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Investigating the Mechanical Strength and Degradation of Bone Scaffold Fabricated from Hydroxyapatite and Polyurethane Foam

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1- Introduction

Tissue engineering is the use of a combination of cells, engineering and materials methods, and suitable biochemical and physicochemical factors to improve or replace biological functions. In the human body, bones have a great tendency toward reproduction and thus is a subject of study in tissue engineering. Small fractures in the human bone can be healed by the healing process of the body. However, bone grafting may be required in huge fractures. In the last thirty years the use of artificial implants in bone restoration has been attractive to researchers. One of the key factors in tissue engineering is the use of bone scaffold in the field of improving the bone healing process. The scaffolds should have similar mechanical properties as the bone and also have appropriate biocompatibility and bio-degradability in the human body during bone healing. The properties of the scaffolds are mainly affected by its materials and the main of these properties is the porosity. The use of hydroxyapatite as a material for bone scaffold has been studied by researchers. Hydroxyapatite is a biocompatible material and because of its similar chemical composition to the human bone has been mainly used as material in orthopedic applications.

2- Experimental

In this study, the fabrication and characterization of bone scaffold which was produced from natural hydroxyapatite and polyurethane foam were investigated. Bovine femur was chosen for extraction of hydroxyapatite. The spongy bones were discarded and the cortical bone was de-fleshed. The bone marrow and all pieces of meat and fat were removed and the bone pieces put in fresh air for 10 days. By using a gas torch and applying direct flame to the cleaned bone, organic components were burned for 3 hours at 400 °C. The product of this thermal process contained some char due to burning of organic components. To remove the remaining char, the black powder (bone ash) was placed in an air furnace at different temperatures between 800 °C for 2 hours and finally it was cooled inside the furnace. Following this process, the black ash turned into a white granular powder. The product which is natural hydroxyapatite was then sieved via 230 mesh to reach a powder particle size of under 65 µm.

For the fabrication of the bone scaffold, polyvinyl alcohol was dissolved in double distilled water at 70°C and then hydroxyapatite powder was added to prepare a slurry with the chemical composition shown in Table 1. slurry was mixed for 20 minutes. Polyurethane sponge was used for the preparation of the scaffold and the slurry was poured on the sponge and after drying at 80 °C for 2 hours they were placed in an air furnace and heated to 600 °C to burn the sponge and then sintered at 1200 °C for 4 hours. Thermal and mechanical properties of the scaffolds were studied via X-ray diffraction (XRD), scanning electron microscopy (SEM), compression test and thermogravimetry technique. Also hardness test, three-point bending and investigation of biological behavior were employed. The chemical composition of the slurry and also the mechanical properties of the resulted scaffolds are presented in Table 1.

Table. 1. The chemical composition of the slurry and mechanical properties of the studied scaffold sintered at 1200 °C

Sample No.	Slurry Composition (Wt.%)			Properties		
	Hydroxyapatite	H_2O	PVA	Compression Strength (MPa)	(g/cm^3) Density	% Porosity
1	69	30	1	1.13	1.48	42.17
2	68	30	2	1.36	1.51	40.45
3	67	30	3	1.52	1.52	36.70
4	65	30	5	1.7	1.57	34.39
5	59	40	1	0.87	1.38	56.30
6	58	40	2	0.93	1.41	55.70
7	57	40	3	1.03	1.42	52.30
8	55	40	5	1.15	1.44	48.40
9	49	50	1	0.62	1.26	64.30
10	48	50	2	0.96	1.31	61.70
11	47	50	3	0.76	1.35	59.50
12	45	50	5	0.82	1.37	57.80

The biodegradability of the studied scaffold was performed via considering the weight loss of sample 7 by putting it in phosphate buffered saline with pH=7.4 at 37±1 °C for 7 days. Furthermore, the biocompatibility was studied by placing sample 7 in

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simulated body fluid (SBF) under same conditions and investigating the weight gain of the samples.

3- Results and Discussion

Fig. 1 shows the result of the thermogravimetric analysis which shows burning of the polyurethane foam at two temperature ranges of 180-320 and 360-600 °C.

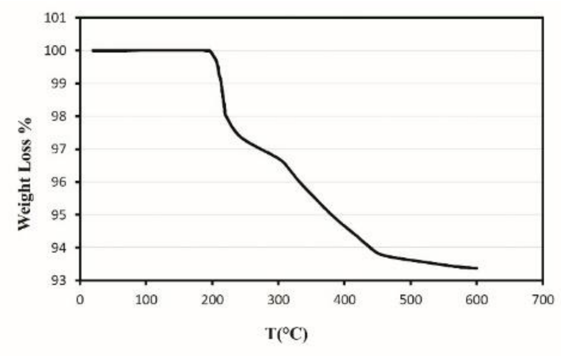

Fig. 1 Thermogravimetry result for the scaffold

The results of the XRD analysis are shown in Fig. 2 which shows the compatibility of the composition of the extracted hydroxyapatite and also the scaffold with standard hydroxyapatite card.

