Design of Porous Structures for Scaffold Synthesis and its FEA

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Abstract- - Injuries are experienced in many forms and take time to heal depending on the severity. Some injuries are recovered from naturally/quickly, while others take longer periods of time. Scaffolds are porous structures which provide a platform for cells to regenerate on. They provide support in times when individuals cannot regenerate tissues on their own. The materials of scaffolds can be varied to determine the best mechanical property for implanting in the body. In our study, we have tested stress and strain of PCL and titanium material for six proposed designs. From our study, we were able to conclude that the ‘sphere’ provided the most stability whereas the ‘eccentric pores’ design was the least stable. These results were persistent for both the materials studied with Ti6Al4V having the greatest properties. As a result, we concluded that titanium is the best material to be used in terms of scaffolds, by implanting it as an eccentric pores and spheres.

Keywords – scaffolds, mechanical properties,

1. INTRODUCTION

Often times bones suffer trauma to an extent in which it takes time for them to heal. Scaffolds provide highly porous ground for cells to regenerate themselves on and aid in speeding up the recovery time. Scaffolds are supporting structures which are porous in nature and provide space for cells to adhere, differentiate and proliferate [1]. Sufficient pore size and proper porosity are essential factors for tissue growth. They provide mechanical support for better and faster growth of cells. A scaffold made for bones must have similar mechanical properties to the bone as it must mimic the mechanical properties and morphology of the bone [2]. The mechanical strength of a scaffold not only depends upon the material being used, but it also depends upon the 3-dimensional structure of the scaffold. The human bone is anisotropic in nature implying that the behavior of the bone will vary according to the direction of the load applied [3],[4]. Porosity and pore size are important factors that have to be taken under consideration while designing orthopedic scaffolds [5]. It is common for the human bone to be loaded longitudinally and less over the surface of the bone [6],[8]. The amount of force acting on the entire bone varies from one place to another [7]. Factors such as compressive strength, elastic modulus, yield strength, Young's modulus, Poisson's ratio, hardness, and energy absorption all affect the bone’s mechanical properties. Among these, yield strength, the elastic modulus, and Young's modulus provide insight into the bone’s load-bearing capacity. When Young’s modulus of a scaffold is increased and porosity decreased, it allows for scaffolds with quality as they can withstand high loads[8].

However, a disadvantage of this method is that it does not allow for the proper growth of cells around the scaffold due to the decreased porosity. Although highly porous scaffolds result in more cell formation, it leads to poor mechanical properties. Thus the 3-dimensional structure of the scaffold is one of the most important factors that must be taken care off. Hence for a scaffold to be successful it should be both mechanically and biologically stable. It is very important to maintain Young's modulus of the scaffold similar to that of bone in order to maintain the equilibrium in the distribution of load. Determining the mechanical strength of a scaffold through in-vitro and in-vivo
procedure is both expensive and time-consuming. The modern day technologies such as CAD models and be tested through simulation softwares [9],[10]. Thus FEA plays an important role in determining the total deformation, mechanical strength, and distribution of stress over the scaffold. It is a much safe, easy and time efficient method which can be used to evaluate the structural strength. Prior to performing on human beings, FEA can be simulated and computed through software such as ANSYS to determine structural strength. PCL (Poly-caprolactone) are widely used for the synthesis of scaffold for tissue engineering application. PCL scaffolds have good mechanical properties. PCL has the extraordinary ability to blend with other polymers. PCL can be used for the fabrication of scaffold for both hard and soft tissues. It has a density of 1.142 g/cm³ [11]. PCL has a low melting point of 60°C along with a high degradation temperature of 350°C. The degraded PCL can be eliminated from the body through renal excretion. The degradation rate of PCL is very slow (about 2 year’s in-vivo). This is due to its crystallinity and hydrophobicity thence limiting its application for short-term usage. The PCL based scaffolds can be prepared by using the solvent casting method or by 3D printing [12]. Solvent casting method is the easiest and reliable method for the fabrication of polymer-based scaffolds.

Ti6Al4V is a titanium alloy which used for manufacturing orthopedic implants. It has 90% of titanium, 6% of aluminium, and 4% of vanadium. It has a Elastic modulus of 114GPa, density of 4.429g/cm³ and a Poisson’s ratio of 0.34. Titanium alloys exists in three structural forms: alpha (α), beta (β) and alpha-beta [13],[14].

2. METHODOLOGY

A total of six designed were constructed using AutoCAD 2017. A cube (dimensions 2mm×2mm×2mm) is the base for all the six designs. The six designs are – Aster, Sphere, Hexagon, Linear Cylinder, Eccentric Pores, Double ‘Y’.

A. Aster

Aster is the name of a flower. This design is inspired from the nature. Firstly a cube of dimensions 2mm×2mm×2mm was drafted. The aster design was created by drawing a simple circle (diameter 1mm) and later many lines were drawn from one end to the other at different angles along the axis of circles. Later small circles were drawn between the two adjacent lines where the line ends on circle. Finally the unnecessary lines were removed using trim and erase command. After the 2D aster design was ready the 2D aster design was extruded for 10mm. The extruded aster design was then placed at the center of each face and later they were subtracted in order to obtain the design. Finally a sphere was drawn from the center of the unit cells and intersection command was executed in order to obtain curved edges.

