Evaluation on Compressive Characteristics of Medical Stents Applied by Mesh Structures

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Abstract. There are concerns about strength reduction and fatigue fracture due to stress concentration in currently used medical stents. To address these problems, meshed stents applied by mesh structures were interested for achieving long life and high strength performance of medical stents. The purpose of this study is to design basic mesh shapes to obtain three dimensional (3D) meshed stent models for mechanical property evaluation. The influence of introduced design variables on compressive characteristics of meshed stent models are evaluated through finite element analysis using ANSYS Workbench code. From the analytical results, the compressive stiffness are changed periodically with compressive directions, average results need to be introduced as the mean value of compressive stiffness of meshed stents. Secondly, compressive flexibility of meshed stents can be improved by increasing the angle proportional to the arm length of the mesh basic shape. By increasing the number of basic mesh shapes arranged in stent’s circumferential direction, compressive rigidity of meshed stent tends to be increased. Finally reducing the mesh line width is found effective to improve compressive flexibility of meshed stents.

1. Introduction

In recent years, lumens in living body, for example blood vessels, bile ducts and tracheas, may narrow and cause various diseases. For mainly treatment of blood vessels, the stent placing surgery has been using widely. The lumens have very complex structures. In addition, they have severe movements such as bending, twisting and stretching. Furthermore, The Rejection may occur when foreign matter enters. From these reasons, it is desirable for the medical stent to have flexible structure, higher biocompatibility and follow ability to blood vessel wall.

On the other hands, previous medical stents have concerns that repetitive strains accompanying pulsation cause strength reduction and fatigue failure as shown in figure 1 [1-5]. There is the MISAGO meshed stents shown in figure 2 (Terumo corp.) [6], which has relatively low stress and high durability, the problems of strength reduction and fatigue failures are still existed [7-9]. More flexible and higher stretchy medical stents which can cope with harsh movements are desired. For these problems, it is considered to solve them by applying mesh structures [10] to the surface of nickel titanium cylinder to obtain meshed stents with higher flexibility and strength.
1.1. Designing basic mesh shapes for 3D meshed stent models.

Basic mesh shape based on regular hexagon, which has higher in-plane isotropy and lower out-of-plane elasticity, is designed for meshed stent application [10]. Design variables like the angle affecting to arm length (hereinafter called “θ”), the number of basic mesh shape in the stent circumferential direction (hereinafter called “n”) and mesh line width (hereinafter called “w”) of the basic mesh shape and meshed stent as shown in figure 3 and figure 4 are introduced for analytical investigation.

The diameter of the mesh stent cylinder is 6.0 mm and the strut thickness is 0.18 mm for sample model analysis. These size are same as the medical stent used in femoral artery. The basic mesh shapes and 3D meshed stent models are designed and created using 3D CAD software Solidworks.
2. Evaluation of compression characteristics of the mesh stent
Analytical evaluation on compressive stiffness of 3D meshed stent models are carried out by using ANSYS Workbench software. Meshed stent model with compressive jigs under compressive loading are introduce and shown in figure 5. Compressive stiffness of mesh stents can be obtained from the maximum displacement with respect to the applied compressive load obtained by analysis.

Material properties of nickel titanium and finite element mesh settings of FEA model of meshed stents are shown in table 1 and sample finite element mesh image is also shown in figure 5 for 3D analytical evaluation.

| Material properties       | Longitudinal elastic modulus [GPa] | 75  |
|---------------------------|------------------------------------|-----|
|                           | Poisson's ratio                    | 0.3 |
| Finite element mesh       | Size of elements [mm]              | 0.06 ~ 0.09 |
|                           | Number of element in thickness direction | 2 or 3 |

2.1. Periodicity due to the basic mesh shapes based from regular hexagon.
In this section, periodicity of compressive property of meshed stent models using regular hexagon based mesh shapes is to be evaluated with mesh line width \( w = 0.1 \) mm, different basic mesh shape number \( n \) and angle affecting to arm length \( \theta \). Analyses are carried out with changing the compressive directions by rotating the meshed stents round the cylindrical axis from 0° to an angle obtained by dividing 360° by basic mesh shape number \( n \). Obtained results are shown in figure 6. From these results, it is found that the periodicity of compressive stiffness of meshed stents is confirmed by changing the compressive directions from 0° to the angle. The periodicity of compressive stiffness can be considered from the application of regular hexagon based mesh shapes.

![Figure 5](image5.png)

**Figure 5.** FEA model evaluating compressive characteristics of meshed stents.

![Figure 6](image6.png)

**Figure 6.** Periodicity of compressive stiffness by stent rotation angle.
2.2. Effects of the angle affecting arm length to compressive stiffness.

In this section, effects of the angle affecting arm length to the compressive property of meshed stent models using regular hexagon based mesh shapes are to be evaluated with basic mesh shape number \( n \) setting at 5, 6 and 8, fixed mesh line width \( w \) of 0.1 mm. Analyses are carried out with changing the angle affecting to arm length \( \theta \) between 0° and 90°. Obtained results are shown in figure 7. From these results, it is found that the more the angle affecting to arm length, the less the compressive stiffness of meshed stents.

![Figure 7. Compressive stiffness by angle proportional to arm length \( \theta \).](image)

2.3. Effects of basic mesh shape number in the circumferential direction.

In this section, the effects of the basic mesh shape number in the circumferential direction on the compressive property of meshed stent models using regular hexagon based mesh shapes are to be evaluated, with the angle affecting arm length \( \theta \) setting at 70° and 30°, mesh line width \( w = 0.1 \) mm. Analyses are carried out with changing the basic mesh shape number \( n \) between 3 and 8. Obtained results are shown in figure 8. From these results, it is found that the more the basic mesh shape number, the more the compressive stiffness of meshed stents.

![Figure 8. Compressive stiffness by number of basic mesh shapes \( n \).](image)

2.4. Effects of the mesh line width \( w \) on compressive stiffness of meshed stents.

In this section, the effects of the mesh line width \( w \) on the compressive property of meshed stent models using regular hexagon based mesh shapes are to be evaluated, with the angle affecting arm length \( \theta \) fixed at 30° and basic mesh shape number \( n \) setting at 3, 4 and 5. Analyses are carried out with changing the mesh line width \( w \) between 0.05mm and 0.5mm. The obtained results are shown in figure 9. From these results, it is found that the narrower the mesh line width, the less the compressive stiffness of meshed stent models.
3. Summary
Meshed stent models using regular hexagon based mesh shapes are designed and created for medical devise applications. The influences of different design variables on compression characteristics of meshed stent models are analytically evaluated by using finite elements method. From the obtained results,

1. The compressive stiffness are changed periodically with compressive directions, average results need to be introduced as the mean value of compressive stiffness of meshed stents.
2. Compressive flexibility of meshed stents can be improved by increasing the angle proportional to the arm length of the mesh basic shape.
3. By increasing the number of basic mesh shapes arranged in stent’s circumferential direction, compressive rigidity of meshed stent tends to be increased.
4. Finaly reducing the mesh line width is found effective to improve compressive flexibility of meshed stents.

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