LC molecules, indicating that the polymer matrix alters dielectric relaxation dynamics. Temperature-dependent FTIR and high-resolution OPTIR mapping demonstrated a homogeneous distribution of the LC phase throughout the fibers, with the confinement providing a stable environment.

Conclusions The results demonstrated that electrospun PMMA/LC composite fibers serve as an effective platform for tailoring mesomorphic behaviour and molecular dynamics properties through confinement and interfacial effects. This approach shows considerable potential for the development of responsive fibrous materials for sensing applications and smart textile technologies.

ACKNOWLEDGMENTS

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Key words liquid crystals, electrospun fibers, spatial confinement, molecular dynamics, dielectric relaxation, infrared spectroscopy

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61 - FROM ELECTROSPUN MATS TO YARNS: ENHANCED TRIBOELECTRIC PERFORMANCE OF PVDF COMPOSITE FIBERS FOR ENERGY HARVESTING IN SMART TEXTILE APPLICATIONS

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Background/Rationale The growing demand for wearable and portable electronics drives the need for sustainable and efficient energy-harvesting solutions. Triboelectric nanogenerators (TENGs) have emerged as a promising approach for converting mechanical energy into electrical energy, owing to their material versatility and superior energy-conversion efficiency. In particular, electrospun poly(vinylidene fluoride) (PVDF) fibers have attracted considerable attention owing to their electroactive β -phase and suitability for flexible textile-based devices. Various strategies, including nanofiller incorporation and structural engineering of electrospun geometries, have been employed to improve the triboelectric performance of PVDF and enable its seamless integration into smart textiles.

Materials and Methods PVDF fiber mats and yarns incorporating different weight percentages of boron nitride (BN) nanoparticles and reduced graphene oxide (rGO) were fabricated via electrospinning. The morphology of the composite fibers was analyzed using scanning electron microscopy (SEM), while the electroactive β -phase content and crystallinity were characterized by Fourier-transform infrared spectroscopy (FTIR) and differential scanning calorimetry (DSC), respectively. The triboelectric performance of the fabricated TENGs was evaluated using a bespoke linear motor setup

Results In this study, the effects of insulating boron nitride (BN) and conductive reduced graphene oxide (rGO) nanofillers on the structural and triboelectric properties of PVDF were systematically investigated. PVDF mats containing 5 wt.% BN exhibited the highest β -phase content (82%) and enhanced crystallinity due to the nucleating effect of BN and strong interfacial interactions with the PVDF matrix. In contrast, 7 wt.% rGO achieved a comparable β -phase fraction (81%), attributed to improved dipole alignment and enhanced charge transport within the fibrous network. The corresponding TENGs exhibited power densities of $281 \mu\text{W}\cdot\text{cm}^{-2}$ for the BN/PVDF composite and $231 \mu\text{W}\cdot\text{cm}^{-2}$ for the rGO/PVDF composite, showing distinct filler-dependent mechanisms governing triboelectric charge generation. To demonstrate their applicability in smart textiles, electrospun yarns based on 5 wt.% BN/PVDF composites were fabricated and exhibited a triboelectric power density of $30.3 \pm 0.03 \mu\text{W}\cdot\text{cm}^{-2}$, corresponding to an approximately 113% enhancement compared to pristine PVDF yarns.

Conclusions The results reveal that both BN and rGO effectively enhance the electroactive properties and triboelectric performance of PVDF fibers. Furthermore, BN/PVDF yarns exhibited promising energy-harvesting capability, highlighting their potential for integration into smart textiles and next-generation self-powered wearable electronics.

Key words PVDF, reduced graphene oxide, boron nitride, triboelectricity, energy harvesting

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67 - FLOW AND FILTRATION IN POROUS MEMBRANES: ELECTROSPINNING APPLICATIONS IN ENHANCED LATERAL FLOW TESTING.

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Background/Rationale Lateral Flow Devices (LFDs), brought to the public's awareness during COVID-19, have been a known technology for decades, with the most widespread example being pregnancy tests. Current LFDs used for rapid diagnostic testing are typically fabricated using nitrocellulose porous membranes or synthetic alternatives. These membranes have well known challenges in ensuring consistent wicking rates between manufactured batches, with added challenges stemming from pore blockages or damage during testing. As interest in LFDs continue to expand, there is increasing demand to improve reliability of test strips and to expand the application of LFDs.

Our research aims to investigate and quantify the variables of flow in the porous membranes, before investigating electrospun nano-fibrous membranes as an alternative membrane fabrication method. We are also seeking to investigate integration of electrospun filtration membranes into LFDs to prevent contaminant blockages that could influence wicking rate and to expand applications into blood-based disease diagnostic testing.

Materials and Methods Our research is investigating both nitrocellulose membranes, fabricated by different industrial suppliers; and electrospun Polyacrylonitrile (PAN) – Jeffamine membranes fabricated in our department. Electrospinning has been conducted using an E-SKE-ED-200 setup. For each membrane, pore and particle size have been measured using scanning electron microscopy, enabling the derivation of porosity and permeability estimates (1,2). Wicking rates in each membrane is determined from measurement of liquid rise in thin (1-15 mm wide) rectangular strips using high-speed imaging. The results are then compared to predictions based on a modified Lucas-Washburn equation (1). The effect of strip geometry, wettability and membrane thickness have been investigated.

Preliminary filtration experiments are being conducted using gravity-driven flow of dilute solutions of fluorescent microspheres and defibrinated blood solutions through electrospun membranes. The impact of fibre welding, solution concentration, nanofiber wettability and membrane thickness are all ongoing areas of our investigation to create the optimal filtration membrane for high filtration and high liquid pass through rate.

Results Current experimental findings have closely aligned with theoretical predications for nitrocellulose test strips but have shown the need for a modification to the effective pore radius in electrospun nanofibrous membrane to accurately describe the wicking rate observed. Pore and fibre imaging has shown our electrospun PAN-Jeffamine membranes to have comparable permeability to tested nitrocellulose membranes, but do current shown greater variability in pore size when compared to these traditional porous membranes. Wicking rates in both membrane types were observed to be reduced by evaporation, with narrower test strips (less than 5mm) seeing a more pronounced slowing due to evaporation. Due to the fragile nature of nanofibrous membranes, current electrospun membranes have shown greater batch-to-batch variability in wicking rates, which ongoing experiments into fibre welding and membrane strengthening are seeking to address.

Preliminary findings regarding filtration applications have shown an up to 90% filtration rate of 5-micron microparticles and defibrinated horse blood cells. Flow rate during filtration was observed to be slower than pure water for these membranes, which we are seeking to optimise as we begin investigating integration into LFD test strips.

Conclusions Our research has developed a better understanding of the variables affecting capillary flow in porous membranes, including identifying how wicking differs in electrospun membranes when compared to traditional porous membranes. These findings can enable more consistent flow-rate testing for LFD manufacturing and has highlighted the possible applications of electrospinning in membrane fabrication. Filtration membranes investigated show strong promise in contaminant filtration, enabling expanded low-cost and rapid diagnostic testing for a greater number of biological makers.

Key words WICKING, FILTRATION, POROUS-MEMBRANES, POLYACRYLONITRILE, JEFFAMINE

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86 - FROM MOLECULE TO SIGNAL: ENGINEERING ELECTROSPUN MIP NANOFIBRES FOR TUNEABLE AMMONIA SENSING

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Background/Rationale Ammonia (NH₃) is a key atmospheric pollutant involved in secondary inorganic aerosol formation, nitrogen deposition, eutrophication and air-quality degradation, with major relevance for agricultural and environmental monitoring. However, its reliable detection under real-world conditions remains challenging because NH₃ is highly reactive, strongly affected by humidity and prone to adsorption-desorption memory effects. Low-power chemiresistive sensors offer attractive opportunities for distributed monitoring, but their performance is often limited by the intrinsic coupling between molecular recognition, polymer swelling, analyte transport and charge transduction. This work addresses this limitation by developing an electrospun MIP–nanofibre sensing platform [1-3] in which molecular recognition and matrix-controlled transport can be partially decoupled.

Materials and Methods NH₃-imprinted polymer nanoparticles (MIP-NPs) were synthesised by precipitation polymerisation using methacrylic acid as functional monomer, ethylene glycol dimethacrylate as crosslinker, AIBN as radical initiator and ammonium chloride as ionic template. After template removal and nanoparticle recovery, MIP-NPs were integrated with multi-walled carbon nanotubes (MWCNTs) into electrospun nanofibres based on three host polymers with different polarity and hygroscopicity: poly(N-vinylpyrrolidone) (PVP), polyacrylonitrile (PAN) and poly(methyl methacrylate) (PMMA). The resulting MIP–MWCNT nanofibrous mats were investigated by TEM, SEM and AFM to assess nanoparticle morphology, fibre architecture, aggregate distribution and mesoscale topography. Chemiresistive NH₃ sensing tests were performed over the 0–100 ppm range at different relative humidity levels, evaluating sensitivity, response kinetics, reversibility and humidity dependence.

Results The NH₃-imprinted nanoparticles showed quasi-spherical morphology with a mean diameter of approximately 120 nm and moderate aggregation. When incorporated into electrospun conductive nanofibres, the same MIP recognition phase produced markedly different sensing behaviours depending on the host polymer matrix. PVP-based fibres generated the highest sensitivity, with rapid response and a tendency toward early saturation. PAN-based fibres showed an intermediate sensitivity, but a broader and quasi-linear response over the investigated concentration range. PMMA-based fibres displayed the lowest sensitivity, together with limited analyte accessibility and early saturation. Morphological analyses revealed that the host matrix controlled not only fibre diameter and surface roughness, but also the spatial organisation of MIP/MWCNT domains. PMMA favoured larger localised aggregates and restricted transport pathways; PVP promoted more hydrated, flexible and highly responsive architectures; PAN provided a compact and reproducible intermediate regime. Humidity-dependent electrical measurements confirmed that charge transport was strongly affected by matrix-controlled water uptake and percolation behaviour. Dynamic exposure tests further showed matrix-specific kinetic fingerprints, with PVP exhibiting fast and intense responses, PAN showing slower but reproducible kinetics, and PMMA displaying weaker responses with more complex recovery profiles.

Conclusions This study demonstrates that electrospun MIP-MWCNT nanofibres can be engineered as modular chemiresistive NH₃ sensors in which selective recognition is provided by imprinted nanoparticles, while analyte accessibility, humidity response and charge transduction are tuned through the host polymer matrix. The results show that the polymer matrix is not a passive scaffold, but an active design parameter governing diffusion, water uptake, polymer mobility and conductive-network modulation. By partially decoupling molecular recognition from transport and transduction, this work provides a rational strategy for designing electrospun MIP-based gas sensors with tunable sensitivity, kinetics and environmental robustness. The approach may be extended to other polar or reactive analytes, supporting the development of next-generation sensing platforms for agricultural, environmental and air-quality monitoring.

Key words Electrospinning; molecularly imprinted polymers; ammonia sensing; nanofibres; chemiresistive sensors; MWCNTs; humidity response; transport modulation

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101 - PEI/PES ELECTROSPUN MEMBRANES FOR PFAS CAPTURE

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Background/Rationale Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are persistent contaminants linked to adverse health effects, including endocrine disruption and carcinogenicity. Their strong carbon-fluorine bonds confer exceptional thermal and chemical stability, making them resistant to conventional water treatment. Adsorption technologies, particularly anion-exchange materials, have proven highly effective for PFAS capture, driven by electrostatic interactions between anionic PFAS headgroups and positively charged adsorbent surfaces, further reinforced by hydrophobic interactions. Polyethyleneimine (PEI), a cationic polymer rich in amine groups, provides excellent binding sites. Its amines protonate over a broad pH range, generating high positive charge density for strong electrostatic attraction to anionic PFAS. In this study, we developed novel electrospun polyethersulfone (PES) membranes functionalized with PEI, capable of capturing PFAS from water.

Materials and Methods

PES was first functionalized and then electrospun to produce ultrathin fibrous mats with high specific surface area. The optimal electrospinning conditions were determined using scanning electron microscopy (SEM). The electrospun membranes were subsequently immersed in a PEI bath. The functional groups introduced on PES prior to electrospinning enabled covalent bonding between the two polymers.

The presence of PEI on the treated membranes was confirmed by Fourier transform infrared spectroscopy (FTIR), elemental analysis, and thermogravimetric analysis (TGA). Changes in membrane morphology were assessed by SEM, and surface charge was analyzed by zeta potential measurements.

The adsorption capacity of the membranes for several per- and polyfluoroalkyl substances (PFAS) was evaluated using liquid chromatography–tandem mass spectrometry (LC-MS/MS).

Results The results show that the first functionalization step is crucial for both successful electrospinning and subsequent PEI attachment. By tailoring the composition of the electrospinning solution (PES concentration) as well as the voltage, virtually defect-free membranes were obtained, with an average fiber diameter in the range of 100 nm. After spinning, the amount of PEI that could be bonded to the membrane was found to depend on the operating conditions, namely the immersion time and the PEI concentration in the bath. Following PEI bonding, the membrane morphology was affected, although the nanofibrous structure was preserved. Zeta potential analyses revealed that the membrane surface charge became highly positive. The thus-prepared membranes were tested for the capture of anionic PFAS and proved to be highly effective (> 97% capture at 100 µg/L).

Conclusions These findings highlight the potential of combining nanostructured polymer processing with rational chemical design to produce highly effective PFAS remediation materials. By synergizing the high surface area of electrospun fibers with the strong electrostatic interactions provided by PEI, this approach offers a promising and efficient route for addressing PFAS contamination in water systems. The study underscores the importance of materials design in environmental remediation and provides a framework for developing functionalized polymeric adsorbents targeting persistent anionic pollutants.

Key words Electrospinning, PFAS, filtration, functionalization, electrostatic interactions

104 - SUSTAINABLE ELECTROSPINNING AND THIOL-ENE PHOTOFUNCTIONALIZATION OF NANOFIBROUS MEMBRANES FOR ADVANCED WATER REMEDIATION

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Background/Rationale Electrospinning is a versatile technique for fabricating nanofibers with high surface area, tunable porosity, and interconnected membrane structure ideal for environmental applications [1]. However, membranes produced by conventional electrospinning are often limited by poor water resistance, low mechanical properties, and the use of toxic organic solvents during processing [2]. The development of sustainable electrospinning strategies based on waterborne systems is therefore essential to reduce environmental and human health impacts.

In parallel, integrating photochemical processes with electrospinning has emerged as a promising approach to enhance membrane performance [3]. In particular, photo-induced thiol–ene chemistry enables rapid, energy-efficient crosslinking and surface functionalization under mild conditions, with precise control over formation and composition [4]. Such an approach is especially attractive for water remediation applications, where membrane stability and surface functionality play a key role in adsorption efficiency.

In this work, sustainable photo-functionalized electrospun membranes for water remediation, with particular emphasis on the removal of heavy metal ions, were developed by combining green electrospinning with a photo-induced process. Styrene–butadiene rubber (SBR) latex was processed with water as the sole solvent, and thiol functionalization was introduced to promote the adsorption of toxic metal ions from aqueous solutions.

Materials and Methods Suspension electrospinning was employed to fabricate SBR latex-based nanofibrous membranes. Poly(ethylene oxide) (PEO) was used as a template to enable fiber formation, while a tetrafunctional thiol monomer (TETRA) was incorporated as both photo-crosslinker and source of thiol functional groups.

Upon UV exposure, thiol-ene reactions occurred between the thiol groups and the C=C double bonds of the SBR backbone, generating a crosslinked network and introducing active thiol functionalities on the nanofiber surface. Finally, the PEO template was removed by water immersion to obtain the final porous membranes[5].

Photo-crosslinking kinetics were monitored using FT-IR spectroscopy, while the properties of the membranes, including morphology, mechanical properties, and wettability, were systematically characterized using FE-SEM, tensile testing, and water contact angle measurements, respectively. The availability of thiol groups was evaluated by Ellman's reagent and UV–Vis spectroscopy, while Hg²⁺ adsorption performance was assessed by ICP-OES.

Results The fabrication strategy successfully produced porous, defect-free nanofibrous membranes composed exclusively of SBR nanoparticles upon PEO removal. FE-SEM analysis revealed well-defined, raspberry-like fibers (550-750 nm diameter).

FT-IR confirmed successful thiol–ene photocrosslinking reaction through the decrease in peak area of the characteristic thiol absorption peak (2552 cm⁻¹), and C=C double bond peaks (910 and 962 cm⁻¹). The photocrosslinking process significantly improved membrane stability while preserving accessible thiol functionalities for heavy metal detection and adsorption. Ellman's reagent technique and UV-Vis spectroscopy demonstrated that the concentration of available thiol groups increased proportionally with the amount of TETRA in the electrospinning formulation, reaching values up to approximately 180 μmol/g. Owing to the high density of accessible thiol groups, the functionalized membranes exhibited effective adsorption capability toward several heavy metal ions (i.e., Cu(II), Pb(II), Hg(II), and Ag(I)), achieving removal capacities up to 70 mg/g from aqueous solution.

Conclusions We demonstrate a sustainable fabrication strategy for multifunctional electrospun membranes by coupling water-based electrospinning with UV-induced thiol–ene photochemistry. The developed approach enables simultaneous membrane stabilization and surface functionalization without hazardous organic solvents. The results reveal a strong relationship between formulation design, photo-induced network formation, and membrane performance, demonstrating how combined electrospinning and photochemistry can effectively tailor membrane structure and functionality. In particular, the resulting thiol-functionalized nanofibrous membranes exhibited tunable morphology, enhanced structural stability, and efficient Hg(II) adsorption capability, confirming their potential for advanced water remediation applications.

Key words Suspension electrospinning, thiol-ene photocrosslinking, thiol-functionalized membrane, water remediation

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107 - ELECTROSPINNING AND PHOTO-INDUCED CROSSLINKING OF POLYVINYL ALCOHOL/ γ -CYCLODEXTRIN INCLUSION COMPLEXES FOR FUNCTIONAL NANOFIBROUS MEMBRANES

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Background/Rationale Coupling electrospinning with photoinduced crosslinking represents an effective strategy to enhance the chemical, mechanical, and thermal properties of nanofibrous materials while enabling morphological control and additional functionalization[1].

Among functional additives to be incorporated into electrospinning systems, cyclodextrins (CDs) have garnered significant interest due to their unique ability to form inclusion complexes with a broad spectrum of guest molecules. Their integration into electrospun systems enables encapsulation and stabilization of volatile or thermo-sensitive compounds, promoting controlled release and prolonged retention. Such characteristics make CD-based electrospun membranes highly promising for applications in active food packaging, drug delivery, and environmental remediation[2].

In this work, electrospinning combined with UV-induced crosslinking was employed to develop water-resistant nanofibrous membranes based on poly(vinyl alcohol) glycidyl methacrylate (PVA-GMA) containing a γ -cyclodextrin/vanillin inclusion complex (γ -CD/Van). The study investigates the influence of inclusion complex incorporation and photocrosslinking on membrane morphology, thermal behavior, and vanillin retention.

Materials and Methods Nanofibrous membranes composed of PVA-GMA and γ -CD/Van inclusion complexes were obtained by electrospinning. The γ -CD/Van complex was prepared first by mixing γ -CD with water at room temperature until complete dissolution followed by the addition of vanillin powder. The complex was then mixed with the PVA-GMA water solution: the vanillin content was 5% (w/w) with respect to PVA-GMA, and the γ -CD amount was adjusted to 43% (w/w) with respect to PVA-GMA. Finally, 1 wt.% of benzophenone (with respect to PVA-GMA) was added to the solution prior to electrospinning. After fabrication, the membranes were subjected to UV irradiation to induce photocrosslinking of the polymer matrix. The morphology and structure of the membranes were characterized by FE-SEM, FT-IR and UV-Vis spectroscopies, while thermal properties were investigated by DSC and TGA analyses. Vanillin retention and release behavior were evaluated during storage.

