Original Article

Apparent Modulus of Honeycomb Structure: A Guideline for Porous Structure Implant Design

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Abstract

Objectives: To investigated the apparent modulus of honeycomb to be used as a guideline for facilitating porous structure implant design.

Methods: Apparent modulus of each honeycomb model was developed based on finite element analysis. Geometry of honeycomb structures included circumcircle radius of 2 mm, 3 mm, and 4 mm with wall high of 0.5 mm, 1.0 mm, 1.5 mm, and 2.0 mm.

Results: Hexagonal shape of honeycomb structure with circumcircle radius 2 mm was compared with circle with 2 mm diameter, both with wall thickness of 1 mm. The relationship is best described by logarithm equation with coefficient of correlation above 0.99. It was found that reduction of modulus for circular shape is 60 percents. The value is greater than hexagonal pattern which is 50 percents of reduction.

Conclusions: The relationship between height of honeycomb and reduction of apparent modulus of each specific circumcircle radius of honeycomb is best described in logarithm equation and as a guideline for facilitating porous structure implant design.

Keywords: dental implant, finite element analysis, honeycomb structure, modulus of elasticity, porous structure

Introduction

Occlusal load transferring to the surrounding bone is an important factor for the long term success or failure of an osseointegrated implant.(1) The transfer of occlusal load across the interface between osseointegrated implants and surrounding bone tissue is a very relevant issue. The absence of a periodontal ligament around the dental implants, biting force are directly transferred from the rigid implant to the surrounding bone, causing relatively high crestal stress concentrations. Previous studies have shown that the crestal bone loss is associated with unfavorable loading conditions.(2-4) Occlusal load from a restoration part of implant system induces strain through the implant into the surrounding bone, which subsequently affects the bone modeling and remodeling processes.(5) In biomechanical point of view, Forst *et al*., (6) demonstrated that the design of implant is important for severals clinical scenario, such as bone densities, jaw regions, implant diameter and length. The macrostructure and micro-structure of implant design influence the biomechanical stability of the implant.

Theoretically, the modulus of Elasticity of an implant material has to be as close as possible to the modulus of bone to assure an optimal occlusal load transfer. Recently, an increasing number of studies focused on the adjustment of the elastic modulus of bone implants by using Ti-based alloys or porous structures of Ti as dental implant materials. The apparent modulus of elasticity is defined as the ratio of stress to strain within the elastic range.(7)

The porous structure is one of the structural design for biomechanical stability of implant as show in Figure1. Previous studies were suggested that porous structure of titanium implant has biomechanical advantage of load transferring to cortical bone.(7-9) Schiefer suggested that the anisotropic behavior of the porous titanium must be considered in the construction of implant devices.(10) Recently, several techniques have been developed to introduce a pore size and a degree of porosity in titanium alloy,(11-13) which has led to the rapid development of various dental implant designs. Additionally the porous structure titanium implant shows a biomechanical behavior of its mechanical properties depending on the pore size and porosity. The knowledge about the biomechanical properties of porous structure dental implants is required for proper design, before fabrication and application. Researchers have investigated biomechanical properties of different porous structure implant designs such as pore size, porosity and morphology.(14)

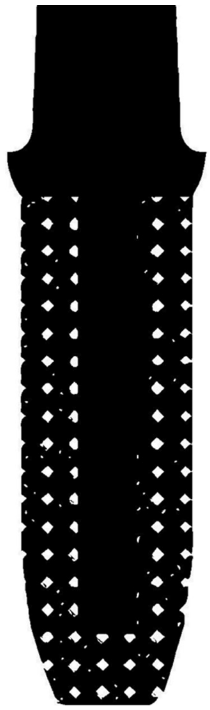

Figure 1: The porous structure implant

Honeycomb structure is commonly used in engineering applications, especially in aircraft and automobile structure(14,15), due to its lightweight with high strength and energy absorption.(15,16) Use of honeycomb structure also recently extends to medical devices where it is used as a part to reducing impact reaction producing from physiological loads. Design engineer therefore needs to have a mechanical property guideline.(17) As an important computer tool, the finite element method is particularly convenient for evaluating and improving implant design without the risk and expense of real implantation.(18) Honeycomb geometries were analyzed their apparent modulus by means of finite element (FE) analysis. The objective of this study was to investigate the relation of honeycomb dimensional characteristics to apparent modules to facilitate the design of porous structure implant.

