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► **To cite this version:**

Mohammad Pazhouhi, Pardis Pazhouhi. An Introduction to Bone Scaffolds and their Features. 7th National Conference on Mechanical and Aerospace Engineering, Feb 2023, Tehran, Iran. ⟨hal-04188579⟩

HAL Id: hal-04188579

<https://hal.science/hal-04188579v1>

Submitted on 26 Aug 2023

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An Introduction to Bone Scaffolds and their Features

Mohammad Pazhouhi^{1,*}, Pardis Pazhouhi²

1. Pharmaceutical Sciences Research Center, School of Pharmacy, Kermanshah University of Medical Sciences, Kermanshah, Iran

2. Hormozgan University of Medical Sciences, Bandar Abbas, Iran

* Corresponding author: moh.pazhouhi@gmail.com

ABSTRACT

Numerous patients suffer from psychological problems due to the non-repair of bone lesions following bone fractures due to aging, trauma, illness, and accidents. However, one of the best treatments is to use a proper bone scaffold. Remodeling the body tissues is the primary purpose of using these scaffolds. Selecting the material and type and paying attention to the scaffold's characteristics is an essential part of the work. So, that ultimately plays an essential role in treating and healing bone injuries. This review-based paper studies the importance, features, and application of research in the bone scaffold.

Keywords: Bone, Scaffold, Bone materials, Biocompatibility, Hydroxyapatite.

1. INTRODUCTION

Bone is one of the body's vital organs and the main skeletal component of the human body, and due to its rigidity and strength, it functions like a framework and plays an essential role in body weight [1]; So, its multifunctional soft tissues are attached to it, and with its help, it provides the possibility of movement for human beings [2, 3]. With age, trauma, crashes with vehicles [4-6], illness, and surgery, many changes occur in the body that leads to tissue damage or disruption of their normal function [7]; one of the most important of these tissues is bone [8, 9]. Although one of the unique features of bone is its ability to heal itself, adjuvant therapy is needed [10-13]. The bone matrix is mainly made of mineral compounds, so it can bear weight and can serve as a strong skeleton for the body. Bone provides joints for muscles and limbs and is a protective covering for many soft organs. However, the bone function is not limited to the aforementioned issues but also participates in hematopoiesis, which is the responsibility of hematopoietic cells in the bone marrow. Furthermore, bones act as a storage source of calcium, phosphorus, and other vital ions needed by the body. Almost all the body's calcium (about 99%) is accumulated in the bones [2, 14]. Statistics show that more than 6.2 million bone fractures are seen each year in the United States alone, and approximately 2.2 million bone grafts are performed to repair the damaged tissues. Bone tissue benefits from a high potential for self-healing, which is due to the continuous process of bone renewal. Therefore, bone fractures are repaired spontaneously if they are properly fixed [15, 16]. For this reason, in recent years, many researchers have focused their studies on the use of biocompatible materials, cultured with cells and related growth factors, to repair damaged bones; these biocompatible materials are called "bone scaffolds". The bone scaffold [17-19] is a porous structure with suitable biological and mechanical properties that is responsible for providing a suitable substrate for bone growth. However, scaffold, in bone tissue engineering, creates a suitable physical space to accommodate cells and, by exchanging biological molecules, encourages the formation of new tissue. Moreover, scaffolds are then gradually removed and have a temporary role in the bone repair process and are usually made of degradable materials that are gradually destroyed over time so that new bone grows and replace [20-23]. The important point is that although scaffold plays a temporary role in bone repair, it is of vital and undeniable importance in this process. Various factors affect the performance of a scaffold, the most important of which are good porosity and good mechanical properties. A bone scaffold, however, must have the appropriate mechanical strength to

withstand the forces applied. Therefore, the study of the mechanical properties of scaffolds is extremely important in understanding their accurate behavior of them in damaged parts of the body [8, 24]. Likewise, another advantage of the scaffolds is the ease of modeling, production, and the possibility of predicting their geometric properties [16]. Other parameters such as porosity size distribution, porosity interconnection rate, scaffold complexity and curvature, porosity surface area, and permeability are other important design factors [25-27].

2. Scaffold Features

Given the history of the scaffold, today, the primary purpose of using scaffold is to regenerate body tissues. However, each tissue has its own biological as well as physical properties, such as its size and shape (Figure 2); Therefore, each scaffold must, in practice, could introduce specific biological and mechanical effects to improve and modify cellular behavior. For this purpose, each scaffold is designed based on the properties of its target texture. One of the most important points in selecting the type and material of the scaffold. Scaffold allows cells to attach and similarly causes cells to migrate, transport biochemical factors, release nutrients and waste products, and produce cells. The scaffold must have a series of structural features [28]. The properties of scaffolds are like Extracellular Cellular Matrix (ECM), which plays an important role in physical and chemical amplification signals. However, ECM is an important component in tissues such as cartilage and blood sweat, which provides the necessary mechanical support to tissues and regulates the movement of water, food, and other dissolved substances. It additionally holds cells and tissues together in a network and provides an organizational matrix in which cells can migrate and interact with each other [29, 30]. Four of the most important features that should be considered in the design and construction of a scaffold are the following:

2.1 Biocompatibility

All scaffolds' primary and important feature is their biocompatibility [17, 18, 31]. Due to this property, cells adhere to the scaffold wall and can migrate there; more importantly, it gives the ability to proliferate [30].