Results FE-SEM analysis revealed continuous and bead-free fibers with nanoscale diameters, and no aggregation of the inclusion complex throughout the polymer matrix, indicating a homogeneous dispersion within the polymer network. FT-IR and UV-vis spectroscopies confirmed the presence of both γ -CD and vanillin in the polymer matrix and their successful complexation through host-guest interactions.

Thermal analyses highlighted the stabilizing effect of cyclodextrin encapsulation on vanillin. TGA and DSC results confirmed that free vanillin has a volatile nature and demonstrated that inclusion complex formation significantly improved its thermal stability. Moreover, the presence of the inclusion complex enhanced the thermal resistance of the polymer matrix due to host–guest interactions and H-bonding within the polymer matrix.

Vanillin retention studies demonstrated that the encapsulation of vanillin in γ -CD can efficiently inhibit the rapid release of vanillin, maintaining significant retention after 24 days of storage. In addition, photocrosslinking improved membrane thermal stability while preserving the fibrous morphology without shrinkage or fiber fusion.

The combined effects of cyclodextrin complexation and photocrosslinking resulted in enhanced vanillin retention and long-term stability, demonstrating effective structure–property tailoring of the electrospun membranes.

Conclusions This work demonstrates the successful fabrication of functional photocrosslinked nanofibrous membranes based on PVA-GMA and γ -CD/Van inclusion complexes through the combination of electrospinning and UV-induced crosslinking. The incorporation of γ -cyclodextrin enabled effective encapsulation and stabilization of volatile vanillin, while photocrosslinking enhanced membrane stability without compromising fiber morphology or inclusion complex integrity. The results highlight the strong relationship between membrane formulation, supramolecular interactions, and final functional performance, demonstrating the potential of cyclodextrin-based electrospun membranes for active and sustainable food-packaging applications.

Key words Cyclodextrins, inclusion complexes, photocrosslinking, nanofibrous membranes, sustainable food packaging.

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114 - ELECTROSPUN FUNCTIONAL MATERIALS FOR ADVANCED BIOLOGICAL APPLICATIONS: FROM EDNA CAPTURE TO BIOMINERALIZATION AND CAROTENOID RECOVERY

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Background/Rationale Electrospun nanofibre materials have emerged as a versatile platform for environmental and bioprocessing applications due to their exceptionally high surface area, tunable surface chemistry, and interconnected porous structures. These properties make them particularly suitable for processes governed by interfacial phenomena such as adsorption, nucleation, and capture (1).

Recent advances in environmental monitoring have highlighted the growing importance of environmental DNA (eDNA) as a non-invasive tool for biodiversity assessment. However, conventional eDNA sampling approaches rely primarily on active filtration, which can be time- and resource-intensive. Nanofibre composite materials offer a promising alternative for the passive collection of aquatic eDNA (2), providing simplified deployment and reduced operational demand. In contrast, the use of nanofibre composites for airborne eDNA capture remains less explored and is investigated in this study.

Beyond eDNA capture, there is increasing interest in developing multifunctional materials that address broader environmental and industrial challenges. For example, incorporating divalent cations such as calcium and magnesium into polymer matrices can promote biomineralization processes (3), enabling carbon capture through mineral formation. Similarly, the integration of biopolymers such as chitosan introduces functional groups that enhance the selective recovery of valuable biomolecules, such as astaxanthin, from fermentation streams.

Materials and Methods Different tailored nanofibre scaffolds and composites were fabricated using solution electrospinning techniques via pilot scale machine (Elmarco Nanospider™), employing environmentally friendly polymer systems with functional additives. These electrospun materials were:

- (i) Crosslinked -Polyvinyl alcohol (PVA) composites for efficient environmental DNA (eDNA) capture in terrestrial species.
- (ii) Crosslinked PVA composites with calcium and magnesium additives for enhancing or promoting biomineralization via microbialite for carbon dioxide removal.
- (iii) Crosslinked PVA with chitosan added for recovery of a high-value biomolecules (astaxanthin) from fermentation streams.

Results The use of water-based PVA electrospun composite materials for airborne environmental DNA (eDNA) capture, biomineralization, and astaxanthin recovery has been demonstrated, highlighting their versatility as multifunctional platforms for diverse environmental and bioprocessing applications.

Conclusions The use of water-based PVA electrospun composite materials for airborne environmental DNA (eDNA) capture, biomineralization, and astaxanthin recovery has been demonstrated, highlighting their versatility as multifunctional platforms for diverse environmental and bioprocessing applications.

Key words Electrospinning; Nanofibers; eDNA capture; Biomineralization; Carbon dioxide, Astaxanthin; Functional materials; Environmental monitoring; Sustainable materials

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119 - LIGHT-CONTROLLED ADVANCED FUNCTIONAL MATERIALS ACROSS DIMENSIONS: ELECTROSPUN NANOFIBERS AND 3D PRINTED PHOTONIC COMPONENTS

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Background/Rationale Photoresponsive organic materials capable of dynamic modulation of light are highly attractive for advanced photonic technologies, including optical switching, sensing, structured light generation, and reconfigurable optical networks. In particular, electrospun fibrous systems offer unique opportunities for molecular organization due to their anisotropic morphology and high surface-to-volume ratio, while additive manufacturing enables the realization of complex three-dimensional optical architectures. Combining these approaches may provide a versatile pathway toward next-generation functional photonic materials operating from the micro- to macroscale.

Materials and Methods Two classes of photoresponsive systems were investigated. The first one was based on electrospun DNA-CTMA fibers doped with nonlinear pyrazoline chromophores. Fibers were fabricated by electrospinning from butanol-based solutions and subsequently characterized by scanning electron microscopy and pump-probe optical measurements. The second system involved 3D printable photoresponsive materials based on azobenzene derivatives embedded in photocurable matrices processed by stereolithography (SLA) and digital light processing (DLP). The optical response of the fabricated materials and devices was studied by laser spectroscopy (effective tool in nonlinear optics), and Raman spectroscopy.

Results Electrospun DNA-based fibers exhibited efficient and fully reversible photoinduced birefringence associated with light-driven molecular alignment within the fibrous biopolymer matrix. The achieved refractive index anisotropy approached 10^{-3} , with sub-millisecond switching times (~ 0.35 ms), demonstrating fast all-optical modulation in electrospun organic materials. The anisotropic organization induced by electrospinning was found to support stable and repeatable optical switching behavior.

In parallel, photoresponsive 3D printed optical components with dynamically tunable birefringence were realized by vat photopolymerization. The fabricated structures exhibited photoinduced birefringence up to $\sim 2.5 \times 10^{-4}$ and enabled optical modulation of both light intensity and polarization properties. Importantly, stable operation over more than 60,000 switching cycles was demonstrated. The study additionally identified a broad UV-processing window in which efficient photopolymerization and preservation of nonlinear optical functionality could be simultaneously achieved.

The combined results demonstrate a dimensional evolution of photoresponsive functional materials, progressing from electrospun fibrous architectures toward fully three-dimensional photonic components with programmable optical behavior.

Conclusions The presented results highlight the potential of combining electrospinning and additive manufacturing for the development of advanced photoresponsive materials with dynamically tunable optical properties. Electrospun DNA-based fibers provide efficient and ultrafast all-optical switching platforms, whereas 3D printed architectures enable scalable and geometrically complex photonic devices with stable long-term operation. These findings open new perspectives for reconfigurable photonic systems, optical logic elements, smart sensors, and emerging 4D photonic technologies.

Key words electrospinning; photoresponsive materials; all-optical switching; nonlinear optics; 3D printing; photonic materials; photoinduced birefringence

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122 - ANTIVIRAL ACTIVITY OF NANOFIBROUS POLYMERS MODIFIED WITH SILVER, ZINC, AND COPPER NANOCLUSTERS

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Background/Rationale Airborne particles and bioaerosols play a major role in the transmission of infectious diseases such as SARS, influenza, and COVID-19, creating a need for more efficient antiviral filtration materials. Conventional microfiber filters are insufficient for capturing particles smaller than 300 nm, while the extensive use of disposable face masks has also generated significant environmental concerns. Electrospinning offers a promising approach for producing nanofibrous membranes with tunable pore structures and high filtration efficiency by adjusting processing parameters. In addition, incorporation of metal nanoparticles such as silver, copper, and zinc can provide virucidal functionality. These metal-modified nanofiber materials have strong potential for use in advanced air filtration systems and personal protective equipment to improve viral protection and reduce environmental impact. The objective of the research was to assess and compare the antiviral activity of these metal-functionalized nanofibers against the human influenza A virus A/WSN/1933 (H1N1) and SARS-CoV-2.

Materials and Methods In this study, nanofiber membranes composed of poly(vinylidene fluoride) dissolved in N,N-dimethylacetamide were produced through electrospinning and modified with copper, silver, and zinc nanoclusters. A wide range of characterization techniques was employed to investigate the relationship between the physical properties of the materials and their biological performance, as well as to evaluate their potential for use in antiviral air filtration systems. These methods included X-ray diffraction, scanning electron microscopy, microwave plasma atomic emission spectroscopy, thermogravimetric analysis, contact angle measurements, nitrogen sorption analysis, mercury intrusion porosimetry, filtration efficiency testing, and virucidal assays.

Results All fabricated nanofiber membranes demonstrated high particle filtration efficiency, exceeding 98%. Structural and surface characterization confirmed the successful incorporation of silver, copper, and zinc nanoclusters into the electrospun poly(vinylidene fluoride) fibers without compromising membrane morphology. Antiviral testing showed clear differences in virucidal activity depending on the incorporated metal. Copper-functionalized membranes exhibited the strongest antiviral effect against the SARS-CoV-2 alpha variant, reducing the number of infectious virions by approximately 1000-fold after 12 h of exposure. In contrast, zinc-functionalized nanofibers showed the highest effectiveness against human influenza A virus A/WSN/1933 (H1N1). The results demonstrate that metal nanocluster incorporation significantly enhances the antiviral performance of electrospun filtration materials while maintaining excellent filtration properties.

Conclusions Materials functionalized with copper nanoclusters demonstrated high effectiveness in inactivating and eliminating SARS-CoV-2 alpha variant virions, whereas activated porous membranes modified with zinc nanoclusters showed strong antiviral activity against human influenza A virus A/WSN/1933 (H1N1) virions.

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Key words Electrospinning; Poly(vinylidene fluoride); Filtration efficiency; Antiviral activity; IAV H1N1; SARS-CoV-2

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143 - PREPARATION OF ELECTROSPUN POLYMERIC MEMBRANES FROM PLANT PROTEINS AND MALTODEXTRINS FOR THE TREATMENT OF GADOLINIUM-CONTAMINATED WASTEWATER

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Background/Rationale The widespread use of Gadolinium-Based Contrast Agents (GBCAs) in medical magnetic resonance imaging has led to the contamination of water resources. These compounds can break down in wastewater, releasing free gadolinium ions that are highly toxic and tend to bioaccumulate in living organisms. To address this issue, the study focuses on developing innovative, sustainable, and biodegradable filtration membranes using plant-based materials.

Materials and Methods Zein, a hydrophobic corn protein, and maltodextrins, which are water-soluble carbohydrates, were used to produce the membranes through an electrospinning process. After the parameter optimization, several types of membranes were created, showing fiber diameters ranging from 0.7 to 1.2 μm :

- i) Membranes made from zein combined with myristic acid.
- ii) Membranes made from maltodextrins combined with citric acid.
- iii) Membranes made from maltodextrins combined with citric acid and activated carbon.
- iv) Membranes consisting of alternating electrospun layers of zein and maltodextrins, designed to enhance mechanical strength while providing a high removal capacity.

Results The maltodextrin-based membrane demonstrated the highest efficiency in removing free gadolinium through electrostatic interactions, achieving a removal of $96.1 \pm 0.6\%$. In contrast, the sample with alternating electrospun layers achieved an $83.0 \pm 0.3\%$ removal, while the zein-only membrane reached only $24.6 \pm 0.5\%$. However, none of the membranes were able to retain gadolinium in its complexed form (Gadoteridol). To address this, activated carbon was incorporated into the fibers to evaluate its effectiveness in removing Gadoteridol through π -interactions. Flow tests were conducted using a 3D-printed multi-step column. The membranes successfully removed free gadolinium ions from aqueous solutions (up to 75 mL permeated) and simulated urine (up to 45 mL permeated) using just 50 mg of membrane material. However, filtration efficiency significantly decreased in real environmental matrices due to their increased complexity.

Conclusions Electrospun zein and maltodextrin membranes represent a promising, eco-friendly alternative for treating gadolinium-contaminated water. While they show excellent retention capacity and kinetics in both batch and flow tests, further optimization is necessary to enhance their mechanical strength and efficiency for large-scale applications in complex environmental conditions.

Key words Biodegradable electrospun membranes; sustainable process; water remediation; Gadolinium-based contamination

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145 - PHOTO-ACTIVITY ENGINEERING OF ELECTROSPUN INDIUM OXIDE NANOFIBERS FOR VISIBLE-LIGHT-ACTIVATED GAS SENSING

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Background/Rationale Chemi-resistive metal oxide gas sensors have been widely studied for detecting hazardous gases owing to their high sensitivity and chemical stability. However, conventional metal oxide sensors typically require elevated operating temperatures to activate surface reactions, leading to high power consumption and limited applicability in wearable, portable, and distributed sensing systems. Light activation has emerged as a promising strategy for enabling low-power, room-temperature gas sensing by generating photocarriers and modulating surface adsorbates. Nevertheless, the wide bandgap of typical metal oxides, including indium oxide, limits their efficient activation under visible light.

Electrospun indium oxide nanofibers provide an attractive platform for light-activated gas sensors because their porous one-dimensional network offers a large surface area, facile gas diffusion, and continuous electron transport pathways. In this work, we present photoactivity-engineering strategies for electrospun In₂O₃ nanofibers to extend their light-stimulated response from the ultraviolet to the visible and to enhance room-temperature gas-sensing performance.

Materials and Methods Electrospun In₂O₃ nanofibers were employed as a model photoactive metal oxide platform. Because In₂O₃ has a wide bandgap of approximately 3.0 eV, its intrinsic photoactivation is mainly limited to the ultraviolet region. To extend its light-activated response into the visible-light region, various sensitization strategies were applied: heterojunction sensitization using graphene quantum dots (GQD), doping sensitization using Bi incorporation, and localized surface plasmon resonance sensitization using Au nanoparticles. First, graphene quantum dots were introduced onto In₂O₃ nanofibers to form heterojunction interfaces that promote visible-light absorption and interfacial charge transfer. Bi dopants were incorporated to modulate the electronic structure of In₂O₃ and generate dopant-induced photoactive states. Au nanoparticles were further decorated onto Bi-doped In₂O₃ nanofibers to utilize plasmonic light harvesting and hot-electron-mediated sensitization.

The electrospun In₂O₃ nanofiber network provided high specific surface area, abundant gas-accessible reaction sites, efficient gas diffusion pathways, and robust electron transport channels, all of which are essential for room-temperature chemi-resistive sensing. The engineered nanofibers were characterized structurally, optically, and chemically, and their NO₂ sensing properties were evaluated under visible-light irradiation at room temperature.

Results The electrospun In₂O₃ nanofibers formed porous, interconnected one-dimensional networks, offering gas-accessible surfaces, efficient diffusion pathways, and stable electron-transport channels. Using this nanofiber platform, two types of photoactivity-engineered sensing systems were demonstrated.

For the GQD-In₂O₃ nanofibers, graphene quantum dots of different sizes were employed as heterojunction photosensitizers to investigate the mechanistic relationship between sensitizer bandgap, excitation wavelength, and gas-sensing behavior. The size-dependent optical properties of GQDs enabled wavelength-selective photoactivation by modulating visible-light absorption and interfacial charge transfer with In₂O₃. This result clarified that the photon-induced sensing response is governed by the energetic alignment between GQDs and In₂O₃, as well as by the efficiency of photocarrier generation and transfer under different light wavelengths.

For the Au-Bi-In₂O₃ nanofibers, a stronger composite photoactivation effect was achieved by combining Bi doping and Au plasmonic sensitization. Bi dopants introduced photoactive electronic states that improved visible-light utilization, while Au nanoparticles enhanced light harvesting through localized surface plasmon resonance and promoted hot-electron-mediated charge transfer. As a result, the optimized Au-Bi-In₂O₃ nanofiber sensor exhibited a high response of 104 toward 0.6 ppm NO₂ under green-light irradiation at room temperature, confirming the synergistic contribution of dopant-mediated band structure modulation and plasmonic interfacial activation.

Conclusions This study demonstrates that electrospun In₂O₃ nanofibers can serve as a versatile and structurally robust platform for visible-light-activated gas sensing. By overcoming the intrinsic wide-bandgap limitation of In₂O₃ through heterojunction, doping, and plasmonic sensitization, the photoactivity of electrospun oxide nanofibers was systematically engineered from mechanistic understanding to high-performance sensor implementation. Overall, this work suggests that electrospun metal oxide nanofibers are not merely passive sensing layers, but tunable photoactive architectures in which light absorption, charge

transfer, and surface gas reactions can be rationally controlled. This strategy offers a promising pathway toward visible-light-driven gas sensors for environmental monitoring, indoor air quality assessment, and artificial olfaction systems.

Key words Electrospinning; Indium oxide; Nanofibers; Photoactivation; Visible light; Gas sensor; Nitrogen dioxide

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158 - SUSTAINABLE ELECTROSPUN ELECTROACTIVE NONWOVENS FOR ADVANCED WEARABLE SENSING APPLICATIONS

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Background/Rationale The rapid evolution of wearable electronics requires flexible, high-performance materials that combine functional excellence with environmental sustainability. Electrospinning has emerged as a key additive manufacturing technique for producing functional nanofiber mats with high surface area-to-volume ratios and precisely tunable properties. This work investigates different electroactive systems to address the need for sustainable, smart textiles and breathable wearable sensors in healthcare and rehabilitation.

Materials and Methods Two primary electroactive systems were developed: conductive poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT:PSS) blended with polyethylene oxide (PEO), and piezoelectric polyvinylidene fluoride (PVDF) nanocomposites enriched with barium titanate (BaTiO₃) nanoparticles. A systematic study of thermal treatment (TT) was conducted on PEDOT-based nonwovens to optimize electrical and mechanical properties. Characterization was performed using field emission scanning electron microscopy (FE-SEM), Fourier transform infrared (FTIR) spectroscopy, and X-ray photoelectron spectroscopy (XPS). The environmental impact was assessed through standardized ecotoxicological assays on freshwater and marine organisms, including bacteria, algae, and crustaceans.

Results Vacuum thermal treatment of PEDOT:PSS/PEO nonwovens successfully induced cross-linking between PSS and PEO chains, significantly improving water resistance and increasing mechanical stiffness by approximately 20 times without compromising deformation capability. In the PVDF system, the introduction of BaTiO₃ nanoparticles enhanced the dielectric properties, while the use of a rotating drum collector at high speeds (up to 4500 rpm) produced highly aligned nanofibers with pronounced mechanical anisotropy.

Ecotoxicological tests confirmed the biocompatibility of these materials, showing no significant toxicity in both freshwater and marine ecosystems.

Practical application is demonstrated via a sensorized laboratory prototype glove, suitable for hand rehabilitation, targeting conditions such as Multiple Sclerosis and stroke recovery, capable of real-time monitoring of precision and power grips. Beyond rehabilitation, these sustainable electroactive nonwovens offer a versatile platform for haptic robotics, tele-rehabilitation, energy harvesting, and biocompatible bioelectronics. [1-3]

Conclusions This multidisciplinary research demonstrates that electrospun electroactive nonwovens can achieve high functional performance, such as superior conductivity and mechanical robustness, while maintaining environmental responsibility. The integration of these materials into wearable devices offers a sustainable platform for next-generation biomedical and wearable technologies.

Key words Electrospinning, Conductive nonwovens, Wearable sensors, Nanocomposites, Ecotoxicity.