Materials and Methods

CAD Model

3D representation of Hexagonal shape-honeycomb structure was created using CAD software (VISI 20, Vero software, UK) Hexagonal shape-honeycomb structure was

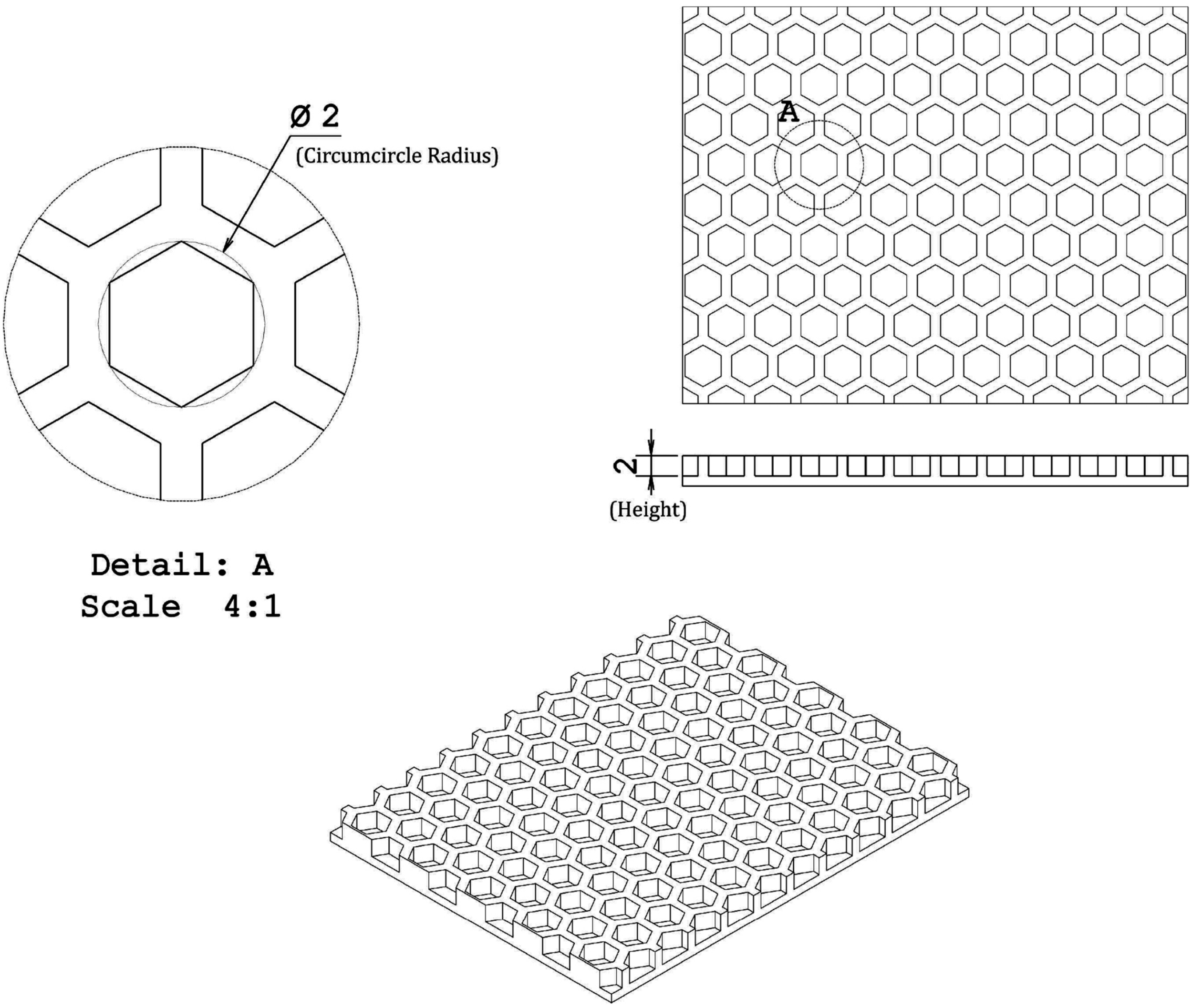

Figure 2: Honeycomb and its parameters

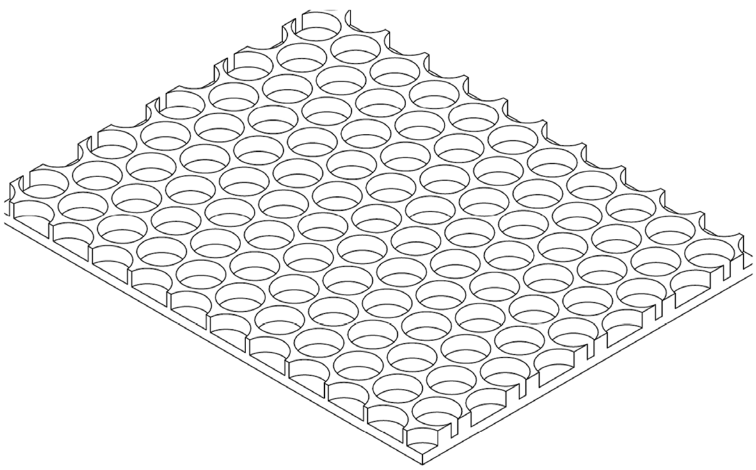

Figure 3: The plate with circle of 2 mm diameter

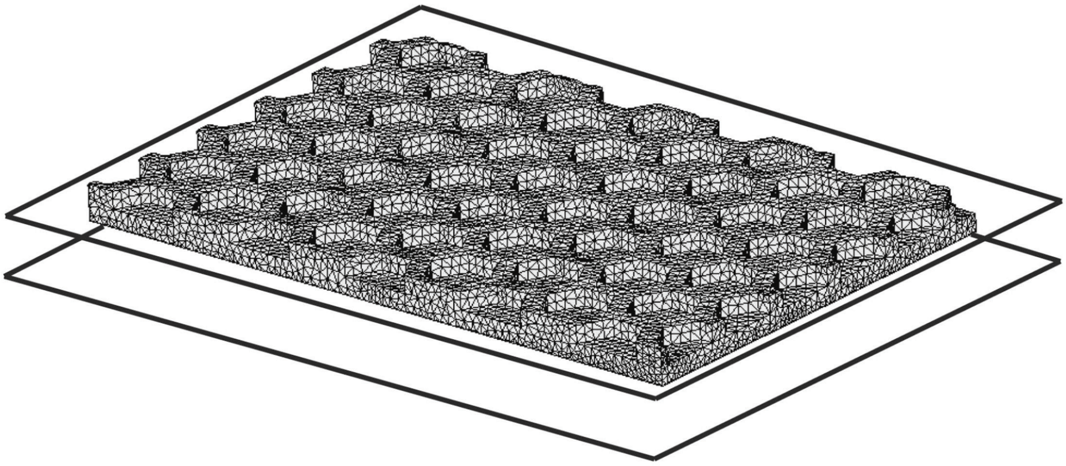

Figure 4: FE Model

under consideration in this study. The material properties assigned to the honeycomb is 5 MPa with Poisson's ratio of 0.3. Honeycomb contains core and facet on one side. Dimension of honeycomb structure included circumcircle radius of 2 mm, 3 mm, and 4 mm with wall high of 0.5 mm, 1.0 mm, 1.5 mm, and 2.0 mm, as shown in Figure 2 and Figure 3.

FE Model

All honeycomb geometries were analyzed their apparent modulus by means of finite element (FE) analysis. In all FE analyses, four-node tetrahedral element was used with total element number ranged from 25,315 to 83,779 (Corresponding to 7,190 to 22,151 nodes). The FE model is compressed with two planes as shown in Figre 4 at distance of 0.1ε. The reaction force exerted on plane was used to analyze the apparent modulus by dividing with multiplying result of effective area and strain. In this case, effective area is 928.00 mm^2 and strain is 0.1. The finite element analysis was performed using FE software (Patran/Marc Mentat 2005 R2, MSC Software Inc., USA).

