Analysis of 3D-Printed Hexagon Pore For Scaffold Fabrication

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ABSTRACT

Scaffold architecture such as pore geometries, porosity and pore size have great effect in tissue engineering in term of mechanical and biological properties. Although 3D-printing has been used in making a porous scaffold, however there are still challenges in designing the geometries in mimicking bone architecture as well as bone properties. A scaffold with hexagon pattern pores and microchannel has been designed and Acrylonitrile Butadiene Styrene (ABS) has been used as the fabricating materials by using a 3D-printer. The 3D-printed scaffold was then observed under an inverted fluorescent microscope to observe the scaffold pores to make comparison with the original pore shape of designed scaffold. The printed scaffold only has 23% to 26% of the original pore size might e due to the material selection as well as the chosen temperature in printing process.

Keywords: Scaffold, 3D-printing, vascular, bone, geometry, pore shape, hexagon

1. Introduction

Human body tissue provides both mechanical support and as well as biological activities for cell attachment, proliferation and differentiation. In bone tissue engineering, bone scaffolds are used to aid in the regeneration of damaged tissue for repairing bone defects generated from various causes. Various approaches have been developed by the researchers with the goals in producing scaffolds made of biomaterials that mimic the in-vivo environment. On the other hand, tissue regeneration including bone scaffold requires rapid vasculature development to aid in the absorption of nutrient mass transfer, oxygen, growth factors, biochemical signaling factors, carbon dioxide and metabolic waste from the surroundings to cells and vice versa [1]. Therefore, the successful of a tissue regeneration is depended on the incorporation of network of capillary vessels. Thus, the development of a functional vascular network within an engineered human tissue construct constitutes a promising hope in tissue engineering and regenerative medicine.

Scaffolds for tissue engineering has been manufactured from various types of materials and fabrication methods. One of the goals is to produce porous scaffolds from a biodegradable polymer that capable in manipulating the cell functions and later able to induce the formation of tissue growth. Nowadays research on fabrication of scaffold is leaning more towards rapid prototyping which is via 3D printing. In bone tissue engineering, 3D-printing has become a popular and widely investigated method for the fabrication of large bone implants and as well as macro-scale bone replacement implants. [2,3]. Besides, 3D printed bone, devices and treatments hold great potential to repair traumatic and chronic injuries with the capability in restoring both the tissue shape and the tissue function. [4].

However, there are significant challenges and limitations for the tissue scaffolds as the alternatives for e conventional treatments of major bone defects. One of the most important challenges associated with bone scaffolding is how to effectively assess and control proper mechanical stimuli required for tissue differentiation, growth, adaptation and maintenance [3]. Adequate 3D porous scaffold structure allows the cell-cell interaction as well as the molecules signaling in providing biomechanical environment in generating new tissue growth. One of the most important factors in fabrication of scaffold is to consider its pore size or porosity and appropriate design of scaffold to optimize its functionality in terms of cell proliferation and differentiation [5]. There have been numerous studies which identifies what porosity size is suitable for scaffold for optimal cell viability and proliferation.

Human bone has great complexity in its structure and properties. Mechanical properties are dependent on intrinsic mechanical properties of the material used and on geometrical features [6]. Mechanical properties, the architecture of bone scaffold including pore shape, pore distribution and strut thickness can influence the compressive strength of the scaffolds [7]. Few types of pore shape have been designed for within a bone substitute such as spherical, rectangular, square, hexagonal, trabecular-like, diamond, cube, truncated cuboctahedron and triangular which depending on the biomaterial and manufacturing process used [8, 9]. For example, scaffolds with rectangular pores and scaffolds with large spherical pores collapse more easily than smaller uniform round pores [10]. Different pore shapes showed different mechanical properties- due to differences in dimensions and orientation of the struts or fibres which lead the stress distribution inside the scaffold [9,11].

However, scaffold architecture such as pore geometries, porosity and pore size have great effect in bone tissue engineering [12]. For example, bone scaffold with good interconnected porous structure and curvature pore structure helps in cell migration, interaction and attachment. Cyclic stress-strain response studies show that circular pore scaffold has better fatigue resistance compared to triangular pore scaffold [13]. Nevertheless, curvature in pore shape can guide and control the process of tissue regeneration curvature with radius larger than cells can interact with the cells [14]. Therefore, pore shape not only affects the mechanical properties of scaffold but also aid in bone regeneration after implantation such as cell proliferation, cell adhesion and cell distribution by affecting the access to cell recruitment, vascularization, nutrients and oxygen [12, 13].