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160 - THREE-DIMENSIONAL ARCHITECTURES FOR ADVANCED FIBER NETWORK LASERS

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Background/Rationale The realization of nanophotonic systems with hierarchical organization is a key challenge in the development of next-generation fiber network lasers. Conventional manufacturing methods often provide limited flexibility in shaping complex architectures while preserving the optical performance of nanofibers. While planar nanofiber structure can be fabricated with well-controlled geometries, some challenges are still present for the realization of 3-dimensional (3D) architectures. Advanced additive manufacturing technologies offer an attractive route to overcome these limitations, enabling the fabrication of complex fiber networks when combined with electrospinning technologies. In this presentation we will review the recent activities of our group aimed at the development of nanophotonic network lasers with 3D architectures.

Materials and Methods 3D arrays of fluorescent nanofibers are produced by embedding laser dyes in a transparent polymer matrix. The lasing properties of the fibers are characterized upon green (532 nm) optical pumping in pulsed mode.

Results The 3D arrays of fibers show lasing emission with well-behaved thresholds and emission in the visible range. Stability over time of the emission, and correlation between the different emission peaks are assessed under constant optical pumping. The dependence of the lasing properties on the fiber architecture is discussed.

Conclusions The results of this works are relevant for applications in optical sensing, miniaturized coherent light sources and advance optical imaging.

Key words Nanophotonic networks, laser, fluorescent fibers

161 - INTELLIGENT ELECTROSPUN NANOFIBERS FOR CONTROLLED PHOTOSWITCHING AND ENERGY HARVESTING

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Background/Rationale Multifunctional nanostructured materials are key elements for advanced energy and optoelectronic technologies. In particular, nanofibers can combine enhanced electronic and optical properties with a small footprint. The use of materials with stimuli-responsive properties further enhances the capabilities of nanofibers, enabling adaptive and reconfigurable features. These intelligent nanofibers might undergo reversible photoswitching upon light irradiation, enabling dynamic modulation of their properties. At the same time, their unique architecture promotes efficient light harvesting and energy transfer processes. In this presentation, we will review the recent activities carried out in our group focused on the development of active nanofibers responsive to optical signals and mechanical deformation.

Materials and Methods Electrospun fibers are produced by embedding photoactive molecules in transparent polymers. The optical properties of the nanofibers are measured by photoexcitation with ultraviolet (375-405 nm) and green (543-561 nm) laser beams and probed by using red laser beams (650 nm). Microscopic investigation is performed by using scanning electron microscopy and fluorescence confocal microscopy.

Results The results of the characterization of nanofibers upon different conditions of mechanical deformation and light irradiation are presented, as well as the assessment of their switching properties and fatigue resistance.

Conclusions The electrospun fibers developed in this work lay the foundation for a novel class of nanostructured materials with physical properties controllable by external stimuli, which can constitute building blocks for nanogenerators, optical computational units and optical sensors.

Key words Photoactive fibers, stimuli-responsive materials, nanophotonics

166 - BIOHYBRID ELECTROSPUN NANOFIBERS FOR FILTRATION, CAPTURE, AND SENSING

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Background/Rationale The integration of biofunctional molecules within electrospun nanofibers offers a promising route toward multifunctional materials capable of both contaminant capture and sensitive detection. In particular, bovine serum albumin (BSA) exhibits a strong affinity toward a wide range of organic molecules, while gold nanostructures provide plasmonic enhancement for surface-enhanced Raman spectroscopy (SERS). This work explores biohybrid electrospun membranes prepared with BSA and poly(vinyl alcohol) (PVA) for filtration of drugs (e.g. ketoprofen). Moreover, we studied the combination of BSA and gold nanorods (AuNRs) within a PVA nanofibrous matrix to create multifunctional platforms for filtration, sensing, and wastewater monitoring applications.

Materials and Methods Biohybrid BSA/PVA nanofibers electrospinning was optimized and characterized to obtain uniform membranes. Chemical filtration of ketoprofen was successfully obtained from the BSA/PVA system. Hybrid BSA/AuNRs/PVA nanofibrous membranes were fabricated by electrospinning aqueous feed solutions containing BSA, PVA, and AuNRs, followed by glutaraldehyde crosslinking to ensure stability in aqueous environments. Fiber morphology was characterized by scanning electron microscopy, while Fourier-transform infrared spectroscopy confirmed successful crosslinking and preservation of the protein structure. Bradford protein assays were employed to evaluate BSA loading and retention. The membranes were investigated as filter-based SERS substrates.

Results The electrospun biohybrid membranes exhibited homogeneous and defect-free fibers with preserved BSA secondary structure after processing. The incorporation of BSA introduced analyte-capturing functionality, while AuNRs enabled plasmon-enhanced Raman detection. Compared with conventional drop-cast SERS measurements, the filter-based configuration significantly improved analyte preconcentration and sensing performance. Rhodamine 6G (Rh6G) and ketoprofen were detected, whereas control membranes lacking BSA showed negligible analyte capture. Bradford analysis confirmed efficient protein incorporation and minimal protein leakage after crosslinking.

Conclusions The combination of bioactive BSA and plasmonic AuNRs within electrospun PVA nanofibers yields a multifunctional membrane capable of simultaneous analyte capture, filtration, and SERS detection. The filter-based sensing strategy enhances sensitivity toward trace contaminants while preserving the biofunctionality of the embedded protein. These results demonstrate the potential of biohybrid electrospun nanofibers as sustainable platforms for water treatment, environmental monitoring, and next-generation sensing technologies.

Key words Biohybrid nanofibers

Electrospinning

Surface-enhanced Raman spectroscopy (SERS)

Gold nanorods (AuNRs)

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179 - BI-LAYER ELECTROSPUN PVDF NANOFIBROUS COMPOSITE MEMBRANES FOR AZO DYE DEGRADATION VIA CATALYTIC HYBRID ADVANCED OXIDATION PROCESSES

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Background/Rationale Advanced oxidation processes (AOPs) represent an appealing strategy for the degradation of organic pollutants in both liquid and gas phases, thanks to the exploitation of strong oxidizing radicals. Catalytic-driven AOPs have the advantage of boosting the degradation pathways and reducing energy consumption, but require adequate recovery strategies or a suitable support to ensure stability and avoid catalyst loss. In particular, the choice of the support should maximize catalyst exposure, especially in light-driven AOPs, and guarantee stability as well as flexibility in relation to different process conditions. In this study, electrospun PVDF-based bilayer membranes were developed with the aim of providing a tunable fibrous support for composite catalytic systems, capable of combining different AOPs in a synergistic way

Materials and Methods PVDF (Kynar HSV 900) nanofibers were fabricated via electrospinning to generate a bi-layer structure comprising a first mechanical support layer of polymer fibers as support and a second catalytic layer based on either a binary magnetite composites with TiO₂ (P25), with a Fe:Ti ratio equal to 1, or ternary composite with graphene oxide (1:10 GO/TiO₂ weight ratio) to promote hybrid catalytic advanced oxidation processes. Two different protocols for magnetite synthesis were compared, with and without ultrasound-assisted precipitation from salt precursors (FeCl₂/FeCl₃). The developed catalysts were characterized by XRD, Raman spectroscopy, transmission and scanning electron microscopy (TEM/SEM). The developed composite membranes (98 cm², catalyst concentration: 0.9 mg/cm²) were characterized by SEM, Fourier infrared spectroscopy, and thermogravimetric analysis. Membranes performance was tested by combining different advanced oxidation processes, with the use of ultrasound (70 W bath, 42 kHz) and the Fenton process (1 ppm of H₂O₂) in combination with a UV light source (λ_{max} = 254 nm, 3 W), using methyl orange as a model azo dye. The starting concentration was 10 ppm in a 90 ml water solution using a batch reactor configuration with a cylindrical glass reactor (d = 5 cm, h = 8.5 cm).

Results Binary and ternary composite catalysts with TiO₂, magnetite, and graphene oxide were produced and deposited on the nanofibrous PVDF bi-layer support to maximize catalyst exposure to the light source. The different catalytic systems modified both fibers surface and dimensions, with thinner fibers in the presence of magnetite and thicker, expanded fibers with graphene oxide. XRD and Raman spectroscopy confirmed the successful composite catalyst syntheses, while the uniform deposition and tailored catalyst loading were confirmed by SEM and TGA, respectively. Degradation tests showed dependence on catalyst composition and synthesis method. Ultrasound-assisted synthesis provided the best-performing composite catalytic system, while the presence of graphene oxide significantly enhanced the contaminant adsorption. The performance, with respect to the TiO₂ benchmark, allowed for a drastic reduction of decoloration time thanks to a combined effect of ultrasound and photocatalytic Fenton process.

Conclusions Electrospun, bi-layer PVDF nanocomposite catalytic membranes were successfully prepared with a one-step approach for the uniform deposition of the catalyst particle on the surface of the fibers. A proper combination of catalyst and co-catalyst, and tailored deposition on the membrane surface allowed tuning the membrane performance and to combine the effect of different AOPs, providing interesting results for the use of electrospun membranes for water purification.

Key words Electrospinning, PVDF, Advanced Oxidation Processes, Nanofibrous composite membrane.

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184 - FROM MEMBRANE REACTOR DESIGN TO ENVIRONMENTAL REMEDIATION: UNLOCKING THE POTENTIAL OF ELECTROSPUN MATERIALS

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Background/Rationale Air and water pollution require remediation technologies that are effective not only under ideal laboratory conditions, but also at environmentally relevant contaminant concentrations. Heterogeneous photocatalysis and related advanced oxidation processes are attractive because they can transform pollutants rather than merely transfer them to another phase. However, performance measured at milligram-per-litre concentrations cannot be extrapolated automatically to the microgram- or nanogram-per-litre range. At low concentration, the apparent rate can become controlled by molecular transport, the probability of encounter with the catalyst surface, and the ability of the pollutant to remain at the interface long enough to react [1-4].

This work reframes the electrospun membrane from a passive catalyst support into a reactive concentrator. The proposed architecture integrates four coupled functions: capture, concentration, activation and degradation. A porous affinity phase first removes molecules from the dilute bulk and enriches them locally; a catalytic phase then generates reactive species at the same interface; and the electrospun scaffold provides short diffusion distances, interconnected porosity, recoverability and a modular platform for one-step, layer-by-layer, coaxial or post-deposition fabrication. The central design objective is therefore not simply to irradiate a dilute solution, but to create a reactive hotspot in which adsorption and catalytic transformation are deliberately co-located [4-8].

Zeolitic imidazolate framework-8 (ZIF-8) was selected as a model capture reservoir because of its high surface area and tunable porous structure, while TiO₂ supplied the photoactive function. Ciprofloxacin (CIP) was used as a mechanistic test molecule to assess adsorption, photoactivation and reactive-species contributions. The same capture-and-react architecture is subsequently considered for per- and polyfluoroalkyl substances (PFAS), while recognising that PFAS require a different reaction chemistry and more stringent proof of destruction.

Materials and Methods ZIF-8 was prepared from zinc chloride and 2-methylimidazole in methanol, followed by washing, centrifugation and drying at 60 °C. A ZIF-8@TiO₂ composite was produced to bring adsorptive and photocatalytic domains into direct contact. The powders were characterised by X-ray diffraction, thermogravimetric analysis, Brunauer-Emmett-Teller surface-area analysis, electron microscopy, high-resolution transmission electron microscopy and selected-area electron diffraction. The crystalline TiO₂ domains were indexed from lattice-fringe and diffraction-ring measurements.

The powders were immobilised in electrospun polyacrylonitrile (PAN) membranes containing 50 wt.% PAN and 50 wt.% ZIF-8 or ZIF-8@TiO₂. This high loading was selected to combine interfacial functionality with macroscopic handling and catalyst recovery. The resulting fibre mats were assessed with particular attention to particle dispersion, accessible surface area and the risk that agglomeration could introduce light shielding, transport resistance or mechanically weak regions.

CIP solutions at approximately 50 mg L⁻¹ were treated with 22-66 mg of membrane in 220-300 mL. Each experiment included a dark-contact period to quantify apparent uptake before UVA or UVC irradiation. The reported UVA operating condition was 367 nm and 40 mW cm⁻². CIP was quantified by LC-DAD/MS, while transformation pathways were examined by LC-QTOF. Reuse was evaluated over three cycles. Reactive-species trapping experiments employed methanol for hydroxyl radicals (•OH), EDTA for photogenerated holes (h⁺), silver nitrate for photogenerated electrons (e⁻), and ascorbic acid for superoxide radicals (O₂•⁻). The scavenger response was interpreted from the complete concentration-time profile and not only from the final removal value [9].

For the PFAS extension, preliminary PFOA screening compared persulfate oxidation, photo-Fenton chemistry, heterogeneous photocatalysis and a combined AOP condition under a 48 W UV source. Initial PFOA concentrations varied between 3.46 and 4.82 mg L⁻¹. Parent-compound removal and defluorination were considered as separate outcomes because loss of the parent compound alone cannot distinguish adsorption from chemical destruction.

Results ZIF-8 exhibited a specific surface area of 1402 m² g⁻¹. After TiO₂ incorporation, the value decreased to 967 m² g⁻¹, while thermogravimetric analysis indicated 18.77 wt.% TiO₂ in the composite and microscopy gave a reported composite particle size of approximately 391 nm. The reduction in surface area reflects the

deliberate trade-off between adsorption capacity and catalytic functionality. HRTEM showed a lattice spacing of 0.348 ± 0.004 nm, assigned to the anatase TiO_2 (101) plane. SAED rings at approximately 0.349, 0.235 and 0.188 nm were consistent with the anatase (101), (004) and (200) reflections, respectively. These results confirmed that crystalline anatase domains were successfully introduced into the ZIF-based composite.

Electrospinning converted the active powders into recoverable, addressable interfaces. The 50/50 wt.% PAN/filler membranes preserved the open fibrous morphology required for liquid access, but the microscopy also revealed particle aggregates. This observation is relevant to reactor performance: a high nominal catalyst loading does not guarantee proportional activity if a fraction of the active phase is buried, optically screened or poorly contacted by the liquid phase.

The dark stage of the CIP experiments separated adsorption from irradiation-driven parent loss. The subsequent irradiated stage demonstrated additional CIP disappearance, while LC-QTOF provided evidence of transformation products. A fragment at m/z 294 was consistent with a pathway involving loss of the fluorine atom as HF. Nevertheless, parent-compound disappearance must not be reported as mineralisation without supporting carbon and product balances. The trapping experiments further showed that mechanistic interpretation requires the full kinetic response. A larger area under the C/C_0 , or equivalently $1-X$, curve indicates that more CIP remains over time and therefore corresponds to stronger integrated apparent inhibition. Because scavengers may also alter adsorption, catalyst chemistry or analytical recovery, their assignments should be supported by product analysis and, where possible, direct ROS measurements [9].

The PFOA screening highlighted the distinction between parent removal and defluorination. At 48 W, persulfate treatment gave 46.28% PFOA removal and 16.28% defluorination; photo-Fenton treatment gave 40.77% and 8.93%, respectively; and photocatalysis gave 51.98% removal and 19.88% defluorination. The combined AOP condition produced the highest reported values, 52.99% removal and 23.95% defluorination. However, the increment over photocatalysis alone was modest. Since the starting concentrations differed among tests and no replicated statistical synergy analysis was available, the results should be interpreted as a mechanism-screening comparison rather than proof that increasing process complexity necessarily produces synergy [10-12].

The combined findings support a membrane-reactor strategy in which trace contaminants are captured before

Conclusions Electrospun materials offer more than a route for immobilising catalysts: they provide an architecture toolbox for controlling where adsorption, mass transfer, photon delivery and chemical reaction occur. The ZIF-8@ TiO_2 /PAN system demonstrates the feasibility of combining a porous capture reservoir, an anatase photocatalytic phase and a recoverable fibrous scaffold. The key engineering message is that capture is not the end of remediation; it is the kinetic strategy that can make degradation at low concentration more plausible.

The architecture developed with CIP can guide PFAS-reactor design, but CIP is not a chemical proxy for PFAS. For PFAS, the reactive species and activation mode must be selected according to molecular structure, water matrix and the desired initiation and chain-shortening pathways. Robust evidence of destruction should include parent-PFAS loss, identification of short-chain products, fluoride mass balance, reduction of adsorbable/extractable/total organic fluorine, mineralisation or toxicity improvement, catalyst stability, leaching, reuse and energy demand. Future development should therefore optimise encounter probability, co-locate capture and activation, identify the dominant reactive pathway and incorporate regeneration from the outset.

Key words electrospinning; membrane reactor; heterogeneous photocatalysis; reactive concentrator; ZIF-8; TiO_2 ; ciprofloxacin; PFAS; advanced oxidation processes; environmental remediation.

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185 - TAILORING ELECTRICAL PROPERTIES OF ELECTROSPUN NANOFIBERS THROUGH DOPING STRATEGIES

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Background/Rationale Conjugated polymers represent a unique class of materials whose electrical properties can be tuned over several orders of magnitude, ranging from semiconducting behavior in the pristine state to highly conductive states upon doping.¹ When combined with electrospinning, these materials offer exciting opportunities for the development of lightweight, porous, and mechanically compliant architectures for flexible and wearable electronics, as well as thermoelectric generators.²⁻⁶ However, achieving high electrical performance in electrospun conjugated polymer fibers remains challenging due to the strong interplay between molecular structure, processing conditions, morphology, and post-processing treatments.

Materials and Methods Different classes of electrospun conjugated polymer nanofibers were investigated, including pristine semiconducting,^{2,4} ambipolar, and conductive systems.⁵⁻⁷ Both p-type and n-type polymers were processed by electrospinning, generally with the use of polyethylene oxide as sacrificial supporting polymers to achieve defect-free fibers.^{2,3} Morphological, structural, spectroscopic, and electrical characterization techniques were employed to evaluate the effects of processing parameters and doping strategies on charge transport. Both p-doping and n-doping approaches⁸⁻¹⁰ were considered and compared with corresponding film-based systems.

Results The results demonstrate that electrospinning can significantly influence the electrical properties of conjugated polymers through changes in molecular orientation, phase organization, and fiber architecture. In pristine semiconducting fibers, optimized processing conditions promoted preferential chain alignment and improved charge transport. Ambipolar fibers were obtained through the combination of p-type and n-type semiconducting polymers, highlighting the critical role of formulation and processing conditions. In conductive systems, post-processing doping treatments produced substantial conductivity enhancements, while the effectiveness of doping was found to depend strongly on the fibrous architecture. In several cases, electrospun fibers exhibited more efficient charge-carrier generation and stronger dopant-polymer interactions than analogous film structures.

Conclusions The electrical performance of electrospun conjugated polymer fibers arises from the combined effects of molecular design, solution formulation, electrospinning conditions, morphology, and post-processing treatments. The presented examples show that electrospinning should be regarded not only as a fabrication technique but also as a powerful tool for tailoring charge transport properties. Understanding the interplay between processing and doping provides valuable guidelines for the development of next-generation electrospun materials for wearable and flexible electronic applications.

Key words Conjugated polymers; Electrospinning; Nanofibers; Doping; Charge transport; PEDOT:PSS; Organic electronics; Wearable electronics.

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Posters

P-01

32 - ELECTROSPUN CELLULOSE ACETATE NANOFIBERS FUNCTIONALIZED WITH ELECTROSPRAYED PS-POLYAMPS NANOPARTICLES FOR CATIONIC DYE REMOVAL

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Background/Rationale Cationic dyes from industrial effluents pose significant environmental risks due to their toxicity and persistence. While electrospun cellulose acetate (CA) nanofibers offer advantages for water treatment, pristine CA exhibits limited adsorption capacity for cationic pollutants. This study develops a functional composite membrane by integrating electrospun CA nanofibers with electrospayed polystyrene-poly(2-acrylamido-2-methyl-1-propanesulfonic acid) (PS-PolyAMPS) nanoparticles to enhance selective removal of cationic dyes through electrostatic interactions.

