

Supramolecular design of poly(urethane)-based polypseudorotaxane scaffolds for bone regeneration

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Introduction

Bone regeneration remains a major challenge in reconstructive medicine, particularly in the treatment of bone defects caused by trauma, disease, or surgical procedures. Tissue engineering strategies based on biomimetic scaffolds have gained increasing attention, as they provide structural support for cell adhesion, proliferation, and tissue growth. Among the materials explored, thermoplastic poly(urethanes) (PURs) are promising due to their tunable thermal and mechanical properties, and biocompatibility. Moreover, supramolecular approaches offer new opportunities to further tailor polymer properties through reversible host–guest interactions.

Aim. This work aims to design and characterize supramolecular scaffolds based on PUR/cyclodextrins (CDs) polypseudorotaxanes (PPRs) for bone tissue engineering applications.

Materials and Methods

A custom-made thermoplastic PUR based on poly(ϵ -caprolactone) (PCL), an aliphatic diisocyanate, and 1,4-butanediol was synthesized and characterized by infrared spectroscopy and size exclusion chromatography to confirm its chemical structure and molecular weight. Supramolecular PPR systems were obtained by combining PUR with CDs, generating formulations with PCL block coverage ranging from 0 to 12%. Complex formation was investigated by X-ray diffraction (XRD). Thermal and mechanical properties were evaluated by differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and atomic force microscopy (AFM). Finally, scaffolds were fabricated using a salt-leaching technique to assess material processability.

Results

The PUR was successfully synthesized, showing a number-average molecular weight of approximately 40 kDa and a polydispersity index of 1.4. The formation of PUR-based PPRs was confirmed by XRD and DSC, which revealed a peak at 20° associated with the channel-like structure of CDs and changes in melting and crystallization behavior compared to pristine PUR. Increasing CD coverage reduced PCL crystallinity due to the threading of CDs along the polymer chains, while supramolecular crystalline domains increased material stiffness, as evidenced by AFM. Porous scaffolds with a porosity of approximately 70% were obtained, and their morphology was evaluated by scanning electron microscopy.

Conclusion

These results demonstrate that supramolecular assembly between CDs and PCL-based PUR chains is an effective strategy to tune the structural and mechanical properties of thermoplastic scaffolds, enabling the fabrication of customizable materials for bone tissue engineering.

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