Effect of PEO Molecular Weight on the Development of Electrospun PVA Nanofibers for Controlled Drug Delivery

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Background: Electrospun nanofibers have gained attention as drug delivery systems due to their high surface area and adjustable properties. Polyvinyl alcohol (PVA) is a widely used polymer for electrospinning, but its mechanical limitations restrict performance. Blending PVA with polyethylene oxide (PEO) offers a strategy to enhance fiber characteristics. This study investigates the effect of PEO molecular weight on the morphology, mechanical strength, wettability, crystallinity, and drug release behaviour of electrospun PVA nanofibers loaded with nicotinamide.

Methods: PVA (75 kDa) was blended with PEO at three different molecular weights of 300 kDa (F1), 600 kDa (F2), and 900 kDa (F3), and using nicotinamide as a model drug. Nanofiber mats were fabricated using an electrospinner (SpinBox). The formulations were characterised for solution viscosity, fiber morphology (Keyence imaging), mechanical strength (Texture Analyzer), surface wettability (contact angle), surface roughness (Alicona imaging), and crystallinity (XRD). In vitro drug release was assessed using Franz diffusion cell methods, while skin permeation studies were performed using pig skin. Drug distribution and release behavior were further analysed using a novel UV imaging technique (Surface Dissolution Imaging 2) with an in-house 3D-printed permeation cell.

Results: The viscosity of the solutions increased with higher PEO molecular weight due to enhanced polymer chain entanglement. Excessive viscosity in F2 and F3 disrupted the electrospinning jet which resulted in beaded fibers and defected mats. Fiber diameter also increased with PEO molecular weight. The measured diameter was as 693 ± 148 nm for PVA-NIC, 898 ± 175 nm for F1, 1005 ± 232 nm for F2, and 1174 ± 192 nm for F3. Blending PVA with PEO improved mechanical strength compared to pure PVA, but fiber integrity was highly dependent on PEO molecular weight. Ultimate tensile strengths were 0.08, 0.038, and 0.021 MPa for F1, F2, and F3, respectively. The reduction in strength for F2 and F3 was attributed to thicker fibers with lower surface area-to-volume ratios, which weakened bonding between fibers and led to a less cohesive mat structure. Surface wettability and roughness analyses (measured as Surface Defect Ratio, SDR%) showed that F1 had the highest contact angle (56.1° ± 5.4°) and lowest SDR% (2.4 ± 1.1%), while F3 had the lowest contact angle (38.5° ± 6.1°) and highest SDR% (34.5 ± 5.7%), indicating a transition to more defective, porous surfaces promoting water infiltration analysis confirmed amorphous structures across all formulations, consistent with hydrophilic behavior observed in contact angle measurements. However, F1 had slightly sharper peaks compared to F2 and F3 which could be attributed to better polymer chains alignment. In vitro drug release studies showed that F1 exhibited controlled release of 20.6 ± 8.1 % over 6 hours, whereas F2 and F3 released 52.4 ± 18.9%, and 58.6 ± 18.2%, respectively, within just 2 hours. Similarly, in vitro permeation through pig skin demonstrated sustained delivery for F1 (8.1 ± 4.1%) compared to faster permeation for F2 (22 ± 9.3%) and F3 (38 ± 12.4%). SDI imaging further supported the slower, more controlled release behavior of F1 nanofibers.

Conclusions: PEO molecular weight significantly influenced the development of electrospun PVA nanofibers. Lower molecular weight PEO enabled smoother, stronger mats with slower drug release and permeation, enhancing sustained delivery performance.