Materials and Methods CA nanofibers were fabricated via electrospinning, followed by uniform deposition of synthesized PS-PolyAMPS polymeric nanoparticles onto the fibrous surface using an electro spray technique. The composite membranes were characterized using Fourier transform infrared spectroscopy (FT-IR), thermogravimetric analysis (TGA), and scanning electron microscopy (SEM). Adsorption performance was evaluated against methylene blue (MB) and crystal violet (CV) as model cationic dyes.

Results FT-IR confirmed successful incorporation of sulfonic acid functionalities from PolyAMPS. SEM revealed homogeneous distribution of nanoparticles on the CA nanofiber surface while maintaining a highly porous morphology. TGA demonstrated enhanced thermal stability of the composite membrane. Adsorption studies showed high removal efficiency and rapid uptake kinetics for both MB and CV, attributed to strong electrostatic attraction between sulfonic acid groups and cationic dye molecules.

Conclusions The CA/PS-PolyAMPS nanocomposite membrane successfully combines the structural advantages of electrospun nanofibers with functional properties of anionic nanoparticles, creating a synergistic platform for efficient cationic dye removal. This scalable electrospinning-electro spray approach presents a promising strategy for advanced water purification applications targeting dye-contaminated wastewater.

Key words Electrospinning, Electro spray; Cellulose acetate nanofibers; PolyAMPS; Cationic dye removal; Nanofibrous composite membrane.

P-02

151 - PRINTING WITH SUBMICRON FIBRES BY ELECTROSTATIC STIRRING OF ELECTROHYDRODYNAMIC JETS

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Background/Rationale Electrohydrodynamic jets generated in air are typically very fast compared to speeds commonly encountered in microfluidics, where the medium is much more viscous than air. In Near-Field Electrospinning or NFES (Sun et al, 2006), the EHD jet is very fast and printing by controlling the needed XY-motions leads to liquid accumulation on the printed substrate. In addition, we are studying how to overcome instabilities like those described by Ramon et al (2024).

Materials and Methods We have built a home-made electrohydrodynamic printer with an XY stage and adjustable needle-to-collector distance. To overcome the mentioned limitations in printing speed, we have introduced electrostatic jet deflection (EJD), where auxiliary electrodes “draw” fibre patterns on the collector by electrostatically deflecting the airborne EHD jet.

Results 3D objects with submicron features have been printed by stacking nanofibers layer-by-layer at unprecedented frequencies and printing speeds (Liashenko et al, 2020). The sideways stirring of the jet can be very fast, enabling the combination of submicrometric resolution with high printing speed. 3D objects with submicron features can be printed by stacking nanofibers on top of each other (Liashenko et al, 2022) at layer-by-layer frequencies above 1 kHz, with printing speeds up to 0.5 m/s in-plane and 0.4 mm/s in the vertical direction, three to four orders of magnitude faster than techniques providing equivalent feature sizes. The method can also be used to determine the speed of the jet in situ, which is difficult to determine otherwise (Liashenko et al., 2021, 2024).

Conclusions By this method one can print a wide variety of structures including fibre tracks characterized by precisely defined width and fibre orientation. The dynamics of electrostatically stirred jets depend on ink rheology. The printing instabilities are associated with changes in drop size and composition and at the jet ejection point, which are related to the solvent evaporation and the drying of the drop surface.

Key words additive manufacturing, near-field electrospinning, NFES, electrohydrodynamic jet, electrostatic stirring

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P-03

95 - OPTIMIZING ELECTROSPUN CELLULOSE BASED SCAFFOLDS: ELECTRIC FIELD DESIGN AND MATERIAL MODIFICATIONS FOR BIOMEDICAL APPLICATIONS

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Background/Rationale Electrospinning is a highly versatile and scalable technique for the fabrication of nano to microscale nonwoven fibrous materials that have found widespread application in biomedical engineering. Due to their high surface to volume ratio, tunable porosity, and structural similarity to the natural extracellular matrix (ECM), electrospun fibrous scaffolds are particularly promising for tissue engineering, wound healing, and regenerative medicine. However, the performance and functionality of such fibers are strongly dependent on a complex interplay between material properties and processing conditions. While polymer–solvent interactions fundamentally determine solution rheology, viscosity, and conductivity, the design of the electrospinning setup and environmental parameters, such as humidity and temperature, critically influence jet stability, fiber morphology, and deposition behavior.

Materials and Methods In this study, we investigate two key factors central to the optimization of electrospun fibers for biomedical applications, combining computational modeling with experimental characterization. First, two and three dimensional electric field simulations are performed using the QuickField software to model different needle–collector configurations. The electric field plays a decisive role in jet initiation, trajectory, and fiber stretching during electrospinning, and thus directly impacts fiber alignment and uniformity. By systematically analyzing the spatial distribution and intensity of the electric field under various configurations, we identify how modifications in collector geometry—such as flat plates, rotating drums, or structured collectors—affect field gradients and fiber deposition patterns. These simulations provide valuable insight into the design of electrospinning systems that promote improved fiber alignment, enhanced uniformity, and higher deposition efficiency, which are critical for producing scaffolds with controlled anisotropic properties.

Results In parallel, we examine the influence of compositional modification and post processing on cellulose acetate (CA) based electrospun fibers, a material widely recognized for its biocompatibility and ease of processing. Specifically, the effect of incorporating calcium chloride (CaCl₂) as an ionic additive is investigated. The presence of such salts can alter the electrical conductivity and surface tension of the spinning solution, thereby influencing jet behavior and fiber formation. Scanning electron microscopy (SEM) is employed to quantitatively assess morphological changes, including fiber diameter distribution, surface structure, and the presence of defects, as a function of CaCl₂ concentration. These analyses enable a deeper understanding of how ionic additives can be used to tailor fiber morphology and macrostructure for specific biomedical applications.

Furthermore, the study explores the impact of post spinning chemical modification through the deacetylation of cellulose acetate to regenerate cellulose fibers. This transformation is particularly relevant for biomedical use, as it enhances hydrophilicity and can improve biodegradability and cell–material interactions. The mechanical properties, structural integrity, and degradation behavior of the resulting cellulose fibers are evaluated to determine how this chemical conversion affects their suitability as scaffold materials.

Conclusions Overall, this integrated computational and experimental investigation sheds light to the relationships between electric field configuration, material composition, and post processing in governing the structure and performance of electrospun cellulose based fibrous networks. The findings contribute to a more systematic understanding of electrospinning parameter optimization and support the rational design of advanced fibrous scaffolds tailored for medical and tissue engineering applications.

Key words Electrospinning, nanofibers, Cellulose-acetate, Computer modelling, Electric field, 3D fiber morphology

P-04

51 - ENABLING THE ELECTROSPINNING OF CARBOXYMETHYL CELLULOSE VIA PCL-BASED CORE-SHELL NANOFIBRES

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Background/Rationale Electrospun nanofibres have been widely investigated for drug delivery applications due to their high surface area and tunable structural properties. Among these, core-shell architectures are particularly attractive as they enable spatial separation of functional components and improved control over drug release profiles [1]. However, the direct electrospinning of hydrophilic polymers such as carboxymethyl cellulose (CMC) remains challenging due to limited chain entanglement, high solution viscosity, and strong intermolecular interactions [2,3]. This study aims to overcome these limitations by employing coaxial electrospinning to fabricate polycaprolactone (PCL)-based core-shell nanofibres incorporating CMC or CMC-polyvinyl alcohol (PVA) as the core, enabling the development of controlled drug delivery systems.

Materials and Methods Core-shell nanofibres were fabricated via coaxial electrospinning, using PCL as a hydrophobic shell material and either CMC or a CMC-PVA blend as the core. Optimised spinning parameters ensured stable jet formation and continuous fibre production. Ibuprofen (IBU) and ibuprofen sodium (IBU Na) were selected as model hydrophobic and hydrophilic drugs, respectively, to investigate encapsulation and release behaviour. Fibre morphology and diameter distributions were analysed using scanning electron microscopy (SEM), while transmission electron microscopy (TEM) was employed to confirm the internal core-shell structure. Encapsulation efficiency (EE) and in vitro drug release profiles were evaluated using UV-Vis spectroscopy.

Results Coaxial electrospinning successfully produced continuous, bead-free nanofibres with diameters ranging from approximately 330 to 770 nm. TEM imaging confirmed well-defined core-shell architectures, demonstrating effective encapsulation of the hydrophilic core within the PCL shell. The electrospinning process achieved high production yields (93–98%) and high encapsulation efficiencies (86–109%) for both drugs. Compared with monolithic fibre systems, core-shell nanofibres significantly reduced the initial burst release and enabled sustained drug release over 72 h. The hydrophobic PCL shell acted as a diffusion barrier, while the hydrophilic CMC-based core facilitated drug loading, resulting in tunable release behaviour. Differences in drug solubility further influenced release kinetics, with IBU Na exhibiting faster release compared to IBU.

Conclusions This study demonstrates that coaxial electrospinning is an effective strategy to fabricate CMC-based core-shell nanofibres despite the intrinsic spinnability limitations of CMC. The resulting fibres exhibit excellent structural integrity, high drug-loading efficiency, and controlled release behaviour. These findings highlight the potential of electrospun PCL/CMC core-shell systems as versatile and tunable platforms for advanced drug delivery applications, and provide insights into the design of nanofibres incorporating otherwise difficult-to-spin polymers.

Key words Electrospinning; Core-shell nanofibres; Carboxymethyl cellulose; Polycaprolactone; Controlled drug release

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P-05

73 - PROBING NANOSCALE FEATURES OF ELECTROSPUN AMORPHOUS SOLID DISPERSIONS USING ADVANCED BIOPHYSICAL ANALYSIS

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Background/Rationale Over 75% of emerging active pharmaceutical ingredients (APIs) suffer from low aqueous solubility which severely constrains their clinical application. One approach to overcome this issue is to disperse APIs in water-miscible polymer carriers to generate molecular dispersions of the API in the polymer (amorphous solid dispersions; ASDs) and remove the lattice energy barrier, thus improving API dissolution. However, the lower free energy of the crystalline form means that there is a major risk of API recrystallization upon storage. To comprehensively understand API recrystallization behavior in an ASD, in addition to the extent of crystallization as a function of time, gaining insight into the early-stage behavior of the drug within the polymer matrix is crucial for the development of stable and effective formulations. Small angle neutron scattering (SANS) has recently been shown to be capable of detecting nanoscale drug domains of ca 10 nm and lower [1]. In this study, poly(ϵ -caprolactone)(PCL) was used as the carrier polymer, and aspirin as a model drug to explore how the physical form of the aspirin changes within the PCL matrix upon wetting.

Materials and Methods ASDs were prepared by electrospinning at drug loadings of 10 and 30% (w/w, drug to polymer). The Sans2d instrument at the UK ISIS Neutron and Muon Source was used to analyze the nanoscale dimensions of phase-separated drug domains in the dry state and during D₂O buffer immersion at 0, 8, 15, and 19 hours.

Results Scanning electron microscopy images show that samples with 10% aspirin loading exhibit a uniform morphology, characterized by smooth, cylindrical fibers without any beads-on-string features observed. For 30% aspirin, there are deposits of aspirin on the fiber surface. In the SANS profiles for membranes with 10% drug loading the scattering exponent approaches 4, consistent with the Porod law, indicating smooth surfaces on the fibrous membranes. In contrast, the membrane with 30% drug loading exhibits a lower exponent ($3 < n < 4$), characteristic of surface fractals and suggestive of a rougher interface[2]. The SANS profiles for drug-loaded membranes upon D₂O immersion show scattering features related to drug-rich domains, indicating the formation of drug aggregates. Higher drug loadings lead to a higher extent of aggregation. In vitro release studies showed that fibers with 10% loading exhibited a more sustained release profile, whereas those with 30% loading displayed a pronounced initial burst followed by slower release.

Conclusions In this study, we successfully used SANS technology to capture nanostructural dynamic evolution of electrospun aspirin-PCL ASDs during incubation in D₂O. The results suggest that increasing drug loading promotes nanoscale drug-rich domains within the fibers. These aggregates appear to play a role in controlling release behavior, as larger domains require extended dissolution times. Overall, this work highlights that SANS provide a powerful approach for probing nanoscale drug-rich domains in electrospun ASDs, enabling their evolution to be correlated with drug release behavior.

Key words Amorphous solid dispersion; Electrospinning; Aspirin; Small angle neutron scattering; Drug-rich domain

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P-07

74 - NANOFIBER-REINFORCED GELMA-PCL COMPOSITE SCAFFOLDS FOR CARTILAGE REGENERATION

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Background/Rationale The aim of this work was to develop the cartilage phase of a scaffold for osteochondral tissue engineering. The scaffold was intended to mimic key structural and mechanical properties of native cartilage while being biocompatible and degradable. The concept was based on a hydrogel reinforced with electrospun nanofibers to combine sufficient mechanical stability with a biomimetic fibrous structure. The combination of electrospun PCL scaffolds with GelMA hydrogel was investigated to improve the mechanical behavior of the scaffold and to generate a nanofiber-reinforced composite suitable for cartilage regeneration.

The predefined design targets for the cartilage phase included a compressive modulus of 0.31 – 0.8 MPa and a thickness of 2 – 3 mm. These properties were selected to support the mechanical function of native cartilage and to reflect the in-vivo dimensions of cartilage in the knee.

Materials and Methods To enable one-step fabrication of three-dimensional PCL scaffolds with a height of 2 – 3 mm, several electrospinning-based 3D approaches were investigated. The modified insulated collector was found most suitable.

For this setup, a cylindrical aluminum block (7 cm height, 9 cm diameter) was insulated on the sides and placed on the flat collector, while the surrounding area was electrically shielded coated baking paper. Electrospinning was performed using a 0.6 mm nozzle at 23 °C and 30 % relative humidity, with a 15 cm working distance, a flow rate of 7 mL/h, and a spinning time of 2.5 h. The initial voltage was +20/-0 kV and was increased every 30 min by +2 kV at the positive electrode and -2 kV at the collector until +26/-8 kV was reached. In addition, the nozzle oscillated along one axis between 230 and 270 mm.

After spinning, the scaffolds were punched into 10 mm discs and stored in 70 % ethanol. For hydrogel infiltration, the PCL scaffolds were vacuum-treated to improve hydrogel uptake. GelMA hydrogel was then pipetted onto the scaffolds and heat-treated to support deeper and more homogeneous penetration. Hydrogel distribution was assessed qualitatively using Bradford reagent staining. Composite scaffolds containing 5% and 10% GelMA were mechanically characterized by unconfined uniaxial compression testing. In vitro cytotoxicity tests were conducted in accordance with ISO 10993-5 standards using L929 (fibroblast, connective tissue cell) and C28/I2 (chondrocyte, cartilage cell), and cell viability was assessed using the LDH (lactate dehydrogenase) assay. In vitro degradation profiles (n = 3) were evaluated by measuring the initial dry weights of the scaffolds (W_0), followed by incubation in 0.5 U/ml Proteinase XIV at 37 °C

Results The modified insulated collector enabled the production of stable one-layer PCL scaffolds within the required thickness range.

The resulting scaffolds showed a gradient in fiber morphology over the scaffold height. Fibers close to the collector were thicker ($3,16 \pm 0,11 \mu\text{m}$), whereas the outer surface consisted of thinner fibers (1.45 ± 0.17).

Bradford staining confirmed that hydrogel infiltration was improved by heat treatment at 40 °C compared with infusion at room temperature. Mechanical testing showed that scaffolds infiltrated with 5% GelMA reached an average elastic modulus of $0.42 \pm 0.16 \text{ MPa}$, while scaffolds filled with 10% GelMA reached $0.50 \pm 0.37 \text{ MPa}$.

All PCL and PCL-GelMA scaffold groups exhibited high cell viability, remaining above 90% at both 24 and 36 hours, with only a slight decrease over time. All values are well above the ISO cytotoxicity threshold of 70%, confirming the non-toxic nature of the materials.

An increase in degradation over time was observed in all groups, with GelMA-containing scaffolds exhibiting higher degradation compared to pure PCL groups.

Conclusions This study identified electrospinning with a modified insulated collector as the most suitable method for fabricating three-dimensional PCL scaffolds with a thickness relevant for cartilage regeneration.

The scaffolds exhibited a graded fiber morphology and could be successfully infiltrated with GelMA hydrogel after vacuum pretreatment. The resulting nanofiber-reinforced hydrogel composites achieved elastic moduli

within the range of native human cartilage, indicating strong potential for use as a cartilage phase in osteochondral scaffold systems.

Key words Electrospinning, PCL, Hydrogel, Composite, Tissue Regeneration, Cartilage

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P-08

165 - ANTIBACTERIAL ELECTROSPUN NANOFIBROUS MEMBRANES THROUGH SILVER-BASED FUNCTIONALIZATION

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Background/Rationale Preventing pathogen transmission remains a major challenge in the development of advanced filtration and protective materials. Electrospun polymeric nanofibers have emerged as promising candidates for these applications due to their high surface area to volume ratio and the possibility of incorporating multifunctional properties. Among the available antibacterial strategies, silver-based materials are particularly attractive because of their wide-spectrum antimicrobial activity and long-term effectiveness[1]. This study aims to compare two silver-based functionalization approaches for electrospun nanofibrous membranes applied for antibacterial filtration applications.

Materials and Methods Electrospun polymeric nanofibrous membranes were functionalized using two silver-based approaches. In the first method, silver nanoparticles (AgNPs) were incorporated into the polymer solution prior to electrospinning, resulting in their embedding within the fiber matrix. In the second method, stabilized electrospun membranes were coated with inorganic composite films containing silver nanoclusters by physical vapor deposition (PVD)[2,3]. Membrane morphology was examined by field emission scanning electron microscopy (FESEM), while surface wettability and elemental composition were assessed through contact angle measurements and energy-dispersive spectroscopy (EDS), respectively. Antibacterial activity was evaluated against representative Gram-positive and Gram-negative bacterial strains. Silver ion release tests were performed to investigate the stability and durability of the antibacterial functionality.

Results Both functionalization strategies successfully imparted antibacterial activity to the electrospun membranes. However, the PVD-based coatings exhibited a more uniform silver distribution and preserved the nanofibrous architecture more effectively than the direct incorporation of AgNPs[1]. Furthermore, the coated membranes showed a more controlled and sustained release of silver ions, resulting in improved stability and prolonged antibacterial performance.

Conclusions The findings demonstrate that both silver-based functionalization approaches are effective in producing antibacterial electrospun membranes. Nevertheless, the PVD-deposited inorganic coatings provided superior control over silver distribution and release while maintaining the structural integrity of the nanofibrous network. These advantages highlight the potential of PVD-engineered silver coatings as a promising strategy for the development of multifunctional electrospun materials for filtration, biomedical, environmental, and personal protective applications.

Key words PVA

Silver nanoparticles AgNPs, Electrospinning, PVD, Antibacterial, Coating

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P-09

175 - ELECTROSPUN NANOCOMPOSITE PATCH FOR LOCAL KETOPROFEN DELIVERY AND INFLAMMATION CONTROL

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Background/Rationale

Topical ketoprofen formulations are widely used for local inflammation, but their effectiveness may be limited by poor drug solubility, low skin permeation and suboptimal application properties. Electrospun membranes can offer a useful alternative when designed as dry, flexible and fast-dissolving systems. In this work, a hybrid topical patch was developed by embedding ketoprofen-loaded lipid nanovesicles (NVs) within polyethylene oxide (PEO) nanofibers, with the aim of combining easy handling, rapid hydration on moist skin, controlled drug release and improved local anti-inflammatory activity.

Materials and Methods Ketoprofen-loaded NVs were prepared by water injection followed by membrane extrusion. The dispersion was incorporated into a PEO solution and processed by single-needle electrospinning to obtain a dry nanocomposite membrane. The resulting ketoprofen-loaded hybrid patch was characterized in terms of morphology, drug distribution, vesicle integrity and thermal behavior. Drug release, in vitro permeation human stratum corneum and epidermis membranes, skin tolerability and local anti-inflammatory activity were also evaluated.

