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Investigation of addition of calcium phosphate ceramic to multilayer scaffold for bone applications with improved mechanical properties: Fuzzy logic analysis

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Abstract

In this study, combining an excellent intrinsic property of polylactic acid (PLA) with the unique properties of three-dimensional (3D) printing technique and coating of chitosan-hydroxyapatite (CHI-HA) is used with electrospun nanofibers for the regeneration of hard tissues. This study aims to fabricate a microstructural scaffold with a PLA base by 3D fused deposition modeling (FDM) technique. High surface-to-volume ratio, high porosity, flexibility in surface performance, and exceptional mechanical performance are just a few of the characteristics that the small-diameter fibers display. Utilizing an examination from a scanning electron microscope (SEM), the morphological research is carried out. Besides, the biological reaction of the scaffolds is studied in phosphate buffer saline (PBS) and simulated body fluid (SBF). The samples are examined for wet and dry biological behavior, by SEM. Moreover, mechanical analyzes, including compressive strength and porosity, are performed on the samples and the results are evaluated in existing number models. Besides, the fuzzy modeling technique is used to forecast the properties of samples before fabricating and examining them. The results generally show that the presence of HA nanoparticles improves mechanical and biological properties. Specifically, the obtained results show that the sample with 10 wt% of HA is capable of suitable mechanical, chemical, and biological properties compared to other samples.

Introduction

Today, composites have many applications in various branches of engineering and science, and this issue has led to a new category of composites with ceramic, polymer bases, etc., in various branches of science [[1], [2], [3], [4], [5], [6], [7], [8], [9]]. In general, ceramics are among the most widely used materials in various applications, which have always been used in various branches of science due to their extraordinary properties [[10], [11], [12]]. In this regard, obtaining mechanical properties for materials is done by researchers to obtain polymers and composites that have the best mechanical properties in various applications [[13], [14], [15], [16], [17], [18]]. Fuzzy logic is based on the observation that people make decisions based on imprecise and non-numerical information. Fuzzy models have the capability of recognizing, representing, manipulating, interpreting, and using information that are vague and lack certainty [[19], [20], [21], [22], [23], [24], [25], [26], [27]]. Cartilage is a connective tissue with the vital structural function as an important human body component. The lower bone protects itself in a joint from wear and tear. Traumatic and destructive injuries to articular cartilage led to its disability [[28], [29]]. Injury to articular cartilage, such as trauma or osteoarthritis of the bone, may lead to a concentration of bone tension and pain. However, the thickness of articular cartilage is high, it is bloodless tissue which has innate ability to limited heal [[28], [29], [30]]. Like the joints of human body bear more weight, the thickness of cartilage can be 3–4 mm. The extent of this limited reparability is related to the lack of a blood source. The synovial fluid nourishes cells with nutrients [[30], [31], [32]]. The unique ability of cartilage to create a load-bearing surface is almost friction-free and painless depending on the complex interactions between the cells and the matrix [[29], [30], [31], [32], [33], [34]]. Articular cartilage is made up of a relatively small number of cells within the extracellular matrix (ECM). Studying tissue and organ failure in terms of various injuries and wounds is an essential issue that accounts for about half of the total annual health expenditure in the United States. Some treatments are performed via surgery and cause many implantation problems. Such problems include shortages of organ donors as well as transplant reversals. Tissue engineering has emerged as a clinically relevant field, including a potentially important opportunity for tissue transplantation [[34], [35], [36], [37]]. Natural, synthetic, or semi-synthetic tissue may be used to correct defects and replace them; this should be taken into account right once. Synthetic biomaterials have advanced at the same time as tissue engineering has. The possibility of easy fabrication of materials on the scale of electrospinning (ELS) biological quantities has made it a desirable method for tissue engineering and drug delivery applications. ELS technique is a versatile technique used to produce continuous fibers of different thicknesses for making three-dimensional (3D) porous scaffolds with a structure similar to the ECM. Besides, electrospun porous scaffolds can control human mesenchymal stem cells (HMSCs) in hard and soft tissue engineering [[38], [39], [40], [41], [42]]. ELS is a simple method and relatively easy technique for producing polymer fibers in nano or micro thickness. These low-diameter fibers exhibit features like high surface-to-volume ratio, proper porosity, outstanding mechanical performance, proliferation, and cell growth. In terms of mechanical and biomimetic properties, obtaining the optimal composition is essential for choosing suitable materials. Fiber orientation is similar to the effects of random orientation on scaffold porosity and porosity size [[43], [44], [45], [46]]. Thus, it can be controlled by setting parameters affecting ELS process. Previous studies [[47], [48], [49], [50]] show that when cells are implanted, synthetic polymeric biomaterials absorb serum and plasma proteins to the surface of the cell adheres. In the literature, nanofiber scaffolds were studied to support the re-differentiation of chondrocytes in the body [[51], [52], [53]]. Besides, the nanofiber scaffold supports cell proliferation to maintain the chondrocyte phenotype [[54], [55], [56], [57]]. These results indicate that the biological activity of chondrocytes depends largely on the scaffold architecture. Besides, nanofiber scaffolds act as a suitable biological substrate for the proliferation and maintenance of chondrocyte phenotypes. Natural polymers, in terms of their high compatibility with cells, are commonly used to make nanofiber scaffolds. Electrospun nanofiber scaffolds made from protein-based polymers, such as collagen, gelatin, elastin, and fibrinogen or from carbohydrate-based polymers, such as chitin, chitosan, and hyaluronic acid have been evaluated for tissue engineering [[58], [59], [60], [61], [62], [63], [64]]. This study uses synthetic polymers to make nanofiber scaffolds due to their desired properties, such as mechanical strength and controlled degradation profiles. Moreover, the fuzzy logic modeling technique is used to forecast the chemical and mechanical properties of the samples before their fabrications. To verify the proposed fuzzy model, the experimental results and the output of model are compared to each other, and the related errors are calculated.

Section snippets

Materials and methods

The polylactic acid (PLA) polymer is prepared by Merck German Company and used in the 3D printing technique with 1.75 mm diameter and feed rate of 50 mm/s with nozzle temperature of 210 °C square structure by a quantum 3D machine. As a consequence of the temperature of the work plate, the temperature of the nozzle, and the print speed of the device, printing various kinds of materials involves three primary factors. For a polymer, such as PLA, the based temperature can vary between 55 and…

Experimental outcome

Several researchers worked on printed PLA scaffolds [[60], [61], [62], [63], [64], [65], [66], [67], [68], [69]]. The behavior of bone and cartilage tissue cells in the scaffold showed the best results in the discussion of cell growth, proliferation, and differentiation. Therefore, this study has used this scaffold as a based architecture regarding the previous achievements. However, some enhancements, such as a biocompatible coating, were conducted on the printed sample. Fig. 1 shows a…

Conclusion

The obtained result of this experimental study shows that chitosan with 5 wt% and 10 wt% HA in chitosan coating has a sufficient mechanical and biological reaction for bone tissue engineering applications. Hence, the presence of HA nanoparticles in the chitosan matrix coated on PLA structure causes the fibers to expand in diameter and decrease in porosity when HA reinforcement is added. The mechanical performance shows the elastic modulus of the samples increases from 35 MPa to 47 MPa by adding …

Declaration of competing interest

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