B. Sphere

Firstly a cube of dimensions 2mm×2mm×2mm was drafted. Later a sphere of diameter 2.5mm was subtracted from the central axis of the cubical cell. This leads to the formation of hollow spherical structure. Finally a sphere was drawn from the center of the unit cells and intersection command was executed in order to obtain curved corners.
Table 1: Designs used in the study and their respective views

| S.No | Aster | Sphere | Hexagon | Linear Cylinder | Eccentric Pores | Double ‘Y’ |
|------|-------|--------|---------|-----------------|-----------------|------------|
|      | ![Aster](image1) | ![Sphere](image2) | ![Hexagon](image3) | ![Linear Cylinder](image4) | ![Eccentric Pores](image5) | ![Double ‘Y’](image6) |
| Isometric View | ![Aster](image1) | ![Sphere](image2) | ![Hexagon](image3) | ![Linear Cylinder](image4) | ![Eccentric Pores](image5) | ![Double ‘Y’](image6) |
| Front View | ![Aster](image1) | ![Sphere](image2) | ![Hexagon](image3) | ![Linear Cylinder](image4) | ![Eccentric Pores](image5) | ![Double ‘Y’](image6) |

C. *Hexagon*

Firstly a cube of dimensions 2mm × 2mm × 2mm was drafted. A 2D hexagon (inscribed in a circle of diameter 1.45mm) was drafted and was later extruded for 10mm. The extruded aster design was then placed at the center of each face and later they were subtracted in order to obtain the design. Finally a sphere was drawn from the center of the unit cells and intersection command was executed in order to obtain curved corners.

D. *Linear Cylinder*

This is a very simple design. The structure has a total of 12 cylinders that were placed at the edges of the cube (dimensions 2mm × 2mm × 2mm).

   (a) *Eccentric Circle*

Firstly, a cube of dimensions 2mm × 2mm × 2mm was drafted. A total of eight spheres of diameter 1.1mm were placed at the eight corners with the center of each sphere placed at the corner of the cube. Later the cube was deleted, thus finally leaving eight spheres that are placed adjacent to each other.

E. *Double ‘Y’*

The double ‘Y’ shaped geometrical structure was drafted using line and trim command. A star shaped structure was obtained. The obtained double ‘Y’ structure was later extruded for 2mm. This gives a star shaped structure.
Table 2: Equivalent (Von-mises) Stress (Mpa)

| S.No | Material | Aster    | Sphere   | Hexagon  | Linear Cylinder | Eccentric Pores | Double ‘Y’ |
|------|----------|----------|----------|----------|----------------|-----------------|------------|
|      | Ti6Al4V  | 88.995   | 431.44   | 75.602   | 82.55          | 2.1553         | 77.143     |
|      | PCL      | 89.788   | 433.49   | 76.074   | 81.984         | 2.1865         | 76.592     |

Fig 1: Stress analysis of A:Aster,B:Sphere,C:Hexagon,D:Linear Cylinder,E:Double Y,F:Eccentric sphere using Ansys Workbench
3. RESULT

Out of the six designs, the design named ‘Sphere’ is the most stable design and the design named ‘Eccentric pores’ is an unstable structure. The ‘Sphere’ design has the highest stress bearing capacity of 433.49Mpa for PCL and 431.44Mpa for Ti6Al4V. The ‘Eccentric pores’ design has the least stress bearing capacity of the six designs. It has a stress bearing capacity of 2.1865Mpa for PCL and 2.1553Mpa for Ti6Al4V. The ‘Sphere’ design has the maximum value for strain and the design ‘Eccentric pores’ has the least value for strain. The ‘Sphere’ design has the maximum strain value of 3.7931mm/mm for Ti6Al4V and 1.6838mm/mm for PCL. The ‘Eccentric pores’ design has the minimum strain value of 0.

Table 3: Equivalent (Von-mises) Strain (mm/mm)

| S.No | Aster | Sphere | Hexagon | Linear Cylinder | Eccentric Pores | Double ‘Y’ |
|------|-------|--------|---------|----------------|-----------------|------------|
| Ti6Al4V | 0.80317 | 3.7931 | 0.70913 | 0.72628 | 0.022632 | 0.67818 |
| PCL | 0.35847 | 1.6838 | 0.31609 | 0.31933 | 0.010455 | 0.29752 |

Graph 1: Equivalent Strain (mm/mm)
4. CONCLUSION

The factors such as strain and stress distribution were studied for six different designs. The study was conducted for two materials namely Ti6Al4V (Titanium alloy), and PCL (Polycaprolactone). There is very less differences in the distribution of stress for both the materials but there is a huge variation in distribution of stress when it comes to change in design. The six designs showed huge variation in the distribution of stress and strain. Out of the six designs the design named ‘Sphere’ has the highest stress bearing capacity and value for stress. Though the is not much significant difference in stress for the two materials used. Thus the ‘Sphere’ design can be used for making scaffolds with higher mechanical strength. Thus can be used for making bone scaffolds. The other designs such as Aster, Hexagon, Linear cylinders, and Double ‘Y’ have moderate amount of stress bearing capacity. Thus they can be used for making scaffolds for soft tissue which experiences moderate amount of stress. ‘Eccentric pores’ is a failure design and it has the least stress bearing capacity.

5. REFERENCES

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