Results The optimized NVs showed a mean size of about 95 nm and a narrow size distribution, with a polydispersity index below 0.1. Their incorporation into PEO fibers produced a homogeneous porous membrane with an average fiber diameter of about 800 nm. Cryo-TEM confirmed that the vesicles preserved their supramolecular organization after electrospinning. PEO fibers containing free ketoprofen released most of the drug within the first hour, while ketoprofen-loaded NVs provided a slower release up to 48 h. The hybrid patch reduced the initial burst and produced a more gradual release profile, suggesting that the hydrated polymer network and the embedded vesicles acted together in controlling drug diffusion. This resulted in

improved skin delivery, with ketoprofen permeation approximately 10-fold higher after 3 h and 30-fold higher compared with a conventional ketoprofen gel. In healthy volunteers, the patch did not induce relevant changes in erythema index or transepidermal water loss after repeated applications. In a methyl nicotinate-induced erythema model, it reduced skin redness by about 60% after 10 min, indicating a rapid local anti-inflammatory effect.

Conclusions The developed system should be considered as a fast-dissolving electrospun topical patch rather than a simple drug-loaded membrane. Its value lies in the integration of three functions in a single product: dry handling before use, rapid hydration and gel-like conversion after contact with moist skin, and controlled ketoprofen delivery through the combined action of PEO nanofibers and lipid NVs. These features make the patch a promising electrospun formulation for localized inflammation treatment.

Key words Electrospinning; lipid nanovesicles; ketoprofen; topical delivery; controlled release.

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P-10

78 - NITROGEN PLASMA-ASSISTED MODIFICATION OF PLA NONWOVENS FOR KERATIN IMMOBILIZATION AND SKIN REPAIR APPLICATIONS

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Background/Rationale Poly(lactic acid) (PLA) is a biodegradable and biocompatible polymer widely used in biomedical applications, particularly in tissue engineering. Its processability into fibrous structures via electrospinning allows for the fabrication of nonwovens that mimic the architecture of the extracellular matrix, promoting cell adhesion and proliferation. However, the inherent hydrophobicity and limited surface functionality of PLA may limit its biological performance. Surface modification techniques, such as plasma treatment, can offer a different approach to introduce functional groups and improve material bioactivity. Nitrogen plasma treatment can enhance surface reactivity, enabling the immobilization of bioactive molecules such as keratin—a structural protein known to support skin regeneration processes [1], [2].

Materials and Methods Electrospun PLA nonwovens were fabricated using a 12% (w/v) PLA solution in DCM:DMF (4:1) under controlled processing conditions to obtain uniform fibrous structures. The obtained materials were subsequently modified using low-temperature plasma treatment in a nitrogen atmosphere to introduce reactive functional groups onto the fibre surface. Following plasma activation, keratin was immobilized onto the modified PLA nonwovens.

Surface chemistry changes were evaluated using Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Photoelectron Spectroscopy (XPS). Morphology and fiber structure were analyzed by Scanning Electron Microscopy (SEM). Wettability measurements were performed to assess changes in surface hydrophilicity. Biocompatibility was evaluated in vitro using HaCaT human keratinocytes and RAW 264.7 murine macrophages. Additionally, in vivo studies in a rat model are planned to assess the potential of the modified materials for supporting skin regeneration.

Results Nitrogen plasma treatment effectively altered the surface properties of PLA nonwovens, increasing surface energy and improving hydrophilicity. FTIR analysis confirmed the successful immobilization of keratin on the modified surfaces through the appearance of characteristic protein-related bands. XPS results further verified the effectiveness of plasma treatment, indicating the incorporation of nitrogen-containing functional groups and confirming surface activation.

SEM observations demonstrated that plasma treatment and keratin immobilization did not significantly affect fiber morphology or structural integrity, with the fibrous architecture and diameter remaining largely unchanged. In vitro studies indicated enhanced cellular response of the modified materials, including improved adhesion and proliferation of HaCaT keratinocytes and RAW 264.7 macrophages compared to unmodified PLA, suggesting increased biocompatibility.

Conclusions The combination of nitrogen plasma treatment and keratin immobilization represents an effective strategy to enhance the biological performance of electrospun PLA nonwovens. The developed materials show potential for application in skin regeneration and wound healing.

Key words Poly(lactic acid), nitrogen plasma, keratin, skin regeneration, electrospinning

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182 - ELECTROSPUN PAN-BASED AEROGELS FOR HEMOADSORPTION: TAILORING MORPHOLOGY AND MECHANICAL PROPERTIES THROUGH ETHANOL-ASSISTED FREEZE-DRYING AND HEAT TREATMENT

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Background/Rationale Hemoadsorption is an extracorporeal blood purification technique based on the direct contact of blood with a solid adsorbent. Polyacrylonitrile (PAN) aerogels derived from electrospun nanofibers are promising sorbents due to their biocompatibility, high porosity, specific surface area, and low density; however, their mechanical fragility may limit their application. This study investigated the effect of ethanol concentration during freezing and subsequent thermal treatment on the morphological and mechanical stability of PAN aerogels.

Materials and Methods PAN membranes were electrospun from a solution of PAN 12% (w/w) DMF, fragmented, dispersed in water–ethanol mixtures (10 or 25% v/v), homogenized, frozen in liquid nitrogen, freeze-dried, and thermally treated at 150 or 180 °C for 1 h.

Results Morphological analysis showed a more ordered and interconnected structure at 10% ethanol, whereas 25% ethanol resulted in a less uniform architecture due to the complex crystallization behaviour of the water–ethanol system. Cyclic compression tests showed the highest recoverability for the 25% ethanol–180 °C aerogel, maintaining ~80% recovery at 50% strain. Creep tests identified the 10% ethanol–180 °C aerogel as the most stable under sustained loading, with ~35% strain during the creep phase and only 4.4% residual strain after recovery.

Conclusions Modulating the freezing solvent composition and applying a thermal treatment at 180 °C effectively improved the mechanical properties of PAN nanofibrous aerogels, overcoming their intrinsic fragility. Future studies will focus on thoroughly evaluating the influence of the different pore morphologies on the material's overall performance.

Key words Electrospinning, PAN aerogels, Freeze-drying, Ethanol-assisted freezing, Hemoadsorption

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P-12

23 - GREEN FABRICATION OF POLYMERIC NANOFIBERS INCORPORATED OIL DERIVED FROM DATE SEED AS SUSTAINED DRUG DELIVERY SYSTEM

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Background/Rationale Nanofibers based drug delivery systems developed particularly by emulsion electrospinning methods with capable of being tailored release mechanism including sustained and extended-release systems. Due to their extensive properties, recent studies have combined electrospinning as a versatile and efficient technique to produce nanofibers that can serve as drug delivery systems. The technique yields nanofibers with a high surface area-to-volume ratio and tunable porosity. The advancement of modern drug release systems in pharmaceuticals emphasizes controlled and sustained release formulations that improve therapeutic efficacy and reduce negative effects. These systems employ diverse polymers and delivery mechanisms to attain specified release profiles, guaranteeing that medications are administered at a uniform rate over time.

Materials and Methods DSO (Date Seed Oil) was extracted from seeds via two distinct procedures with solvents of differing polarity. The core-shell structured nanofibers encapsulated antibiotic were fabricated by emulsion electrospinning using biocompatible and biodegradable polymeric mixtures loaded with DSO as an oil-in-water emulsion system. The amount of DSO in polymeric mixtures were optimized. Poly Vinyl alcohol (PVA) and Dextran are the polymer mixture used in different ratio as shell in fabrication of nanofibers.

Results The smooth and bead less morphology of the nanofibers and the form of the core-shell structures were observed by Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM), respectively. The OH interaction between the polymeric mixture and drug was confirmed by the prominent peak at 1050-1000 cm^{-1} . The addition of dextran to the PVA lowers the Tg because of the interaction between the two polymers, while the addition of oil raises the Tg because oil contains a number of components that interact with the mixed polymers during crosslinking. Additionally, GC-MS characterization has been utilized to examine the role of solvent in oil extract. The drug-loaded nanofibers varying with different volumes of DSO, displayed an initial burst release based on the solvent used for DSO extraction and the amount of DSO present. The mechanism of drug release was assessed by the Korsmeyer-Peppas, Higuchi and Hixon-Crowell kinetic models.

Conclusions Emulsion electrospinning technique was used for fabrication of new drug release systems that involved a date seed oil derived from biowaste combined with a biopolymer Dextran and a synthetic polymer PVA for the fabrication of core-shell nanofibers. The smooth morphology and core shell structure was clearly observed from SEM and TEM. Physical characterization methods FTIR confirmed the formation of hydrogen bonding between polymeric chains, and polymer-drug. Thermal analysis showed the increased thermal stability of oil and drug encapsulated nanofibers. DSC analysis showed single Tg value confirmed the polymeric interaction. The lowest amount of drug release was observed for PDCO-hex-b around 26.86% in 24 h. The mechanism drug release was assessed by Korsmeyer-Peppas, Peppas-Sahlin, Higuchi, and Hixon-Crowell kinetic models. The kinetic drug release showed that the Korsmeyer-Peppas model was the most suitable fit, confirming the Fickian diffusion release mechanism.

Key words date seed oil; drug release; emulsion electrospinning; biocompatible polymers

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93 - FULLY INORGANIC ELECTROSPUN COPPER-DOPED BIOACTIVE BORATE GLASS FIBERS

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Background/Rationale Borate bioactive glasses are degradable inorganic materials capable of releasing biologically active ions and being tailored for regenerative applications. Their fibrous forms are of particular interest due to their high surface area and ECM-like morphology, which supports cell attachment and tissue regeneration. In the context of wound healing, there is a growing shift toward advanced bioactive dressings capable of actively modulating the healing cascade, including inflammation, proliferation, and tissue remodeling. BBGs also allow incorporation of therapeutic ions such as copper, which is known to promote angiogenesis and exhibit antibacterial activity. Therefore, the development of Cu-doped BBG fibers using electrospinning offers a promising strategy for multifunctional bioactive wound dressings and materials for regenerative medicine.

Materials and Methods Borate glass fibers from the $\text{CaO-B}_2\text{O}_3\text{-P}_2\text{O}_5$ system modified with copper ions were fabricated via a core-shell electrospinning process, where a polymer shell enabled fiber formation and stabilization, followed by thermal treatment to obtain inorganic fibrous materials. The morphology and microstructure of the obtained fibers were investigated using scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM/EDS). Phase composition and amorphous character of the materials were evaluated by X-ray diffraction (XRD), while structural analysis was performed using Fourier transform infrared spectroscopy (FTIR).

The in vitro bioactivity of the fibers was assessed by immersion in simulated body fluid (SBF). After incubation, surface morphology and chemical composition changes were analyzed using SEM/EDS, while FTIR was applied to identify structural changes and formation of an apatite-like layer. Ion release profiles during immersion were determined by inductively coupled plasma optical emission spectroscopy (ICP-OES).

Results SEM analysis revealed that the obtained fibers were smooth, homogeneous, and defect-free, with randomly oriented morphology. FTIR spectra confirmed the presence of characteristic bands associated with the borate glass network, while XRD analysis indicated the predominantly amorphous nature of the materials. Following immersion in simulated body fluid (SBF), the transformation of fibers into apatite-like phase was observed by SEM and FTIR analyses, indicating the high in vitro bioactivity of the materials. ICP-OES results demonstrated changes in ion concentrations during incubation, confirming ongoing ion exchange processes between the glass fibers and the incubation fluid.

Conclusions The study demonstrated for the first time the successful fabrication of fully inorganic copper-modified borate glass fibers with homogeneous morphology and amorphous structure. The obtained materials exhibited high in vitro bioactivity and ion release capability, indicating their potential for wound healing and tissue engineering applications.

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Key words bioactive borate glass, electrospinning, core-shell, sol-gel method, therapeutic ions

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94 - FIRST FULLY CERAMIC BORATE BIOACTIVE GLASS FIBERS OBTAINED VIA ELECTROSPINNING

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Background/Rationale Bioactive glasses are biocompatible materials that promote the formation of new bone tissue, thereby contributing to the regeneration process. They can be used as bone defect fillers, coatings for implants (e.g., titanium implants), scaffolds, bone cements component of toothpastes and composites, supporting the treatment of hard tissue.

The most commonly used bioactive glasses are silicate-based ones. They are mainly applied in bone tissue regeneration. However, due to their slow degradation rate and incomplete dissolution, they are less attractive for soft tissue regeneration applications. Instead, materials with faster degradation rates, such as phosphate or borate glasses, are being developed for these purposes.

Bioactive borate glasses (BBGs) are a group of materials particularly attractive for the treatment of chronic wounds, provide controlled release of therapeutic ions, and serve as biodegradable scaffolds for skin regeneration.

The wound healing process consists of four stages: hemostasis, inflammation, cell proliferation, and extracellular matrix remodeling. In the case of chronic wounds and infection, the inflammatory response is unable to eliminate the infection with the support of the immune system; consequently, materials with antibacterial activity, capable of reducing inflammation, and accelerating healing processes are required. Conventional treatment methods involve the use of collagen-based dressings, natural polymers, or vacuum-assisted therapy. Innovative approach includes the application of bioactive and highly soluble glasses, for example in the form of fibers. Wound treatment is based on the rapid release of boron, calcium, and phosphorus ions. The dissolution of large amounts of Ca^{2+} from the glass promotes the migration of epidermal cells into the wound site and contributes to skin regeneration. Boron enhances vascularization by stimulating vascular endothelial growth factor (VEGF) and basic fibroblast growth factor (bFGF), which are crucial for angiogenesis and wound healing. Furthermore, an important property of borate glasses is their antibacterial activity.

Materials and Methods In this study novel method for producing fibrous borate bioactive glasses has been developed. Glasses were manufactured using sol-gel method combined with electrospinning. Sol of the borate glass is non-spinnable therefore the core-shell technique was implemented. Sol of the glass in ternary oxide system $\text{CaO-B}_2\text{O}_3\text{-P}_2\text{O}_5$ was used as a core and polymer polyvinylpyrrolidone as a shell. The next step was calcination at 500°C to remove the organic parts. The materials were characterized in terms of their structure (FTIR, Raman), phase composition (XRD) and ability of glass transformation into calcium phosphate biomimetic phase (SEM, FTIR, ICP-OES).

Results The obtained fibers are continuous, defect-free and fully inorganic. It was shown that $\text{B}_2\text{O}_3/\text{CaO}$ molar ratio greatly affected fiber morphology and diameter. The FTIR spectra reveal the borate units characteristic of borate glass network. The glass incubation in simulated body fluid (SBF) confirmed that materials demonstrate rapid apatite-like transformation just after few hours of immersion.

Conclusions The fibrous bioactive borate glasses were obtained for the first time via electrospinning. The fiber morphology and diameter were affected by $\text{B}_2\text{O}_3/\text{CaO}$ molar ratio. Their properties suggest they could be effectively used in fiber form to support the regeneration of soft tissues.

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Key words Bioactive borate glasses, glass fibers, core-shell, soft tissue regeneration

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125 - IMPACT OF APPLIED VOLTAGE ON THE VIABILITY OF ENCAPSULATED MICROORGANISMS DURING ELECTROSPINNING

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Background/Rationale Electrospinning is a polymer processing technique well known for its convenient use and wide applicability. It allows fibre fabrication using combinations of multiple polymers, loaded with drugs, bioactive ingredients, and even cells. Over the past decade, numerous studies have demonstrated that electrospinning is a promising technique for encapsulating probiotics for targeted delivery for optimum nutritional benefits.

The electrospinning process involves high voltage and high shear stress at the nozzle during ejection, which may negatively affect the viability of the encapsulated microorganisms. However, compared with the growing development in fabrication and delivery, there is limited research that has investigated how these processing parameters may affect the viability of microorganisms.

Materials and Methods In our research, we investigate the influence of the applied voltage on the viability of encapsulated microorganisms. A variety of microorganisms are evaluated under different electrospinning conditions, and their viability has been studied by microscopic and optical density measurements. In this contribution, we will report on the impact of high applied voltage in electrospinning on the viability of *Lactobacillus rhamnosus* (*L. rhamnosus*). First, fibre networks with incorporated *L. rhamnosus* were manufactured via electrospinning of simple mixtures of polyethylene glycol (PEG) with *L. rhamnosus* under various voltage conditions, i.e. 10 to 25kV. After fabrication, the network was soaked in water, allowing PEG to dissolve, and ultimately the viability of the *L. rhamnosus* was assessed by optical density measurement.

Results It is expected that increasing the applied voltage during electrospinning will lead to a reduction of the viability in *L. rhamnosus*. The optimal voltage range is anticipated to be identified, and it will produce consistent and smooth fibre while maintain high bacteria viability.

Conclusions We envision our findings providing practical guidance for selecting parameters for future research on the electrospinning of live microorganisms, including probiotics. The work will be of relevance to the growing community in the food and nutraceuticals sectors interested in applying electrospinning for bioactive/probiotic encapsulation.

Key words Electrospinning, Microorganisms, Probiotics, Process parameters, *Lactobacillus*

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65 - EFFECT OF MOLECULAR WEIGHT ON STRUCTURE, SURFACE CHARGE AND BIOINTERFACIAL INTERACTIONS OF ELECTROSPUN POLY(VINYLIDENE FLUORIDE) NONWOVENS

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Background/Rationale The performance of biomaterials is determined primarily by the physicochemical properties of their surface, which control interactions with the biological environment. Among these properties, surface charge and wettability strongly influence protein adsorption, ion distribution, and cellular responses. Electrostatic interactions at the interface can affect protein organization and the local concentration of biologically important ions, such as calcium, involved in signaling pathways [1].

Poly(vinylidene fluoride) (PVDF) is a promising material for tailoring interfacial properties due to its dipolar nature and polymorphism. Polar crystalline phases allow modulation of surface charge without additional chemical modification. Moreover, electrospinning produces fibrous structures with high surface area and promotes chain alignment, affecting crystalline phase composition and surface-related phenomena [2].

Despite extensive studies on the processing-structure relationships in electrospun PVDF systems, the role of fundamental polymer parameters, such as molecular weight, in governing biointerfacial properties remains insufficiently understood. In particular, there is a lack of systematic investigations linking molecular weight-dependent changes in crystalline structure and surface charge to the material's ability to interact with ions and biomolecules.

In this work, we address this gap by examining how molecular weight influences the structure, surface properties, and biointerfacial behavior of electrospun PVDF nonwovens, with a particular focus on surface charge, wettability, and their impact on calcium ion affinity and protein interactions.

Materials and Methods The polyvinylidene fluoride (Mw~275 kDa and ~600 kDa) solutions were prepared using dimethylformamide (DMF) and acetone (Ac). Before electrospinning, the solutions were homogenized using ultrasonic homogenizer. An electrospinning machine able to stabilize humidity and temperature was used to obtain the fibres.

Scanning Electron Microscopy (SEM) was used to assess fibre morphology and diameter distribution. Differential Scanning Calorimetry (DSC) was used to determine crystallinity of the materials and phase composition. Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Diffraction (XRD) were further used to study crystalline phases of PVDF.

The surface charge was measured to determine the sign and amount of the charge on the nonwoven. In addition, a test with Ca²⁺ ions was conducted by incubating the nonwoven fabric in a CaCl₂ solution and measuring the calcium ion concentration before and after incubation using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) to indirectly estimate the surface charge density by observing the adsorption of positively charged ions onto the surface.

Results Electrospinning parameters were optimized for both PVDF molecular weights. Based on SEM images, fibres were measured and their average thickness for both PVDF Mw was found around 120 nm, although higher molecular weight PVDF (600 kDa) produced more uniform fibres.

DSC indicated variations in crystallinity, with the 600 kDa samples showing a higher degree of crystallinity. Similarly, FTIR and XRD confirmed the higher presence of β -phase compared to initial polymers, due to in situ poling process occurring during electrospinning, with a higher amount detected in the 600 kDa samples. Measurements of surface charge and calcium ion adsorption revealed that the nonwovens are negatively charged, with a stronger negative charge present on the 600 kDa nonwovens.