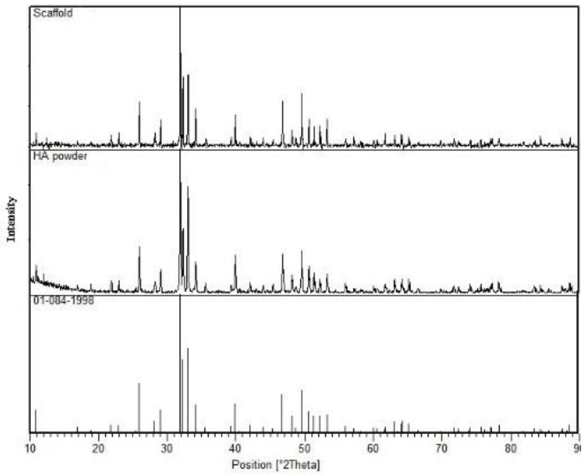

Fig. 2 Comparison of the XRD pattern of natural hydroxyapatite and the studied scaffold with the standard hydroxyapatite

As can be seen from Table 1, the fabricated scaffolds showed high compressive strength with favorable percentage of porosity. By increasing the weight percentage of hydroxyapatite from 45 to 65, the density of the scaffold was increased from 1.37 to 1.57 g/cm^3 and the compressive strength increased from 0.82 to 1.7 MPa while the porosity decreased from 57.8 to 34.4.

Fig. 3 and Fig. 4 show the results of the biodegradability and biocompatibility tests on the studied bone scaffold (sample 7). As can be seen the weight loss of the sample in phosphate buffered saline indicates the biodegradability and also the weight gain of the sample in SBF solution proves the biocompatibility of the investigated bone scaffold.

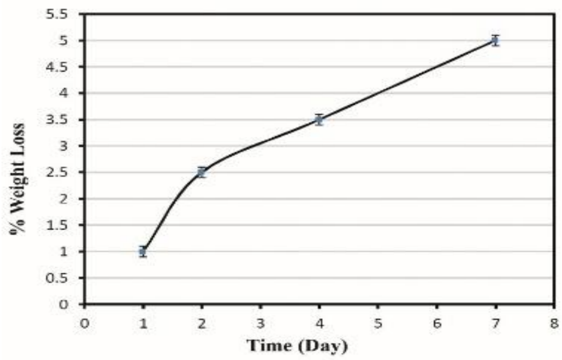

Fig. 3 Weight loss percent (biodegradability) trend of the bone scaffold sample 7 in phosphate buffered saline

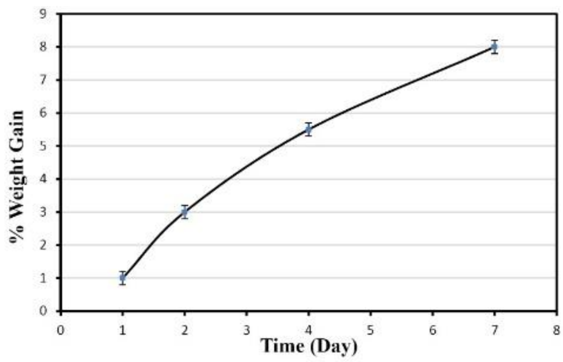

Fig. 4 Weight gain percent (biodegradability) trend of the bone scaffold sample 7 in phosphate buffered saline

The porous structure of the investigated bone scaffold is shown in Fig. 5 which indicates the presence of macroscopic porosity in the range of 200 to 400 µm and also microscopic porosity in the range of 2-100 µm which can promote bone ingrowth.

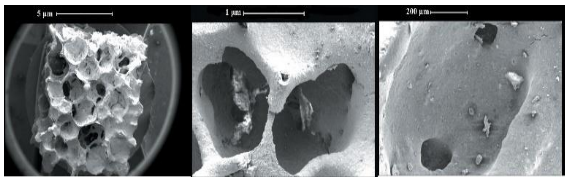

Fig. 5 SEM photomicrograph of the investigated bone scaffold

4- Conclusions

In this study, the fabrication and characterization of bone scaffold which was produced from natural hydroxyapatite and polyurethane foam were investigated. The fabricated scaffolds showed high compressive strength with favorable percentage of porosity. The biodegradability and biocompatibility of the investigated bone scaffold were presented by in vivo investigations. It can be concluded that polymer foam fabrication technique can be an appropriate technique for producing bone scaffold.