Results

The modulus of each honeycomb is as follows in the Table 1. The result of percentage of modulus reduction of each honeycomb dimension shows in Figure 5. It can be seen that the apparent modulus decreases with the increase of height and circumcircle radius. The regression analysis was used to determine the relationship equation between geometric property and reduction of modulus percentage. According to analysis, the relationship is beset described by logarithm equation as shown in Table 2. In each equation, x is honeycomb height and is reduction of modulus. The mesh convergence is show in Figure 6 that exhibits solution convergence's mesh independences.

Hexagonal shape of honeycomb structure with circumcircle radius 2 mm was compared with circle with 2 mm diameter, both with wall thickness of 1 mm. The relationship is beset described by logarithm equation with coefficient of correlation above 0.99. It was found that reduction of modulus for circular shape is 60 percents. The value is greater than hexagonal pattern which is 50 percents of reduction.

Discussion

The result from this study may not be able to directly compare with elastic modulus of human bone. Since the study aims to assess how the dimension of geometry affects the apparent modulus. Since the material properties assigned here in this FE study were intended to polymer, it cannot be used for bone application unless this honeycomb structure is made from metallic materials. The reduction of modulus from these metallic materials potentially close to the bone modulus.

This study provides a relationship between wall thickness and modulus reduction of honeycomb structure as a guideline for facilitating porous structure implant design. The apparent modulus decreases with the increase of height and circumcircle radius. Beside the hexagonal shape honeycomb structure, circular shape is also the common used pattern. In order to investigate how different honeycomb structure affect to the apparent modulus,

Table 1: Modulus of the honeycomb

No.	Inscribed Radius (mm)	Wall Height (mm)	Stiffness (MPa)	% Modulus Reduction
1	2.0	0.5	2.77	44.70
2	2.0	1.0	2.51	49.78
3	2.0	1.5	2.42	51.66
4	2.0	2.0	2.34	53.28
5	3.0	0.5	2.16	56.70
6	3.0	1.0	1.98	60.47
7	3.0	1.5	1.87	62.63
8	3.0	2.0	1.81	63.81
9	4.0	0.5	1.73	65.34
10	4.0	1.0	1.60	67.95
11	4.0	1.5	1.53	69.38
12	4.0	2.0	1.48	70.30

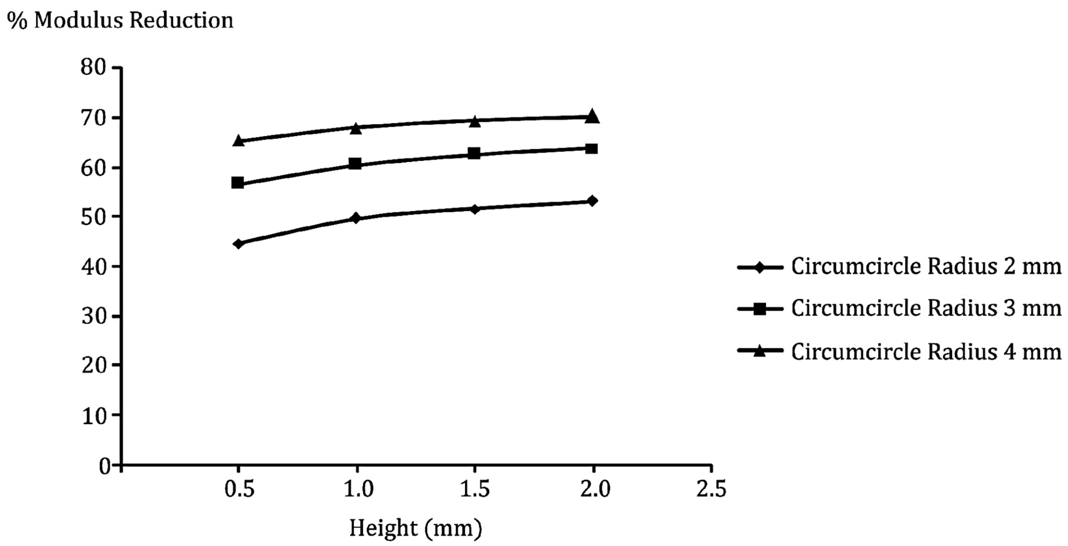

Figure 5: Percentage of modulus reduction of each honeycomb dimension

hexagonal with circumcircle radius 2 mm was compared with circle with 2 mm diameter, both with wall thickness of 1 mm. It was found that reduction of modulus for circular shape is 60 percents. The value is greater than hexagonal pattern which is 50 percents of reduction.