Conclusions PVDF molecular weight plays a critical role in determining fibre structure and β -phase formation. The 600 kDa PVDF electrospun nonwovens show enhanced potential for use in soft tissue repair applications, where mechanical-electrical coupling can promote tissue regeneration.

Key words Poly(vinylidene fluoride), piezoelectric, biointerface, cells-materials interaction

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P-17

130 - DEVELOPMENT AND CHARACTERISATION OF POLYMER NANOFIBERS CONTAINING MAGNETITE PARTICLES

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Background/Rationale The biomedical application of metal colloidal materials has experienced dynamic growth in recent years, owing to their versatile utility in targeted drug delivery, diagnostics, and therapeutic procedures. Notably, the broad-spectrum antibacterial activity of these colloidal particles—driven by multiple simultaneous mechanisms, such as the generation of reactive oxygen species and the physical disruption of cell membranes—offers a promising alternative for overcoming escalating antibiotic resistance, while also showing significant potential in cancer therapies.[1] However, during their application, cytotoxicity is a critical factor, which is fundamentally determined by the physical and chemical characteristics of the particles. [2][3] The objective of our study is to develop a biocompatible, polymer-based wound dressing matrix incorporating embedded magnetite colloid particles (MPs). The integration of these magnetic particles is designed not only to enhance the mechanical and antimicrobial properties of the dressing but also to provide a unique opportunity for non-invasive monitoring. This work focuses on evaluating the composite system using Magnetic Resonance Imaging (MRI), enabling the in situ tracking of the scaffold, as well as the real-time assessment of its structural integrity and degradation dynamics.

Materials and Methods For the experiments, we produced polysuccinimide (PSI) by thermal polycondensation of L-Aspartic acid. MPs were made by a co-precipitation method and stabilized with oleic acid. The colloid particles were dispersed in a polymer solution, after which the nanocomposite was produced by electrospinning, using a rotating drum collector. The MPs were characterized by dynamic light scattering (DLS) and by transmission electron microscopy (TEM), while the PSI–MP network was examined using scanning electron microscopy (SEM) equipped with an EDX detector. The iron content of the electrospun scaffold was analyzed by UV-Vis spectroscopy. Residual solvent in the network was measured using gas chromatography (GCMS); mechanical- and MRI measurements were performed.

Results Magnetically active particles with the size of ~200nm were successfully synthesized in an aqueous system; however, homogenizing the MPs in an organic medium proved challenging. A fibrous system was successfully formed by electrospinning from the heterogeneous colloidal solution. SEM studies confirmed that the addition of magnetite particles increased the fiber diameter. The resulting scaffold was composed of fibers with diameters of approximately 600–700 nm, containing an average of 8 wt% MPs. TEM and EDX analyses proved that the particles are homogeneously distributed within the fibrous structure. Mechanical tests showed that the PSI scaffolds had lower tensile strength and Young's modulus than commercial gauze, but they exhibited much higher flexibility and elongation. Furthermore, statistical analysis confirmed that adding the magnetite particles did not significantly alter the mechanical properties of the polymer matrix.

Conclusions In summary we successfully created a MPs loaded dry electrospun scaffold which is residual solvent free and visible in MRI.

Key words polysuccinimide, wound dressing, electrospinning, magnetic particles, MRI

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P-18

71 - INVESTIGATION OF THE SWELLING KINETICS OF SUBMICRON- AND MICRON-SIZED HYDROGEL FIBROUS MESHES

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Background/Rationale Hydrogels are unique three-dimensional networks capable of absorbing large amounts of water, representing a state between liquids and solids. They play a pivotal role in modern medicine, ranging from advanced drug delivery systems to tissue regeneration, owing to a structure that resembles natural tissues and a sensitive response to environmental stimuli such as pH and osmolarity [1]. Electrospinning can be used to create fibrous hydrogel structures with a morphology mimicking the native extracellular matrix [2]. However, our knowledge of their swelling behavior is still limited. This research aims to characterize the morphology of hydrogel fibrous membranes crosslinked with 1,4-diaminobutane (DAB) based on poly(aspartic acid) (PASPDAB) and to investigate their pH-dependent macroscopic and microscopic swelling properties.

Materials and Methods Fabrics with different fiber thicknesses were synthesized from polysuccinimide (PSI) via electrospinning. To prepare PASPDAB hydrogel fibers, PSI was crosslinked with an ethanol solution of DAB and then hydrolyzed in a pH 8 buffer [3]. The morphology of the samples was examined using scanning electron microscopy (SEM) and confocal laser scanning microscopy (CLSM). Swelling tests were conducted over a pH range from 3 to 8, and swelling kinetics were studied through repeated pH changes between pH 3 and pH 8. Changes in sample size were monitored using a high-resolution camera, and the recorded image data were analyzed using ImageJ software. To determine the swelling half-life, we used a well-established computational model described in the literature [4].

Results A series of four distinct fibrous PSI meshes was synthesized to investigate the effect of fiber thickness on swelling behavior. Morphological analysis revealed that these samples provided a controlled progression of mean fiber diameters, ranging from approximately 620 nm to 1500 nm; specifically, the minimum and maximum local fiber diameters observed across this series were 406 nm and 1805 nm, respectively. The crosslinking and subsequent hydrolysis of the four PSI precursor meshes resulted in a distinct increase in fiber thickness. Upon swelling, the fiber diameters shifted significantly toward higher values; for the thickest sample, the mean diameter of 1514 nm increased to an average of 1652 nm at pH 3 and reached up to 2068 nm at pH 8. Furthermore, CLSM confirms that well-separated, individual fibers remain present in the native sample even after crosslinking.

The volume change yields a sigmoidal curve in a logarithmic plot, with an inflection point at a pH of approximately 6, both macroscopically and microscopically. According to kinetic studies, the majority of swelling occurs within the first hour. However, total swelling time and half-life are strongly dependent on fiber thickness; for instance, as thickness increases, half-life rises from 9.8 to 28.0 minutes, while the total time to reach equilibrium extends from approximately 360 to 5000 minutes.

Conclusions In summary, these fibrous hydrogels are flexible, suturable, and reproducible alternatives to brittle bulk gels, offering faster, more controlled, and reliable swelling responses suitable for various biomedical applications.

Key words Electrospinning, Hydrogel, Polysuccinimide, Poly(aspartic acid), Swelling kinetics

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P-19

120 - RECONSTRUCTING THE BLOOD-BRAIN BARRIER ON ELECTROSPUN NANOFIBERS: A STATIC VERSUS DYNAMIC APPROACH

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Background/Rationale The blood-brain barrier (BBB) regulates molecular exchange between the bloodstream and the central nervous system, creating a major challenge for drug delivery to the brain. Conventional in vitro BBB models based on static membrane inserts lack physiological relevance due to rigid substrates, absence of shear stress, and limited cellular diversity. To address these limitations, an advanced biomimetic BBB model was developed using electrospun nanofibers scaffold inserts combined with primary human brain microvascular endothelial cells (HBMECs), astrocytes, and pericytes under both static and dynamic culture conditions.

Materials and Methods Electrospun nanofibers were fabricated from 10% polyacrylonitrile (PAN) and 3% Jeffamine dissolved in dimethylformamide (DMF) and directly deposited on 3D printed plate inserts. Scaffold morphology and structural properties were characterized by scanning electron microscopy (SEM) and optical coherence tomography (OCT). Cell cultures were established as mono- and tri-cultures under static conditions and within the QV1200 perfusion system (Kirkstall Ltd.) under dynamic flow to apply shear stress. Barrier integrity and cellular morphology were assessed by immunofluorescence staining for ZO-1, GFAP, and PDGFR β , followed by ImageJ and MATLAB analysis. Barrier function was evaluated via Transendothelial electrical resistance (TEER) and FITC-dextran permeability assay.

Results Scaffolds' analysis by SEM and OCT confirmed their extracellular matrix-like architecture, porosity ($38.9 \pm 4.2\%$), and thickness ($\sim 100 \mu\text{m}$). Compared with conventional porous membrane inserts, nanofibers-based cultures demonstrated enhanced tight junction formation, with ZO-1 solidity up to 3.2-fold higher under flow conditions, alongside increased astrocytic branching and more physiologically relevant pericyte morphology. Dynamic perfusion accelerated barrier maturation, reducing culture establishment time from 9 to 7 days while improving endothelial cohesion. Functionally, nanofibers scaffolds exhibited increased TEER, indicating improved barrier integrity. Permeability studies further demonstrated scaffold-dependent transport characteristics, highlighting the importance of integrating both structural and functional assessments in BBB model evaluation.

Conclusions Electrospun nanofibers scaffolds provided a biomimetic and physiologically relevant platform for BBB reconstruction. When combined with dynamic perfusion, the system improved barrier integrity, and accelerated maturation compared with conventional static membrane-based models. This platform offers significant potential for drug permeability studies, disease modelling, and the development of next-generation in vitro BBB systems for translational research.

Key words Blood-brain barrier; electrospun nanofibers; scaffolds; tight junctions; TEER.

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P-20

135 - DEVELOPMENT AND CHARACTERISATION OF MONOAXIAL AND COAXIAL PCL-BASED NANOFIBROUS SCAFFOLDS FOR LOCALISED GLIOBLASTOMA THERAPY

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Background/Rationale Glioblastoma (GBM) remains the most aggressive primary brain tumour, with high recurrence rates driven by residual infiltrative cells that survive surgery and systemic chemotherapy. Localised, implantable, drug delivery systems offer a promising strategy to bypass the blood-brain barrier and provide sustained therapeutic exposure as an adjuvant therapy to prevent recurrence.

This study developed and characterised electrospun polycaprolactone (PCL) based nanofibrous scaffolds for GBM therapy, with the delivery of Clomiphene citrate, a repurposed therapeutic that has demonstrated anti-proliferative effects in glioma cells by inducing apoptosis and inhibiting cell viability pathways. To optimise therapeutic delivery, monoaxial fibres and preliminary coaxial PCL (shell) and poly (lactic-co-glycolic acid) (PLGA; core) systems were developed for enhanced release control.

Materials and Methods Polycaprolactone (PCL), poly (lactic-co-glycolic acid) (PLGA), dichloromethane (DCM), dimethylformamide (DMF), 2,2,2-trifluoroethanol (TFE), and Clomiphene citrate were used as received. Nanofibrous scaffolds were fabricated via monoaxial electrospinning using optimised PCL solvent systems. Clomiphene citrate was incorporated (5–15% w/w) to evaluate encapsulation and release kinetics. Additionally, coaxial electrospinning was performed using PCL as the shell and PLGA as the core with 1 and 2% drug loading. Scaffolds were characterised via Scanning Electron Microscopy (SEM), Fourier Transform Infrared (FTIR), and UV-Visible Spectrophotometry to assess morphology, chemical interactions, and in vitro release monitored under physiological conditions (37°C).

Results Electrospinning produced smooth, bead-free nanofibers. Increasing Clomiphene citrate loading significantly increased average fibre diameters, while maintaining high encapsulation efficiency of more than 80%. FTIR confirmed successful physical encapsulation of the drug without altering the polymer backbone. In vitro studies revealed a biphasic release profile: an initial burst followed by sustained diffusion-controlled release over 48 hours. Higher drug loading correlated with increased burst release, likely due to greater surface associated drug content. Preliminary coaxial studies successfully demonstrated stable PCL PLGA core-shell formation, providing a more complex architecture for fine-tuning future drug release kinetics compared to monoaxial fibres.

Conclusions PCL nanofibrous scaffolds were successfully engineered with uniform morphology and high loading capacity. The transition to coaxial PCL-shell PLGA-core offers a viable pathway for more sophisticated, programmable drug delivery. These findings support the potential of electrospun implants as localised therapeutic platforms to improve outcomes in GBM treatment.

Key words Electrospinning, Nanofiber scaffolds; Polycaprolactone (PCL), Controlled drug release, Drug loading.

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P-22

62 - ELECTROSPINNING OF ELASTOMERS

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Background/Rationale Elastomeric materials offer remarkable elasticity, extensibility, flexibility, and resilience, making them highly desirable for diverse modern applications. Elastomer-based electrospun membranes are particularly well-suited for stretchable and wearable devices, tissue engineering, and selectively permeable membranes. Despite their advantages, the three-dimensional crosslinked network poses challenges for electrospinning due to poor solubility and processing limitations. Earlier studies depended on hazardous organic solvents such as acetone, dimethylformamide (DMF), and tetrahydrofuran (THF). Today, growing environmental and regulatory concerns drive the search for greener alternatives. Aqueous processing has emerged as a promising, sustainable route, typically utilizing small quantities of high-molecular-weight, water-soluble carrier polymers such as polyvinyl alcohol (PVA), polyethylene oxide (PEO), or polyvinylpyrrolidone (PVP) to enable electrospinning [1] [2].

Materials and Methods In this work, we aim to reduce the environmental impact of the process by using aqueous suspensions of natural rubber (NR) and styrene-butadiene rubber (SBR). Electrospinning is performed using PEO as the carrier polymer, with the elastomer/PEO ratio optimized to maximize elastomer content while maintaining spinnability. The morphology of the fibrous mats is characterized using scanning electron microscopy (SEM), and their mechanical properties are assessed via tensile testing. UV crosslinking experiments and viscosity measurements are also performed.

Results The results show a strong influence of formulation parameters (solid content, particle size, molar mass, and carrier polymer concentration) on fiber morphology. We successfully obtain nanofibrous mats with elastomer/PEO ratios up to 30:1. The fiber diameter increases with the SBR/PEO ratio, whereas it remains nearly constant for NR. The presence of PEO increases stiffness in both systems, as indicated by an increase in Young's modulus. After UV crosslinking and PEO removal, SBR mats retain their fibrous structure, suggesting a certain degree of crosslinking, whereas NR mats lose their structural integrity under similar conditions.

Conclusions These results demonstrate the feasibility of electrospinning both natural and synthetic elastomers using very low amounts of PEO, while highlighting the significant impact of its presence on the final properties of the resulting fibrous mats.

Key words elastomeric nanofibers, electrospinning, carrier polymer

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170 - ELECTROSPUN POROUS OXIDE NANOFIBER INTERLAYERS FOR REGULATING LITHIUM METAL INTERPHASES

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Background/Rationale Lithium metal batteries (LMBs) suffer from unstable solid electrolyte interphase (SEI) formation and dendritic lithium growth, limiting their practical application. Recent studies suggest that interphase chemistry plays a critical role in governing lithium deposition behavior. Therefore, regulating the interfacial environment near lithium metal anodes is essential for improving cycling stability and suppressing non-uniform lithium deposition.

Materials and Methods Porous oxide nanofiber interlayers were fabricated by electrospinning precursor solutions containing polymer carriers and metal oxide precursors, followed by thermal calcination to remove organic components and convert the precursors into oxide nanofiber networks. Representative oxide systems, including Al₂O₃, SiO₂, and ZrO₂, were investigated to compare the effect of oxide chemistry on interphase formation. The resulting porous oxide nanofiber membranes were integrated onto lithium metal anodes by hot pressing under controlled conditions, forming artificial protective interlayers at the electrode surface. The morphology and structure of the nanofiber interlayers were characterized, and their interfacial effects were evaluated through electrochemical cycling and post-cycling morphological analysis.

Results The porous oxide nanofiber interlayers provide a continuous and spatially confined oxide network at the lithium metal interface. Compared with unprotected lithium metal electrodes, the oxide nanofiber-modified electrodes showed improved interfacial stability during electrochemical cycling and more uniform lithium deposition morphology. The oxide-based interlayers are expected to facilitate the formation of inorganic-rich interphases and contribute to more homogeneous Li⁺ flux at the electrode surface, thereby mitigating dendritic lithium growth.

Conclusions This work presents a scalable strategy for interphase engineering through electrospun porous oxide nanofiber interlayers. By combining oxide surface chemistry with a structurally confined nanofiber network, this approach provides a promising platform for stabilizing lithium metal anodes and developing advanced lithium metal batteries.

Key words Electrospinning; Oxide nanofibers; Lithium metal batteries; Artificial interphase; Solid electrolyte interphase

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133 - COMPARTMENTALISED ELECTROSPUN-ELECTROSPRAYED COATINGS FOR SUSTAINABLE WOOD PROTECTION USING LIGNIN-BASED NANOMATERIALS

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Background/Rationale Wood protection requires surface treatments able to limit photodegradation, moisture uptake, biological colonisation and colour/texture alteration while preserving the natural appearance and permeability of the substrate. Conventional coatings often provide barrier protection, but may lack multifunctionality, sustainability or compatibility with bio-based circular-economy approaches [1]. Within the PRIN2022-NUTISFORU project, hazelnut biowaste was exploited as a source of functional lignin for the design of nanostructured protective coatings. Lignin-based materials (LNPs and TiO₂-lignin nanocomposites [2]) were selected as active components because lignin provides UV absorption, radical-scavenging activity and possible antimicrobial contribution, while TiO₂ offers photoactive behaviour that can be tuned through their combination. Electrospinning and electrospraying were used to fabricate compartmentalised multilayer coatings, where each layer was designed to contribute a specific function: surface adhesion, photoprotection, antioxidant/biological activity, water repellence and ageing resistance.

Materials and Methods TiO₂-lignin nanocomposites with different lignin contents were previously developed and characterised by FTIR, TEM, diffuse reflectance UV-Vis spectroscopy, antioxidant/radical-scavenging assays, dye adsorption/photocatalytic tests and preliminary antimicrobial/antifungal screening. Two systems, referred to as L50 and L400, were selected for coating integration. They differed in their TiO₂/lignin mass ratio, with L400 containing a higher lignin fraction than L50, thus providing complementary functional properties for multilayer coating design in photoprotective and antioxidant contributions. Multilayer coatings were fabricated on beech wood substrates through a sequential electrofluidodynamic approach. First, lignin nanoparticles were directly deposited onto the wood surface by electrospraying. Then, two electrospun nanofibrous layers based on poly(lactic acid) (PLA) or poly(3-hydroxybutyrate) (PHB) were sequentially deposited: an inner polymer layer containing L400, followed by an outer polymer layer containing L50. PLA and PHB were used in parallel to compare the effect of the biodegradable polymer matrix on coating morphology, surface stability, hydrophobicity and ageing behaviour. Coated samples were exposed to accelerated ageing under combined UV-Vis irradiation and controlled relative humidity. Optical stereomicroscopy images were acquired at different ageing times and analysed through descriptors related to brightness/intensity, texture, colour variation and surface heterogeneity. Water contact angle measurements were performed before and after ageing to evaluate hydrophobicity and water-repellent behaviour.

Results The sequential electrofluidodynamic process enabled the formation of continuous multilayer nanostructured coatings on beech wood, combining electrosprayed lignin nanoparticles with L400- and L50-loaded electrospun fibres. The coatings produced a thin fibrous network on the wood surface, maintaining partial visibility of the underlying substrate while introducing a functional nanostructured layer. After accelerated UV-humidity ageing, clear differences emerged between the two polymer matrices. PLA-based coatings showed more pronounced surface rearrangement, with stronger changes in brightness, texture and colour descriptors. In contrast, PHB-based coatings displayed a more stable surface morphology and better preservation of the coated appearance over the ageing cycles. WCA measurements showed that both PLA- and PHB-based multilayers increased the hydrophobic character of wood compared with untreated substrates. However, PHB-based architectures retained higher contact angles after ageing, indicating improved water-repellent stability. Overall, the results show that the combination of electrosprayed lignin nanoparticles and TiO₂-lignin-loaded electrospun fibres can generate compartmentalised protective coatings, with the biodegradable polymer matrix playing a decisive role in surface stability, hydrophobicity retention and ageing resistance.