2.2 Biodegradability

Scalable biodegradability [17] is considered another necessary factor so that the scaffold is absorbed by the surrounding tissues and surgery is no longer needed to remove the scaffold. Here is another component called scalability rates for the scaffold. In these cases, the severity of scaffold loss is adjusted by the time required for tissue formation. When the cells on the scaffold acquire the ability to maintain themselves without the need for a scaffold and build a natural matrix structure around them, at this time the scaffold degradability begins [30, 32]. Scaffold demolition behavior varies according to their application; e.g., the lifespan of scaffolds used in the spine is nine months. However, the scaffolds used in the jawbone should be 3 - 6 months old [32, 33].

2.3 Mechanical properties

The mechanical properties of the scaffold must be follow the place of planting and must be able to withstand external loads applied to the area. In the research, carbon nanotubes are utilized to improve the mechanical properties of the scaffold [34, 35].

2.4 Scaffold architecture

The scaffold should be designed so that the cavities form an interconnected mesh with high porosity; this is because the penetration of cells and nutrients is accomplished properly and the extracellular matrix is well made. Furthermore, the porous structure of the scaffold must construct in such a way as to allow waste to be eliminated from the scaffold (Figure 1). Generally, the cavities should be large enough to allow cells to migrate inside the scaffold structure; on the other hand, they should be small enough to allow cells to adhesion to the scaffold. As a result, the cells have different cavities for different scaffolds according to their application and construction [36].

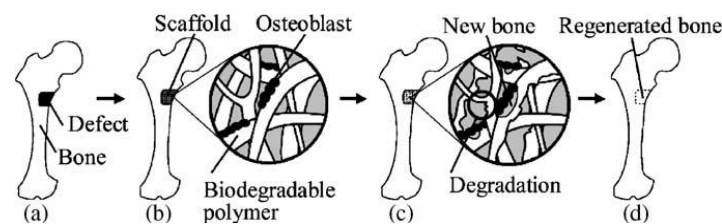


Fig. 1. Schematic of process using biodegradable porous scaffold [21]

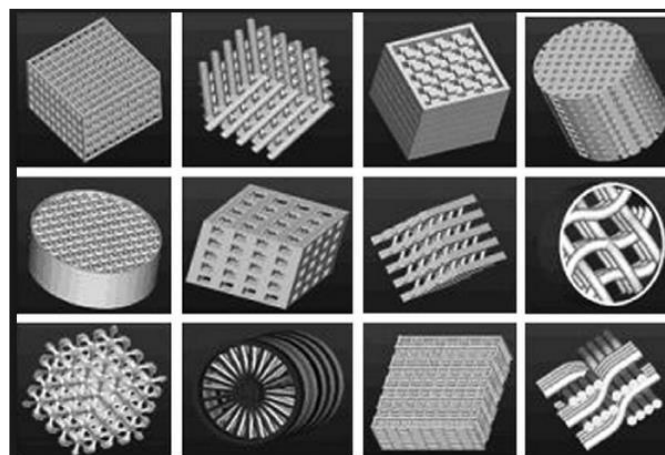


Fig. 2. Various shapes of scaffolding [36]

As a result of the importance of this issue, abundant studies have been conducted in recent years. Tavakol et al. [37], Offeddu et al. [38], and Liu et al. [39] investigated the mechanical properties of bone scaffolds in the laboratory. However, such laboratory studies are very time consuming and costly; For this reason, in recent years, with the development of numerical methods [6, 40], several researchers are attempted to apply the methods to evaluate the performance of scaffolds. Naghie et al. [20] also used the Finite Element Method (FEM) [41-44] to predict the mechanical behavior of bone scaffolds produced by the polymer fiber extrusion Fused Deposition Modeling (FDM). Tagliabue, et al. [45] obtained the mechanical properties of porous glass-ceramic scaffolds using the Finite Element Method based on Micro-Computed Tomography (Micro-CT). The use of micro-CT scan data to accurately simulate the internal structure of scaffolds has been used by numerous academics; including Young [46], Perez Ramirez et al. [47], Madi et al. [48], Sandino and Lacroix [49], and Solang et al. [50]. On the other hand, hydroxyapatite has been widely used in the construction of bone scaffolds [19]. The substance provides the greatest potential for use as a bone substitute due to having a composition similar to real bone and not having any adverse effects on the body. In addition, the components are based on hydroxyapatite and could bond strongly to bone. The components provide osteoconductivity, osteoinductivity, and high degradability, among the desirable properties of bone scaffolds [51]. Consequently, many researchers have used hydroxyapatite to make bone scaffolds [52-55]. Moreover, silk is another natural polymer that is widely used in bone scaffolds; silk is highly regarded as a natural polymer in recovery therapies [56, 57]. The mechanical strength, biocompatibility as well as long-term degradability of silk have led to much research in bone tissue engineering [58-60]. The silk application may be the beginning of a new phase in the bone tissue engineering scaffold.

3. DISCUSSION AND CONCLUSION

Following bone fractures caused by aging, trauma, accidents, and illness accidents, many affected individuals suffer from psychological difficulties because of the non-repair of bone lesions. However, one of the best treatments is the bone scaffold. Mechanical properties are one of the factors affecting the performance of bone scaffolds, and for this reason, in recent years, many studies have been conducted to investigate these properties. Furthermore, making

scaffolds used to replace bone tissue can only be achieved if the scaffold is made in various ways, such as chemical, physical, biological, and mechanical properties similar to bone tissue. Combining all these properties in an out-of-body set is only possible if there is a significant resemblance between that external environment and the biological environment of the body due to the complexity of bone tissue and the characteristics of bone tissue and its unique characteristics.

Funding information: The authors received no financial support for this research, authorship, and/or publication.

Declaration of interests: The authors declares that there is no conflict of interest in this work.

Ethical approval: This article does not contain any studies with human participants or animals performed by the authors.

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