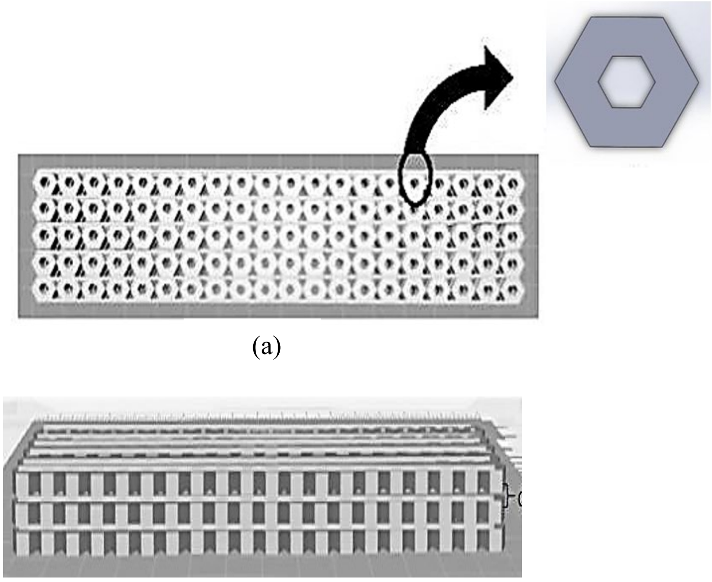
Although normal 3D printing and bioprinting can produce a porous scaffold, but there still have challenges in the predesigned geometries or architecture [15]. Among the variety of pore shape, hexagonal shape was recognized that may provide a chance to create 3D printed hexagonal pores that are smaller than the smallest printable square pores [16]. Due to the complexity of the hexagon shape itself, here, we investigated the quality of 3D-printed pore shape for the scaffold fabrication.

2. Methods

2.1 SolidWorks

In this experiment, the three-dimensional (3D) scaffold model was designed by using SolidWorks software and AcrylonitrileButadiene Styrene (ABS) was used as material to print the scaffold model. Our aim is to design scaffold that has hexagonal shape element in order to produce macro channels and micro channels in the scaffold. The design consists of two body parts, first part is hexagonal shape and second part is struts. Figure 1(a) and 1(b) shows the scaffolds design with side view. Then, sixty hexagonal shape part was arranged in five different layers that sides to each other. Each layer consists of 20 hexagonal shape part. For the struts design, the square shape was designed in 2-dimensional view. Then, in three-dimensional view, the square shape was extruded boss to 6mm. The design of the hexagonal body shape and the struts was assembled to form the macro channels and micro channels in the scaffold model. The assembled design was produced by sandwich arrangements. The six struts were aligned between two layers of hexagonal shape arrangement.

In order to produce the three- dimensional model of the scaffold, the Z- Suite software was used to open the assembled design in the SolidWorks. Then the three-dimensional design of the scaffold was printed by using Zortrax 3D m200 printer. Firstly, the assembled design is saved in stl file. Then, the design in stl file is opened in Z-Suite software. The parameters for the three-dimensional design was set in the Z-Suite software. After that, the design in stl file was exported to z code file. In order to transfer the design file to the Zortrax 3D printer, the z code file was saved into SD card. The Zortrax m200 3D printer was turn ON. After the printer ON, the SD card is uploaded to Zortrax 3D printer Then, the saved file in the SD card was chosen to produce three-dimensional design of the scaffold.



(a)

(b)

Figure. 1. (a) SolidWorks designed vascular scaffold with (b) side view

2.1 Analysis Hexagon Shape of the Scaffold

In this experiment, the pore of the hexagonal shape for the printed design scaffold was compared with the original design in the SolidWorks software. The image of the hexagonal shape of the printed scaffold was observed by using Inverted Fluorescent Microscope (ZEISS). Then the Snap1521-ZEN pro 2012 software was used to display the image in the computer. The captured image was saved in jpg file. In the image processing part, measurement of three different angles was taken from the hexagonal shape of the scaffold by using ImageJ software. The measurements of the angles that was taken are 90°, 135° and 45°, as shown in Figure 2. Twenty images were captured that has similar shape with the original hexagonal shape of the design.

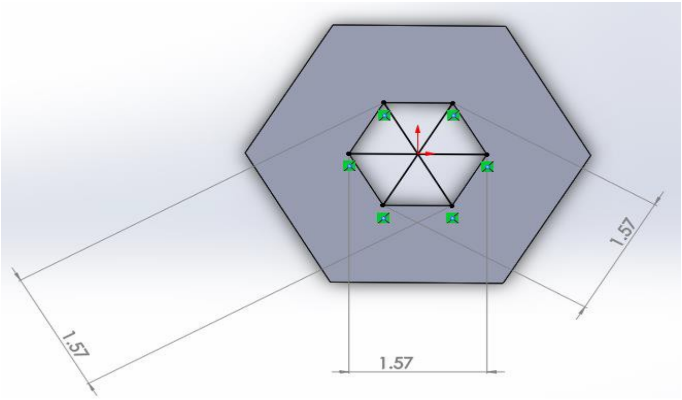
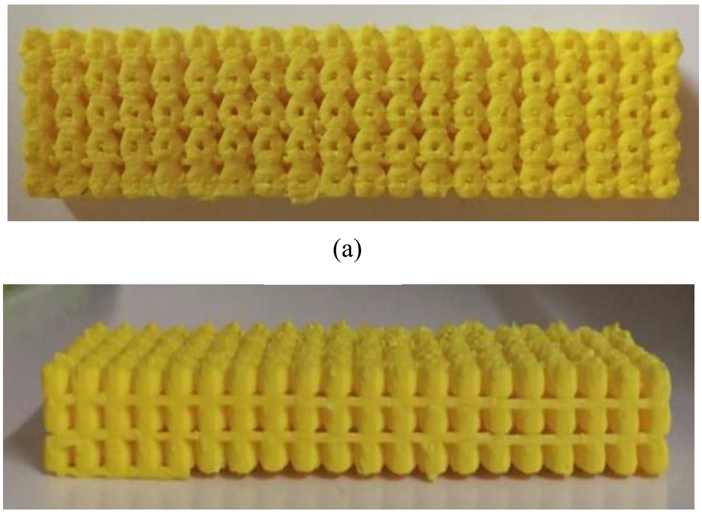