Conclusions This work demonstrates that electrofluidodynamic processing can be used to fabricate compartmentalised multilayer coatings for sustainable wood protection. The proposed architecture integrated complementary functions, including interfacial compatibility, UV/antioxidant protection, hybrid photoactivity and polymer-mediated barrier behaviour. The comparison between PLA and PHB showed that the polymer matrix strongly influenced hydrophobicity, surface stability and ageing response. PHB-based architectures retained more promising water-repellent behaviour after UV–humidity ageing, while PLA-based systems showed more evident surface rearrangement and colour/texture variations. Overall, the results support the use of hazelnut-derived lignin and TiO₂–lignin hybrids as active components in bio-based wood coatings and highlight electrospinning/electrospraying as versatile tools for designing hierarchical protective layers with tunable functionality and reduced environmental impact.

Key words Electrospinning; electrospraying; electrofluidodynamic processing; wood protective coatings; lignin nanoparticles; TiO₂–lignin hybrids; biodegradable polymers; PLA; PHB; UV shielding; antioxidant activity; water repellence; accelerated ageing; hazelnut biowaste.

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34 - DEVELOPMENT OF PHASE CHANGE MATERIALS BY COMBINING ELECTROSPINNING WITH ELECTROSPRAYING

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Background/Rationale Form-stable phase change fibers (PCFs) have gained significant attention as advanced functional materials for thermal energy storage and smart textile applications [1]. The hybrid electrospinning/electrospraying approach enables precise control over fiber morphology and particle distribution, facilitating the development of hierarchical structures.

Materials and Methods N-eicosane was used as a phase change component. Polyethylene oxide (PEO) and poly(methyl)methacrylate (PMMA) were employed as the polymer matrix in the development of phase change fibers and particles loaded with n-eicosane, by using electrospinning and electrospraying, alone or in combination. Processing parameters influencing fiber formation, PCM encapsulation efficiency and particle dispersion are systematically investigated.

Results Giving further credence to our recent studies on the fabrication of n-eicosane-loaded electrospun PCF and evaluation of their thermal energy storage performance [2, 3], this study explores the fabrication of form-stable phase change materials in which electrospun fibers and combined with electrosprayed particles, both incorporating a selected hydrocarbon as the phase change component. The produced materials (fibers, particles and combine fiber/particle configurations) are characterized by using scanning electron microscopy (SEM) for morphological analysis, differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) for thermal performance and mechanical testing for structural evaluation.

Conclusions This new approach aims in enhancing thermal energy storage performance, structural stability and inducing multifunctional properties [4].

Key words Electrospinning; Electrospraying; Thermal analysis; Phase change materials

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106 - ELECTROSPUN NICKEL-BASED NANOFIBERS: A PLATFORM FOR SOFT ACTUATION SYSTEMS

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Background/Rationale Magnetic electrospun fibers have attracted significant attention in the development of soft actuation systems due to their unique combination of magnetic responsiveness, mechanical flexibility, and high surface-area-to-volume ratio [1]. These fibrous materials enable remote and reversible actuation under externally applied magnetic fields, offering precise control without direct physical contact [2]. The integration of nickel into electrospun polymeric fibers enhances magnetic, electrical, and thermal properties, making them suitable for multifunctional smart materials. Owing to their lightweight and porous structure, nickel-based electrospun fibers exhibit rapid response times, improved deformation capabilities, and adaptable mechanical behavior. Such characteristics are highly desirable in emerging applications including soft robotics, artificial muscles, wearable electronics, biomedical devices, and flexible sensors. Additionally, the ability of nickel-containing fibers to generate localized heating under alternating magnetic fields further expands their applicability in thermally responsive actuation systems. Recent advances in electrospinning and surface modification techniques have enabled improved control over fiber morphology, alignment, and magnetic performance. Consequently, nmagnetic fibers represent a promising platform for next-generation soft actuators with enhanced responsiveness, durability, and functional versatility.

Materials and Methods Nickel-coated nylon nanofiber mats were fabricated through a combination of sputter metallization and electrochemical deposition to obtain conductive nanostructures suitable for soft actuation applications. Initially, electrospun nylon nanofibers were coated with a thin conductive layer using magnetron-assisted sputtering to improve electrical conductivity and promote uniform nickel growth. Nickel deposition was then performed in an aqueous electrolyte solution under controlled temperature conditions using a standard three-electrode electrochemical setup. The electrodeposition process enabled the formation of conformal nickel coatings on the nanofiber surfaces, resulting in flexible and conductive fibrous structures. After synthesis, the samples were rinsed and dried under ambient conditions.

Results In this study, electrospun polymer nanofibers coated with nickel were developed to investigate their potential in remotely controlled actuation applications. The morphology and surface characteristics of the fibers were investigated by scanning electron microscopy (SEM), while their structural and compositional properties were analyzed using X-ray photoelectron spectroscopy (XPS), transmission electron microscopy (TEM) coupled with selected area electron diffraction (SAED), and X-ray diffraction (XRD). In addition, a thermal analysis and the actuation performance were evaluated through under induction heating conditions and movement displacement measurements to assess the dynamic response of the magnetic fibrous structures. The study demonstrates that nickel-based electrospun nanofibers represent a versatile platform for the development of next-generation smart soft actuators with remote control capabilities and multifunctional performance. The resulting nickel-coated fibers exhibited rapid and reversible responses under externally applied magnetic fields, enabling controlled deformation and motion without direct physical contact. Their high surface-area-to-volume ratio and porous architecture contributed to improved actuation efficiency and mechanical adaptability. Furthermore, the magnetic properties of nickel allowed localized heating and dynamic movement under alternating magnetic fields, making these materials suitable for soft robotics, artificial muscles, flexible sensors, and biomedical microdevices.

Conclusions Nickel-based electrospun fibers have attracted significant attention in the development of soft actuation systems due to their unique combination of magnetic responsiveness, mechanical flexibility, and high surface-area-to-volume ratio. These fibrous materials enable remote and reversible actuation under externally applied magnetic fields, offering precise control without direct physical contact. The integration of

nickel into electrospun polymeric fibers enhances magnetic, electrical, and thermal properties, making them suitable for multifunctional smart materials. Owing to their lightweight and porous structure, nickel-based

electrospun fibers exhibit rapid response times, improved deformation capabilities, and adaptable mechanical behavior. Such characteristics are highly desirable in emerging applications including soft robotics, artificial muscles, wearable electronics, biomedical devices, and flexible sensors. Additionally, the ability of nickel-containing fibers to generate localized heating under alternating magnetic fields further expands their applicability in thermally responsive actuation systems. Recent advances in electrospinning and surface modification techniques have enabled improved control over fiber morphology, alignment, and magnetic performance. Consequently, nickel-based electrospun fibers represent a promising platform for next-generation soft actuators with enhanced responsiveness, durability, and functional versatility.

Key words nickel, magnetic fibers, electrospinning, actuator, responsive materials

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173 - ELECTROSPUN METAL-COATED NYLON 6/6 FIBER NETWORKS INTEGRATED WITH PDMS FOR ARTIFICIAL MUSCLE APPLICATIONS

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Background/Rationale Electrospun fibrous materials offer unique advantages – such as high specific surface area, interconnected porous morphology, low weight, flexibility and tunable mechanical properties. These features have enabled their use in a wide range of fields, such as filtration, tissue engineering, sensing, energy storage, and smart materials. Among these applications, electrospun fibers have emerged as promising components for soft actuators, where their ability to provide mechanical reinforcement while maintaining structural flexibility is highly advantageous.

Soft actuators based on dielectric elastomers (DEAs) are widely investigated for biomimetic systems due to their large deformation capabilities, rapid response time, and compliance with soft biological tissues. As electronic electroactive polymers, DEAs convert electrical energy into mechanical motion, offering high energy density and muscle-like actuation behavior. Among these materials, polydimethylsiloxane (PDMS) is expensively employed due to its excellent elasticity, biocompatibility, and capacity to form conformal interfaces with various substrates. Integrating metalized electrospun fibrous networks into dielectric elastomer systems represents an effective strategy to enhance the structural integrity and electrochemical performance of soft actuators.

Materials and Methods Sylgard 184 Silicone Elastomer Kit from Dow Chemicals, USA, was used for obtaining PDMS sheets, while nylon 6/6 and formic acid ($\geq 88\%$) from Sigma-Aldrich were utilized in electrospun fiber meshes fabrication process. A gold target with 99.99% purity from Kurt Lesker was used for metalizing the fiber webs.

The fabrication of the actuating device involves three main stages, (i) preparation of PDMS sheets, (ii) fabrication and metallization of the electrospun fiber networks, and assembly of the two components. Initially, the PDMS prepolymer and curing agent were mixed in a 10:1 weight ratio, degassed to remove trapped air bubbles, and cast into thin films using a Byko Drive film applicator. The electrospun fiber networks were subsequently produced from a 22% (w/w) nylon 6/6 solution in formic acid. Electrospinning was carried out under the following operating conditions: an applied voltage of 25 kV, a spinneret-to-collector distance of 15 cm, and a solution flow rate of 0.2 mL/h. All the free-standing fiber networks were collected on copper wire frames. To impart electrical conductivity the electrospun fiber networks were coated with a thin gold layer by radio-frequency magnetron sputtering. The deposition process was performed in an argon atmosphere using a gold target, at a chamber pressure of 5.4×10^{-3} mbar and a magnetron power of 30W, for a deposition time of 2 h. For the final assembly, the gold coated electrospun fiber networks were transferred onto the warm PDMS surface, followed by thermal bonding at 120°C for an additional time of 30 min under mild compression. The resulting composite materials were subsequently cut into different geometries and dimensions for functional and actuating testing.

Results The Au/Nylon-PDMS actuator exhibited reversible bending actuation at low voltages (0.5–2.2 V), reaching a maximum displacement of 0.8 cm with good stability over 500 operating cycles. The actuation was driven by Joule heating and the mismatch in thermomechanical properties between the metallized electrospun fiber network and the PDMS layer. Experimental thermal characterization and finite element modeling confirmed a bilayer actuation mechanism, while uniform heating and rapid thermal response enabled efficient movement. The actuator also demonstrated wireless operation under an RF electromagnetic field, achieving fast and reversible bending without the need for direct electrical contacts.

Conclusions An artificial muscle based on electrospun nylon fiber networks and PDMS sheets was successfully developed, exhibiting reversible bending actuation, large displacement, and good mechanical stability. The combination of flexible metallized electrospun fiber electrodes and elastic PDMS enabled efficient actuation at low voltages, while the use of conductive fiber meshes promoted rapid heating and cooling. The actuation mechanism was governed by the mismatch in the thermomechanical properties of the two components and was consistent with theoretical predictions. Moreover, wireless actuation was

demonstrated under an RF electromagnetic field, highlighting its potential for soft robotic and biomimetic applications.

Key words metalized electrospun fiber networks, artificial muscles

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P-29**89 - DEVELOPMENT OF ANTIMICROBIAL POLYCAPROLACTONE ELECTROSPUN MATS LOADED WITH CARVACROL FOR FUNCTIONAL POLYMER SYSTEMS**

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Background/Rationale The development of polymeric systems with long-lasting antimicrobial functionality is of increasing interest for advanced materials intended for user-contact applications. Within the BIOADBACT project, electrospinning was investigated as a strategy to encapsulate natural essential oils into a polymeric nanofibrous matrix. Poly(ϵ -caprolactone) (PCL) was selected as the encapsulating polymer due to its processability, compatibility with solution-based fiber formation and suitability for producing flexible fibrous structures. The aim of this work was to obtain stable and processable electrospun mats containing bioactive compounds with potential antimicrobial functionality for future integration into functional polymer systems.

Materials and Methods Prior to electrospinning, the starting materials were characterized to support the formulation strategy and verify their suitability for the encapsulation process. Fourier transform infrared spectroscopy (FTIR) was used to confirm the structural identity of the polymeric matrix and the bioactive components, while differential scanning calorimetry (DSC) provided information about their thermal behavior. These preliminary analyses allowed the selection of suitable processing conditions and supported the development of formulations capable of generating continuous fibrous structures. Different solution compositions were evaluated in order to improve fiber formation, mat consistency and the incorporation of the essential oils into the PCL matrix.

Results The optimized formulation led to a stable electrospinning process and enabled the successful formation of continuous, uniform, and mechanically handleable PCL-based nanofibrous mats loaded with essential oils. The resulting mats could be removed from the collector and subjected to subsequent characterization. Optical microscopy revealed fibrous structures compatible with the formation of encapsulated domains within the polymeric matrix, although further analysis by higher-resolution techniques would be required to assess the detailed morphology, distribution and homogeneity of the encapsulated compounds. FTIR analysis of the final electrospun mats confirmed the simultaneous presence of characteristic signals associated with both PCL and the incorporated bioactive compounds, supporting the successful incorporation of the essential oils into the electrospun matrix.

The antimicrobial performance of the electrospun samples was preliminarily assessed by agar diffusion inhibition halo assays. The photographic evaluation showed visible inhibition zones around the electrospun mats containing essential oils, in contrast to the polymer control samples, which did not show observable inhibition. These results suggest that the antimicrobial activity of the encapsulated essential oils is retained after electrospinning. However, the intensity and definition of the inhibition zones may depend on factors such as the distribution of the active compounds within the fibers, the interaction between the oils and the polymer matrix, and possible storage-related effects.

Conclusions Overall, this study demonstrates the feasibility of producing PCL-based electrospun mats loaded with essential oils through solution electrospinning. The results highlight the potential of electrospinning as a versatile technique for incorporating natural bioactive compounds into polymeric nanofibrous platforms. The developed material represents a promising antimicrobial system for future integration into functional polymer applications, where controlled encapsulation, processability and preservation of bioactivity are key requirements.

Key words Electrospinning; Polycaprolactone; Essential oils; Antimicrobial nanofibers; Encapsulation

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83 - THERMORESPONSIVE CROSSLINKED ELECTROSPUN METHYLCELLULOSE FIBER MATS FOR WATER-RESPONSIVE MEMBRANE AND ACTUATOR APPLICATIONS

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Background/Rationale Thermoresponsive polymeric fiber networks are promising materials for applications in smart textiles, responsive membranes, and soft biomaterials. Methylcellulose (MC), a bio-based polymer, is particularly attractive due to its biocompatibility and temperature-dependent phase transition behavior. However, the fabrication of water-stable electrospun MC fiber mats with preserved thermo-responsivity remains challenging because of the inherent water solubility of MC.

Materials and Methods In this work, electrospun MC fiber mats were fabricated using poly(ethylene oxide) (PEO) as spinning aid and subsequently stabilized by crosslinking with citric acid. The influence of crosslinking conditions on the morphology, aqueous stability, and thermo-responsive behavior of the resulting fiber networks is currently under investigation.

Results Preliminary results demonstrate successful fabrication of homogeneous electrospun fiber mats and indicate that thermal treatment significantly improves structural stability in aqueous environments. Initial observations further reveal a pronounced temperature response above the lower critical solution temperature (LCST) of MC, including temperature-dependent opacity changes and structural contraction of the fiber mats in water. Ongoing work focuses on correlating crosslinking density with swelling behavior, morphological evolution, and reversibility of the fibers during cyclic temperature exposure.

Conclusions The presented work aims to establish structure–property relationships in thermoresponsive electrospun MC fiber networks and to provide a basis for future responsive membrane materials and soft actuator systems.

Key words electrospinning; methylcellulose; thermoresponsive fibers; citric acid crosslinking; smart materials; soft actuators

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172 - ONE-POT ELECTROSPINNING OF TEOS-DERIVED WO₃/PDO-BLENDED CERAMIC NANOFIBERS FOR VISUAL HYDROGEN COLOR-CHANGE SENSING

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Background/Rationale Hydrogen is a promising clean energy carrier, but its colorless, odorless, and highly flammable nature requires simple visual sensing platforms for early leakage detection. Colorimetric gas sensors are attractive because they provide direct information without complex electrical readout. Inspired by electrospun fibrous colorimetric sensing platforms, this study develops a tetraethyl orthosilicate (TEOS)-derived one-pot electrospinning strategy for fabricating WO₃/PdO-blended ceramic nanofibers for visual hydrogen sensing. The main concept is to incorporate tungsten and palladium precursors directly into a TEOS-containing spinning dope, so that the ceramic scaffold and gasochromic active components are integrated before fiber formation.

Materials and Methods A TEOS-based sol-gel spinning solution containing tungsten and palladium precursors was electrospun into precursor nanofiber mats, followed by thermal treatment in air. The resulting ceramic nanofibers were analyzed by electron microscopy, elemental mapping, phase analysis, and surface chemical characterization. Hydrogen-induced color change was evaluated using optical images, RGB analysis, UV-vis absorbance, and color difference values.

Results The one-pot electrospinning process produced continuous WO₃/PdO-blended ceramic nanofiber mats with a porous and interconnected morphology. The TEOS-derived ceramic framework preserved the fibrous network after high-temperature treatment, enabling the formation of a mechanically handleable ceramic sensing mat. This is important because unsupported ceramic oxide fibers can collapse, aggregate, or lose network continuity during calcination.

A key advantage of this process is that it avoids the difficulty of depositing active sensing components onto an already-formed TEOS-derived ceramic mat. Because the mat has a rough, porous, and three-dimensional fiber network, post-deposition methods such as sputtering are not suitable for forming a uniform active layer throughout the entire structure. In contrast, precursor-level one-pot blending introduces tungsten and palladium species before fiber formation, allowing the active components to be distributed more effectively throughout the nanofiber mat.

After thermal treatment at 800 °C, tungsten species underwent outward redistribution and crystallization, forming a WO₃-rich shell-like active surface on the TEOS-derived ceramic scaffold. This structure is beneficial because WO₃/PdO active sites are exposed near the gas-accessible surface rather than being buried inside a dense matrix. The electrospun nanofiber morphology further increases the effective surface area and creates open diffusion pathways for rapid gas access.

Upon exposure to 1–4% H₂, PdO was reduced to catalytically active Pd, which promoted H₂ dissociation and hydrogen spillover into the WO₃ lattice. This process induced the formation of hydrogen tungsten bronze-like species and generated a distinct gasochromic color transition from pale yellow or light gray to blue within 1 min. The optimized mat showed a color difference value higher than 60, indicating a strong and visually distinguishable response. In contrast, interfering gases such as NO, CO, and NH₃ produced color difference values below 5, confirming that the WO₃/PdO-blended nanofiber mat provides highly selective visual discrimination of H₂. These results demonstrate that TEOS-derived one-pot electrospinning can integrate structural stability, high effective surface area, shell-like WO₃ exposure, catalytic Pd formation, and selective visual hydrogen sensing in a single ceramic nanofiber mat.

Conclusions This study demonstrates a TEOS-derived one-pot electrospinning strategy for selective visual hydrogen color-change sensing. By incorporating tungsten and palladium precursors before fiber formation, this approach overcomes the nonuniformity and limited penetration of post-deposition processes on porous ceramic mats. The 800 °C thermal treatment produced a WO₃-rich shell-like active surface on the TEOS-derived ceramic scaffold, while PdO was converted to catalytically active Pd under H₂ exposure. The resulting Pd-assisted hydrogen spillover into WO₃ induced a rapid and distinct blue coloration within 1 min under 1–4% H₂, with a color difference value higher than 60. In contrast, NO, CO, and NH₃ showed negligible colorimetric responses with color difference values below 5, enabling selective visual

discrimination of H₂. This platform provides a scalable route toward uniform, porous, and visually readable hydrogen sensors based on metal oxide-blended ceramic nanofibers.

Key words TEOS; one-pot electrospinning; WO₃; PdO; ceramic nanofibers; gasochromic sensor; hydrogen sensing; color-change sensor; precursor blending; visual gas detection

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140 - MULTIFUNCTIONAL QUERCETIN/PEO NANOFIBERS FOR SUSTAINABLE AIR FILTRATION APPLICATIONS

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Background/Rationale Nanofibrous filtration materials have emerged as promising alternatives to conventional microfibrous filters owing to their high porosity, interconnected pore structures, and large specific surface area. These structural advantages enable efficient particulate capture while maintaining low airflow resistance. However, the development of sustainable filtration materials that simultaneously provide high filtration performance, environmental degradability, and additional functional properties remains a significant challenge. In particular, most commercial filtration media rely on petroleum-based polymers and provide only passive filtration. Here, we developed multifunctional quercetin/poly(ethylene oxide) (QU/PEO) nanofibers as a sustainable filtration platform that combines efficient particle removal, biodegradability, and bioactive functionality.