The result of this study was in agreement with the previous study, which the porous structure of implant effectively reduced crestal cortical bone and enhanced the load-bearing capacity.[(8)] The long-term success of implant depended upon the biomechanical stability; therefore, the proper relationship between wall thickness and modulus reduction of honeycomb structure may be an alternative design for dental implant.

The finding of this novel study is beneficial for designing the implant macrostructure. Our implant design provided optimal biomechanical stability, which could reduce of risk of biomechanical complications. The previous study demonstrated that the success of osseointegrated implant therapy depends on a combination of biological and biomechanical factors.[(19)] Current study suggested that some conditions with percent of porosity and pore size offer an optimal balance between biomechanical and biofunctional properties.[(20)] However, further *in vitro* and *in vivo* studies are required. It is worth noting that the mechanical performances analyzed by finite element could have been different depending upon materials and properties assigned.

Table 2: Equation between honeycomb height and reduction of modulus of each circumcircle radius

Honeycomb Dimension	Equation	Coefficient of Correlation
Circumcircle radius 2 mm	$y = 5.19\ln(x)+60.37$	0.999
Circumcircle radius 3 mm	$y = 6.16\ln(x)+49.23$	0.998
Circumcircle radius 4 mm	$y = 3.59\ln(x)+67.87$	0.999

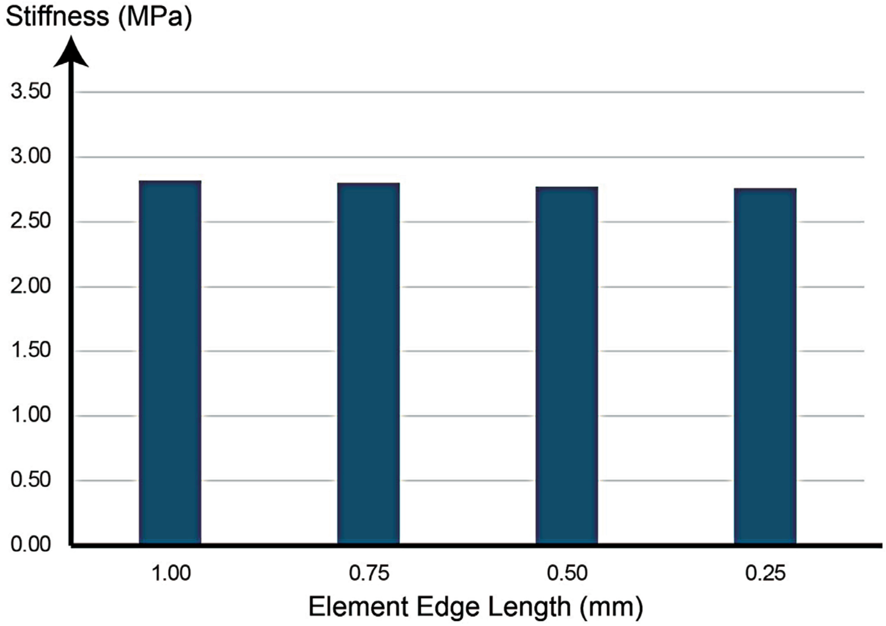

Figure 6: The mesh convergence figure

Conclusions

The relationship between height of honeycomb and reduction of apparent modulus of each specific circumcircle radius of honeycomb is beset described in logarithm equation with high coefficient of correlation so the honeycomb structure base on apparent modulus analysis might have application potential in the porous design of implants. Further studies are needed to justify this novel porous structure implant designs.

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Conflicts of interest

The authors declare no conflicts of interest.

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