Figure. 2. Dimension of pore length in SolidWorks drawing (1.57mm)

3. Result and Discussion

The scaffold was designed using SolidWorks and was printed by using a 3D printer by using Acrylonitrile Butadiene Styrene (ABS) as the materials, as shown as in Figure. 3.



(a)

(b)

Figure. 3. (a) 3D-printed vascular scaffold b) 3D printed vascular scaffold side view

The 3D-printed scaffold was placed under an inverted fluorescent microscope (ZEISS) to observe the scaffold pores. Later, the image that has been captured by using the microscope was measured using ImageJ software. ImageJ software has been used to measure the length of pores at three different angles which are 45°, 90°, and 135°. For the pore's length measurement, 20 images were captured were all these 20 images taken for different pores on the 3D printed scaffold. Figure 4 shows the hexagon-shaped pore observed under the microscope.

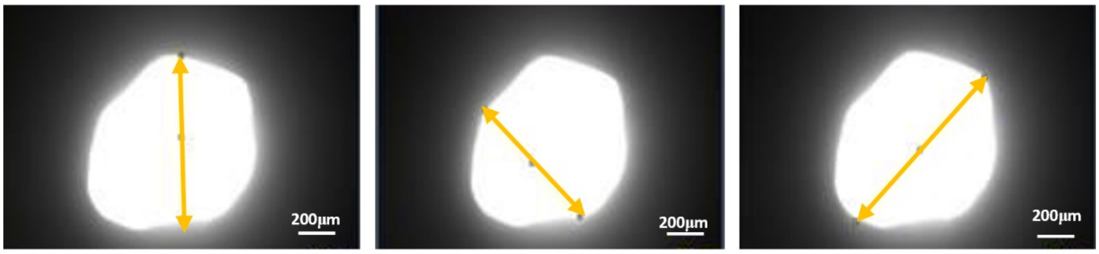


Figure. 4. The measurement of hexagonal shape from three different angles

From the ImageJ software analysis, the length of the pores was measured to compare with the original pore length. As for the result, the average pore length at three different angles has been obtained as shown in Table 1. By using this measurement, the percentage of pores length was calculated to compare with original pores length which was 1570µm.

Table 1. Average of pores length at different angles

Angle (°)	Length (µm)
45	427.710
90	371.945
135	421.562

The successful application of a scaffold depends on many features such as biocompatibility, biodegradability, mechanical and chemical properties, scaffold design and manufacturing technologies [5]. For our scaffold design, hexagon patterned pores were chosen due to its unique design with a maximum contact area between layers at intersections producing a highly anisotropic scaffold architecture leading to enhanced load transfer compared to other conventional patterns (rectangular, curved and zigzag) while maintaining the high porosity [7]. From the calculation, the measured length at three different angles shows 3D-printed scaffold has only 23% to 26% as the original pore size that was designed using SolidWorks.

3D printing technique is a layer by layer manufacturing method which is suitable for scaffold fabrication with several advantages such as making cost-effective and reproducible patient-based geometry with high accuracy [18]. However, for our result, the 3D printed scaffold only has 23% to 26% of the original pore size due to the 3D printer resolution. The 3D printing method that was used for our project was fused deposition modeling (FDM) that is relies on the nozzle and moving platform to construct the 3D structure. However, unlike indirect ink writing (DIW), FDM needs an extra heater to soften material first with a fan is located at the end of the nozzle to control the solidifying velocity of the molten material. However, the limitation of FDM lies in the poor choice of printing materials since only thermoplastic materials are more suitable with this method. For our experiment, we have used ABS as material to print out our scaffold and the temperature used was 200°C that may affect the printed pore shape.

4. Conclusion

A scaffold with hexagon pores had been designed and fabricated in this paper. The printed scaffold pore lengths were compared with the original pores lengths that draw in Solidworks. However, there are only 23%-26 % similarity between the pore's lengths of printed scaffold with the original scaffold in Solidworks. This occurred might be due to the materials selection and the high temperature in the printing process.

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