Materials and Methods QU/PEO nanofibers were fabricated using a scalable solution-blowing process. The morphology and fiber architecture were characterized by scanning electron microscopy, while physicochemical properties were investigated using X-ray diffraction, Fourier-transform infrared spectroscopy, and thermogravimetric analysis. Mechanical properties were evaluated by tensile testing. Filtration performance was assessed using PM0.5 particles and NaCl aerosols under simulated breathing conditions. Biodegradation behavior was examined through soil degradation tests. To investigate the added functionality of the nanofibers, quercetin release behavior, cytocompatibility, oxidative stress regulation, and antiviral activity against SARS-CoV-2 were also evaluated.

Results The fabricated QU/PEO nanofibers formed a highly porous nonwoven network with an average fiber diameter of $1.12 \pm 0.47 \mu\text{m}$. The nanofiber structure exhibited excellent mechanical robustness, achieving a yield strength of approximately 30 MPa, which was significantly higher than that of conventional commercial mask filters.

The porous architecture enabled efficient particulate capture while maintaining favorable breathability. The QU/PEO nanofiber filter achieved a PM0.5 filtration efficiency of up to 96.2% with a low pressure drop of 20.4 Pa at an airflow rate of 20 L min^{-1} . In addition, NaCl aerosol filtration tests demonstrated enhanced filtration performance compared with commercial dental mask filters.

Environmental sustainability was demonstrated through rapid biodegradation under composting conditions. The nanofiber matrix decomposed substantially faster than conventional polypropylene-based filtration materials, indicating its potential to reduce disposable filter waste.

Physicochemical analyses confirmed the successful incorporation of quercetin within the nanofiber network. Sustained release of quercetin provided additional bioactive functionality without compromising filtration performance. The released quercetin reduced intracellular oxidative stress and inflammatory responses in human dermal fibroblasts and exhibited antiviral activity against SARS-CoV-2 pseudovirus and live Omicron variants. These results demonstrate that bioactive compounds can be integrated into nanofiber filtration systems to provide active functionality beyond passive particle capture.

Conclusions A multifunctional QU/PEO nanofiber filtration platform was successfully developed using a scalable nanofiber fabrication process. The resulting material combined high filtration efficiency, low airflow resistance, mechanical durability, rapid biodegradability, and bioactive antiviral functionality within a single nanofibrous architecture. This study demonstrates the potential of incorporating natural bioactive compounds into sustainable nanofiber filters and highlights their applicability as next-generation materials for air filtration and functional textile applications.

Key words Antiviral Quercetin/Poly(ethylene oxide) Nanofibers, Sustainable Biodegradable Filters, Functional Air Filtration

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P-33**159 - ELECTROSPUN PVDF-TRFE/BATIO₃ COMPOSITE NANOFIBRES FOR FLEXIBLE PIEZOELECTRIC SENSING**Qinrong He ⁽¹⁾ - Dagou Zeze ⁽¹⁾ - Ensieh Hosseini ⁽¹⁾⁽¹⁾ *Durham University, Department Of Engineering, Durham, United Kingdom*

Background/Rationale Electrospun functional nanofibres offer significant opportunities for the development of lightweight, flexible and highly responsive sensing platforms for wearable technologies. Among these materials, poly(vinylidene fluoride-co-trifluoroethylene) (PVDF-TrFE) exhibits excellent piezoelectric behaviour, which can be further enhanced through the incorporation of functional ceramic nanofillers. This work investigates electrospun PVDF-TrFE/BaTiO₃ nanocomposite nanofibres for flexible piezoelectric sensing applications.

Materials and Methods PVDF-TrFE/BaTiO₃ nanofibre mats containing different BaTiO₃ concentrations are being fabricated by electrospinning and integrated into flexible piezoelectric sensing devices. The morphology, crystalline structure and β -phase content of the nanocomposite fibres are being characterised using scanning electron microscopy, X-ray diffraction and Fourier-transform infrared spectroscopy. The electromechanical performance of the fabricated sensors is being evaluated under different pressure and frequency conditions, and their applicability for wearable sensing is being assessed through physiological signal monitoring.

Results Preliminary results indicate that the incorporation of BaTiO₃ enhances the crystallinity and β -phase content of the electrospun PVDF-TrFE fibres, leading to improved piezoelectric performance. The sensor containing 3 wt.% BaTiO₃ exhibits the highest sensitivity among the compositions investigated. The developed devices demonstrate a linear response to pressure and frequency stimuli and show the capability to detect arterial pulse signals and body motion.

Conclusions The results obtained demonstrate that electrospun PVDF-TrFE/BaTiO₃ nanocomposite fibres provide a promising platform for flexible and highly sensitive piezoelectric sensing. The combination of enhanced electromechanical performance and mechanical flexibility highlights their potential for wearable electronics, smart textiles and next-generation sensing systems.

Key words Electrospun nanofibres; PVDF-TrFE/BaTiO₃; Piezoelectric sensing; Wearable systems

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85 - ELECTROSPUN FIBER MEMBRANES FOR NONLINEAR OPTICS: DECOUPLING MEMBRANE ALIGNMENT AND DYE ORIENTATION

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Background/Rationale Oriented electrospun fiber membranes are a promising platform for nonlinear optical materials as electrospinning combines a high electric field, required both for jet formation and for the orientation of dipolar dyes within the polymer matrix, with ultrafast jet solidification, which freezes the molecules in the oriented state. The degree of optical anisotropy in a fibrous membrane is commonly quantified by the dichroic ratio, defined as the ratio of optical absorption measured for two mutually perpendicular orientations of the incident polarized light. However, the measured dichroic response reflects a combination of two distinct levels of order: the orientation of dye molecules within individual fibers and the orientation of the fibers within the membrane. To assess dye alignment correctly, membrane-scale disorder must therefore be separated from the intrinsic molecular orientation at the single-fiber level. At the same time, the choice of polymer matrix is expected to be critical because the host polymer determines both the nanofiber morphology and the local environment in which guest molecules are immobilized.

Materials and Methods Membrane-scale fiber orientation was quantified by computer-assisted analysis of SEM micrographs. The angular distribution of the fibers was converted into a second-order orientation tensor. The optical anisotropy of the membranes was quantified by measuring the dichroic ratio using UV-Vis spectroscopy.

Results Tensor formalism allows each partially oriented membrane to be treated as a superposition of two limiting cases: an ideally aligned membrane and an ideally isotropic membrane. Because each of these limiting states interacts with polarized light in a known manner, the experimentally measured dichroic response of a real membrane can be converted into the intrinsic dichroic ratio of the fibers without the need to isolate individual fibers. To identify polymer-related factors governing dye alignment, a broad set of electrospinnable matrices, including polyesters, polyethers, and polyamides, doped with various Disperse dyes, was screened. Membrane morphology, degree of fiber alignment, and optical anisotropy were compared quantitatively across these polymer families. Key requirements for the polymer matrices were formulated to ensure efficient transfer of polymer-chain orientation to the dopant molecules. The structural and electronic parameters of the Disperse dyes were investigated and correlated with the optical anisotropy of the electrospun membranes.

Conclusions Electrospinning provides a useful platform for the fabrication of dye-containing fibrous membranes with anisotropic optical response. The combination of membrane morphology analysis and polarized spectroscopy enables a more reliable evaluation of molecular orientation in such systems. The results also highlight the importance of polymer-matrix selection for achieving efficient guest-molecule alignment. Taken together, these observations support the potential of electrospinning as a versatile approach to the design of new fibrous nonlinear optical materials.

Key words electrospinning, fiber orientation, orientation tensor, nonlinear optics, dichroic ratio

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171 - HIGH-ENTROPY OXIDE NANOFIBER VIA ELECTROSPINNING FOR SELECTIVE DETECTION OF SULFUR GASES

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Background/Rationale High-entropy oxide (HEO) has emerged as a highly attractive candidate for next-generation gas sensing owing to its unprecedented compositional diversity, tunable oxygen vacancies, and robust crystal structure. However, synthesizing single phase HEO without phase segregation remains a formidable challenge. The complex thermodynamics and varying precipitation kinetics of multiple transition metal cations often lead to the formation of secondary phases during thermal treatment. In this regard, nanofibers fabricated via electrospinning offer a highly advantageous platform. The rapid solvent evaporation during electrospinning ensures the homogeneous dispersion of diverse metal precursors within the polymeric matrix, effectively restricting the mobility of individual ions. This confinement critically suppresses phase separation and facilitates the stabilization of a uniform high-entropy state upon calcination.

Materials and Methods In this work, five distinct types of HEO nanofibers, incorporating six different transition metals (Fe, Co, Ni, Cr, Mn, and Zn), were successfully fabricated via a facile electrospinning technique followed by a controlled thermal treatment. By systematically varying the stoichiometric ratios of five specific metal cations (Fe, Co, Ni, Cr, and Mn) within the hexanary system, we generated five unique compositional variants. Leveraging the spatial confinement of the electrospun template, a single spinel phase was successfully stabilized across all varying compositions. The microstructural, compositional, and morphological characteristics of the electrospun nanofibers were systematically investigated using Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), X-ray Diffraction (XRD), and X-ray Photoelectron Spectroscopy (XPS).

Results Detailed structural characterizations confirmed the formation of uniform, highly interconnected porous nanofiber networks for all five HEO variants. Elemental mapping further verified the uniform distribution of all six metallic elements without any noticeable elemental clustering or phase segregation, highlighting the distinct advantage of the electrospun architecture for realizing and precisely tuning the complex multi-elemental HEO system. When integrated into sensing devices, the five different HEO nanofibers exhibited tunable and composition-dependent gas sensing behaviors. Remarkably, by altering the internal elemental ratios, each of the five HEO compositions demonstrated tailored selectivity toward completely different types of target gases. Among them, a specific compositional variant showed distinct and highly sensitive responsiveness to sulfur-containing gases, demonstrating reliable gas responses and remarkable selectivity toward methyl mercaptan, a critical volatile sulfur compound and key biomarker associated with periodontitis.

Conclusions These findings not only underscore the viability of electrospinning as a highly effective and scalable strategy to overcome the thermodynamic hurdles of synthesizing multicomponent HEO, but also demonstrate the structural promise of HEO nanofiber platforms for practical, non-invasive bio-diagnostics and environmental monitoring applications.

Key words High Entropy Oxide Nanofiber, Spinel structure, gas sensor, methyl mercaptan

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90 - ONE-STEP FABRICATION AND DEPHOSPHORYLATION PERFORMANCE OF CeO₂-MODIFIED PA6 NANOFIBERS

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Background/Rationale Cerium dioxide nanoparticles (CeNPs or nanoceria) have gained significant attention due to their exceptional multi-enzyme mimicking properties, particularly their phosphatase-like activity, which allows for the hydrolytic cleavage of resistant phosphoester bonds. However, the practical application of loose nanoparticles is often hindered by their tendency to aggregate and the difficulty of their recovery from reaction media. Immobilization onto one-dimensional fibrous supports, such as Nylon 6 (PA6), offers a solution by providing a stable, high-surface-area platform with improved handleability. This study explores the development of functional PA6 electrospun nanofiber networks carrying CeNPs to create a robust catalytic system for the dephosphorylation of organophosphate diesters

Materials and Methods Two distinct types of CeNPs (CeAMM and CePER) were synthesized via low-temperature (<100 °C) water-based precipitation methods without subsequent calcination. To ensure optimal integration, colloidal solutions of these CeNPs in acetic acid (AcOH) were directly blended with a 16 wt % PA6 solution (dissolved in an acetic and formic acid mixture) before undergoing a needle electrospinning process. The resulting nanocomposite mats were characterized using X-ray diffraction (XRD), scanning and transmission electron microscopy (SEM/TEM) with EDS mapping, X-ray photoelectron spectroscopy (XPS), and zeta potential measurements to assess surface chemistry and particle distribution. The dephosphorylation catalytic activity was evaluated by monitoring the hydrolysis of three phosphodiester molecules—p-nitrophenyl thymidine 5'-monophosphate (p-NP-TMP), p-nitrophenyl phosphorylcholine (p-NPPC), and bis(p-nitrophenyl)phosphate (BNPP)—using HPLC/DAD to quantify parent compound degradation and product formation.

Results Characterization confirmed that CeNPs (crystallite sizes 2.9–3.8 nm) were successfully embedded within the structure and exposed on the surface of the PA6 nanofibers without degrading the polymer's original quality. XRD analysis indicated that the presence of CeNPs promoted the crystallization of the PA6 matrix. Zeta potential measurements showed a significant shift from –37.40 mV (pristine PA6) to values between –4.95 and –9.41 mV for the modified fibers, confirming the availability of the active catalyst surfaces. Both PA6-CeAMM and PA6-CePER mats exhibited robust catalytic activity in water, demonstrating both phospholipase C- and D-like activities. A unique synergistic effect was observed: while the CeNPs catalyzed the cleavage of the phosphoester bonds, the PA6 nanofiber matrix effectively adsorbed one of the primary hydrolysis products, p-nitrophenol, potentially facilitating the selective separation of degradation products from the liquid phase.

Conclusions The study demonstrates a successful and gentle strategy for immobilizing functional CeO₂ nanoparticles into electrospun PA6 nanofibers while retaining their intrinsic dephosphorylation activity. These modified nanofibers exhibit robust performance in aqueous environments, making them promising candidates for environmental remediation, protective equipment, or biomedical applications where the degradation of organophosphates is required. The combination of catalytic nanoparticles and an adsorbent polymer matrix provides a multifunctional platform capable of both chemical transformation and product separation

Key words Nanoceria, Nanofibers, Dephosphorylation activity, Nanocomposite

P-38

116 - A BI-METAL BASED NANOFIBROUS FILTER MATERIAL FOR INACTIVATION OF INFLUENZA A AND SARS-COV-2

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Background/Rationale Respiratory viruses spread via respiratory droplets, aerosols, and contaminated surfaces [1]. Virus-laden particles, particularly aerosols, can remain airborne for hours, thereby facilitating viral transmission. Consequently, personal protective equipment, ventilation, and air filtration can limit the spread of viruses [2]. Nanotechnology approaches, particularly electrospinning, enable the fabrication of filters with reduced pore sizes for improved particle capture [3]. Viruses may also remain infectious on mask surfaces [4], hence polymer activation strategies have been developed to overcome these limitations.

The aim of this study was to create a nanofibrous poly(vinylidene fluoride) (PVDF) based membrane functionalized with a combination of Cu and Zn nanoclusters, and to evaluate its antiviral activity against the influenza A virus (IAV) and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

Materials and Methods PVDF membranes activated with Cu and Zn nanoclusters were fabricated by electrospinning a PVDF solution in dimethylacetamide (DMA) with the addition of 2.0 wt% Cu(NO₃)₂·2.5H₂O and 2.0 wt% ZnCl₂. Characterization of modified materials was performed using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (SEM-EDX), X-ray diffraction (XRD), mercury intrusion porosimetry, thermogravimetric analysis (TGA), contact angle measurement, and microwave plasma atomic emission spectroscopy (MP-AES). Particle filtration efficiency was determined using particles with diameters ranging from 100 to 3000 nm. Tissue culture infectious dose 50 assay (TCID₅₀) was employed to determine virucidal activity against IAV and SARS-CoV-2.

Results SEM images confirmed the successful fabrication of a nanofibrous material with an average fiber diameter of 520 nm. SEM-EDX and MP-AES analysis confirmed the presence of Cu and Zn in the nanofibers. Observed metal concentrations were in agreement with theoretical values. Furthermore, even distribution of metals in the material was achieved. XRD analysis confirmed the presence of paratacamite and atacamite deposits. The produced fibers were thermally stable over a wide temperature range. The addition of salts decreased average pore sizes of the produced modified nanofibrous materials. While all tested materials showed hydrophobic properties, the bi-metal based membrane resulted in the least hydrophobic material (contact angle of 128°).

Membranes containing both Cu and Zn nanoclusters showed superior filtration efficiency compared to pure PVDF fibers; however a filtration efficiency of over 99% for particle sizes of 100 and 300 nm was only reached for materials with a thickness of 200 µm. The pressure drop of 85 µm mats were lower than that of materials with comparable thickness fabricated using the Cu salt separately, while unmodified materials achieved lowest pressure drop.

Superior antiviral activity against IAV and SARS-CoV-2 was achieved with materials electrospun from solutions containing both Cu and Zn. Very high efficiency, a 3.67 log reduction of IAV titers after 8 h, was observed for the materials activated with Cu and Zn nanoclusters. Membranes containing Cu nanoclusters showed similar reduction of SARS-CoV-2 titers as materials spun with both salts after 8 h. However, the decrease in viral titers was achieved much faster with materials activated with Cu and Zn nanoclusters, reaching 2.22 log reduction after 2 h of contact. Therefore, an enhanced passivating effect of IAV and SARS-CoV-2 has been demonstrated for PVDF membranes electrospun with the addition of 2.0 wt% Cu(NO₃)₂ and 2.0 wt% ZnCl₂ in the spinning solutions against both IAV and SARS-CoV-2 virions.

Conclusions A PVDF solution containing Cu and Zn salts can be used to fabricate a bi-metal based nanofibrous material. A PVDF-based nanofibrous membrane doped with Cu and Zn may offer superior antiviral activity against IAV and SARS-CoV-2 compared to pure PVDF membranes or membranes doped with a single metal.

Key words Poly(vinylidene fluoride); Filtration efficiency; Antiviral activity; Influenza A; SARS-CoV-2

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P-39**183 - ELECTROSPUN TiO₂/POLYIMIDE MEMBRANES FOR PHOTOCATALYTIC DEGRADATION OF PFAS IN WATER**

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Background/Rationale Per- and polyfluoroalkyl substances (PFAS) are persistent and toxic aquatic contaminants that are highly resistant to conventional remediation treatments. This work focuses on perfluorooctanoic acid (PFOA) and investigates electrospun TiO₂/polyimide (PI) membranes as active materials for Advanced Oxidation Processes (AOPs). The objective is to combine membrane-based removal with photocatalytic and oxidative pathways in order to enhance PFOA degradation and defluorination in water.

Materials and Methods A 21.6 wt% polyamic acid (PAA) solution in DMF, synthesized from ODA and PMDA, and a catalytic precursor solution containing tetrabutyl titanate (TBT), PVP, acetic acid and ethanol were simultaneously deposited by dual-needle co-electrospinning. The membrane was thermally treated using a controlled 80–400 °C ramp (770 min), converting PAA into PI, removing the PVP carrier and promoting TiO₂ formation. Membranes were characterized by FT-IR, thermogravimetric analysis and electron microscopy. PFOA degradation tests were performed in a continuously recirculating batch photoreactor combining TiO₂ photocatalysis, Photo-Fenton chemistry and persulfate oxidation. Samples were collected hourly for 5 h and analyzed by HPLC-MS to monitor PFOA and shorter-chain fluorinated intermediates.

Results PFOA removal increased progressively across the tested configurations. Reagents alone, without membrane, produced 18.30% removal and 13.59% defluorination. Introducing the membrane increased PFOA removal to 44.72%, with an estimated fluorine adsorption contribution of 29.11%. Under UV irradiation, the membrane/reagents system reached the highest performance, with 60.80% PFOA removal and 30.68% defluorination. Membrane characterization confirmed successful PAA-to-PI conversion and the presence of TiO₂ nanostructures after thermal treatment.

Conclusions Electrospun PI/ TiO₂ membranes provide a stable fibrous support combined with photocatalytically active TiO₂ nanostructures. The membrane substantially increases PFOA removal, while UV irradiation further enhances both removal and defluorination in the combined AOP system. Future work should optimize the photoreactor configuration and membrane properties to improve pollutant–catalyst contact, adsorption capacity and photocatalytic efficiency.

Key words PFAS; PFOA; electrospinning; polyimide; TiO₂; photocatalysis; Advanced Oxidation Processes.

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