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# Trabecular scaffolds´ mechanical properties of bone reconstruction using biomimetic implants

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**Abstract**

Several studies characterized and tested properties related to bone structure like the biomimicry and strength in different printing materials. However, all attempts were unsuccessful in finding the perfect material. Current 3D printing bone technologies can create either hard inert bone structure; that are structurally compatible but functionally inert; or, fragile soft structures that have osteoconductive properties but are extremely weak in structure. The present paper test the designing process of 3D-printed ABS scaffolds using bone's trabecular pattern as an option to enhance the strength of the scaffolds in physiologic load-bearing directions. For this experience, ABS has been considered, as it is widely available in desktop 3D printers. Finally, the mechanical properties of biomimetic scaffolds for compression strength and modulus have been analyzed.


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*Keywords:* bone scaffolds; implants; 3D printing, orthopedics

## 1. Introduction

Current 3D printing bone technologies can create either hard inert bone structures (based on primary scaffolds) that are structurally compatible but functionally inert; or, fragile soft structures that have osteoconductive properties but are extremely weak in structure. However, the best bone scaffolds should be able to withstand heavy loads and, at the same time, allow for osteoconductivity [1]. Several studies tested the biomimicry and structural strength of different printing materials, however, all attempts were unsuccessful in finding the perfect material [2].

Thus, the present paper has as objective to create and to model artificial bone by using structural design obtained from micro Computed Tomography Scan (μCT) of bones to create bone scaffolds and strengthen the scaffolds based on their trabecular pattern.

Ideal scaffolds should have similar mechanical behavior from natural bone. However, several studies highlighted some deficiencies, such as the poor strength of polymeric scaffolds [3]. Thus, different manufacturing process, like 3D printing, are used now to test how to improve scaffolds´ mechanical strength; property which is directly related to the scaffolds´ porosity, and it is primarily controlled by pore volume. This is also true for one-dimensional (1D) and three-dimensional (3D) printed scaffolds and limits their use to only non-load bearing and low-load bearing applications. A majority of materials currently used in creating artificial bones, though biocompatible, are inert. Few materials like mineralized collagen and hydroxyapatite allow osteogenic activity; and, are capable of guiding bone regeneration. However, these materials are very difficult to use in fabricating bony scaffolds and the mechanical strength of this artificial bone is too low to provide effective support at human load-bearing sites. Hence it can only

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Nomenclature

| | |
|---|---|
| CAD | computer aided design |
| μCT | micro computed tomography scan |
| 1D | one-dimensional |
| 3D | three-dimensional |
| ABS | acrylonitrile butadiene styrene |
| STL | stereolitography format |
| DICOM | digital imaging and communication in medicin |
| FDM | fused deposition modelling |
| $\sigma_1$, $\sigma_2$, $\sigma_3$ | axis of compression with respect to trabecular feature. |
| ISO | International Organization for Standardization |
| $\sigma_M$ | compression strength |
| $E_c$ | compressive modulus |
| $\varepsilon_1$, $\varepsilon_2$ | strain values |

be used for the repair at non-load-bearing sites, such as bone defect filling and bone graft augmentation.

Porosity and pore size of material scaffolds play a critical role in bone formation; the morphological effect of these, as well as relationships to mechanical properties of the scaffolds, must be addressed. Some studies relate a lower porosity within osteogenesis by suppressing cell proliferation and forcing cell aggregation. At the other hand, higher porosity and pore size result in greater bone ingrowth. Nonetheless, this trend results in diminished mechanical properties, thereby setting an upper functional limit for pore size and porosity. Hence, for being used in bone reconstruction by biomimetic implants, scaffolds must be flexible and resistant to compression. Thus, the mechanical behavior of the 3D scaffolds produced in this study must be characterized by testing their resistance to compression.

Furthermore, we hypothesize that introduction of trabeculae pattern of the bone in the design of these scaffolds would increase the mechanical strength of them due to its structural configuration.

## 2. Designing process of 3D-printed ABS scaffolds using bone's trabecular pattern

Designing process must consider that a scaffold with a porous structure favors tissue ingrowth, among other advantages. Furthermore, to facilitate desired bone tissue regeneration, the structural design of the scaffold must considers factors such as porosity, pore size and orientation of the channels inside the scaffold; in order to accomplish with the tissue ingrowth and the mechanical properties [4].

To meet both conditions, our design process has considering the medical imaging computed tomography (CT), a CAD draws development tool and a 3D printing system; as a new technique to create high tensile artificial bone; using ABS has been proposed. An overview of the steps to accomplish these objectives is presented in Fig. 1.

The process to design 3D-printed ABS scaffolds start with a μCT of an example rat vertebrae, which was chosen due to previous work performed in our lab using rat animal models. Furthermore, to continue our research and as part of a future work, bone implants will be design, based on these scaffolds, and tested *in vivo* in rat animal models.

After importing the CT Scan file and converting it to STL extension using In Vesalius (Brazilian Sciences and Technology Center, Brazil), a medical imaging reconstruction software, editing is required to reduce noise. Such process was performed using Geomagic (3D systems, USA) software in which virtual models are treated as a cloud of polygons and user can erase unwanted polygons manually. Besides, Geomagic offers a powerful algorithm of mesh optimization.

Finally, a CAD software, Solidworks (Dassault Systemes, France), is used for feature extraction to replicate the trabeculae pattern over scaffold's surface.

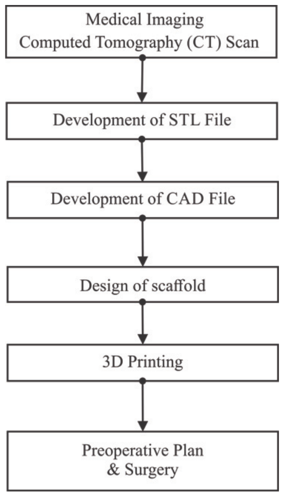


Fig. 1. Flowchart for biomimetic scaffold project fabrication from CT scan.

Figure 2 presents a simplified schematic of these steps. Also, the editing process using CAD software is presented in sequential steps from digital imaging and communication in medicine (DICOM); as result, a final CAD with the most relevant data about geometry and texture of the trabecular scaffold is obtained (Figure 3). After the design is ready, the scaffolds will be 3D-printed using fused deposition modeling (FDM) process in a Cube Pro (3D systems, USA) 3D printer. ABS was selected as the printing material and the printing parameters presented in Table 1.

Table 1. Parameters used in 3D printing process

| Parameter | Value | Units |
|---|---|---|
| Extruder temperature | 250 | $^{o}C$ |
| Heated Bed | No | ----- |
| Printing speed | 4800 | mm/min |
| Infill | 70 | % |
| Layer height | 0.2 | mm |