Effects of Material Properties in Spinal Fusion Cage for Lumbar Vertebrae

Rusnani Yahya1,2, Muhammad Lukman Shudin2, Muhammad Hazli Mazlan3, Solehuddin Shuib2, Abdul Halim Abdullah*2

1Department of Electrical Engineering, Politeknik Sultan Salahuddin Abdul Aziz Shah, Seksyen U1, 40150 Shah Alam, Malaysia
2Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia
3Microelectronics and Nanotechnology-Shamsudin Research Center (MiNT-SRC), Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Malaysia

*halim471@uitm.edu.my

Abstract. Vertebral endplate subsidence failure will increase the possibility of mechanical instability in the lumbar spinal fusion. The spinal implants of cages are many type of design that can be use in spinal fusion and the type of material also been considerate. Posterior lumbar interbody fusion (PLIF) cage is believed to maintain the stability and to promote fusion between vertebrae. Different type biomaterial of cage was made by metal, ceramic and polymer, also composite. The Posterior Instrument (PI) such pedicle screw and rod was made by Titanium Alloy. The aim of this study was to examine the effects of different materials of cage in lumbar fusion. 3D vertebrae model (L3–L4) with interbody fusion using different material properties such as PEEK, PLA, Cobalt Chromium, Titanium Alloy and Stainless Steel. A fusion model with pedicle screw systems L3–L4 levels were reconstructed based on the respective surgical protocols. The stress distribution and total deformation of the cage were measured under different compressive loading conditions and motion. Results show that the titanium alloy is the best material for metal categories while PLA (Poly lactic acid) for composite category.

1. Introduction
Spinal fusion surgery is one of the most common procedure in treating spinal disorders. Although it has been implemented for many years, there are still many important challenges and issues need to be highlighted especially the level of unity. The finite element analysis is part of the current approaches in predicting the influence of different cage designs on the fusion process [1, 2]. Spinal fusion is a surgical technique performed to combine two or more vertebrae in the spine. It is usually performed to treat a number of conditions such as trauma, spinal defect (eg, scoliosis or kyphosis), degenerative diseases, and infectious or neoplastic diseases [3]. The procedure of this surgery is by using the interbody fusion technique which the cages implant will be inserted between the vertebra bones to fill the disk space with supported by rods and screws to hold the vertebra bones. There are many type of interbody cages implant design available in market and some model had been approved by the United States Food and Drug Administration (FDA) [4].

Interbody implants are developed for a rigid axial mechanical support which will improve the initial stability. The grafting material housed within and around the spacer could achieve a better biological
fusion [5-7]. It will correct deformity and achieve nerve root decompression through restoration of lost disk space with implantation of cages [8]. The cages are designed to restore normal disc height, improve construct stiffness and thus reduce posterior instrumentation failure. Cages also have several type of material which is PEEK, PLA, Titanium Alloy, Cobalt Chromium and Stainless Steel. The most commonly used materials used for interbody cages are titanium metal and polymer polyetheretherketone (PEEK). Poly lactic acid (PLA) is assumed to be the alternative material which could provide cheaper material and lower production cost.

The aim of this study is to investigate the effect of material properties of intervertebral fusion cage and the posterior instrumentation on compressive load, and four loading condition of a treated spinal lumbar motion segment.

2. Material & Methods

2.1. Development of 3D model

Finite Element Analysis was applied to evaluate the cage subsidence phenomenon in the lumbar vertebra. The 3D finite element model of third to fourth lumbar vertebrae, known as L3 and L4, respectively as shown in Figure 1.

![Figure 1. 3D model of L3-L4 bones](image)

The CT scan data of vertebra bone of patient is transfer to 3D model. The CT scan data of lumbar vertebra cutting process is performing by biomedical software. The part of lumbar vertebra that needs to develop is L3 and L4 lumbar vertebra bone only. So, the vertebra need to be slice by each CT scan data to ensure it is not connected to lower and the upper part of lumbar vertebra bones. The other part of vertebra bones and pelvis will be deleted by slices of CT scan data, shown in Figure 2 whole region of the vertebra bone.

![Figure 2. The green region of whole part](image)

After all part that connected to L3 and L4 lumbar vertebra bone have been deleted by edit 3D mask of the model, the part left will be import to dedicated design software to edit the surfaces and shells of
the model. Finally, it will be imported back to biomedical software to gets the model of L3 and L4 vertebra bones completely edited and export it to igs file.

Five different of material of fusion cages were simulated. A conventional monobloc cage namely convex-shaped (Figure 3) was modelled to better fit the disc space anatomy. The cage was modelled as a material composite of PEEK and PLA. The all implant design that written in .stl file will be converted into igs by using the CAD Converter software. Then, import the .igs file in computational software to get the detail of the implant design. Then, design software (CATIA) was used to convert the written file as .sat for the model and further to perform the FE analysis.

![Figure 3. The imported cages implant in CATIA software](image)

The spinal implant will be placed at the L3 and L4 lumbar vertebra to complete the spinal fusion model which it will be import to CATIA software to perform analysis step. The screws will be implanted bilateral at each lumbar vertebra bone and the rods will be placed at each two screw to connect it together. The cages implant will be inserted between lumbar vertebrae with same spot (Figure 4).

![Figure 4. Example of reconstructed model of spinal fusion on lumbar vertebra at different views](image)

### 2.2 Finite Element Modelling

The mechanical properties of the lumbar model and implant was assigned as linear, isotropic and homogeneous material as shown in Table 1.

| Material            | Young’s Modulus (MPa) | Poisson ratio | Yield’s Strength (MPa) |
|---------------------|-----------------------|---------------|------------------------|
| Cancellous Bone     | 350                   | 0.25          | -                      |
| Cortical Bone       | 12000                 | 0.3           | -                      |
| Intervertebral disc | 8.4                   | 0.45          | -                      |
| Facet Joint         | 11                    | 0.2           | -                      |
| PLA                 | $3.620 \times 10^3$   | 0.39          | 130                    |
| PEEK                | $1.459 \times 10^3$   | 0.4           | 231.2                  |
| Titanium Alloy      | $105x10^5$            | 0.34          | 795                    |
| Stainless Steel     | $210 \times 10^5$     | 0.29          | 190                    |
| CoCr                | $200x10^5$            | 0.3           | 450                    |

The spinal fusion on lumbar vertebra model of L3 and L4 will be import to computational software to perform the analysis on it with the applying distributed loading of compressive force at the top of the
lumbar vertebra bones. Boundary condition applied in this study represent the normal physiological activities of the spine. The FE models were loaded with compressive load of 1000N. The results of FE analysis for each material properties of cages implant on spinal fusion will be compared each other to get the different effect on using different type of material properties cages implant.

3. Results and Discussion
The effects of different material properties of the cages were discussed in the resulting von-mises stress and displacement. Simulation result demonstrated good slip behaviour under axial rotation, flexion, extension and lateral bending, as compared with the different material properties interbody cages, even with the additional posterior fixation. However, the flexion of Titanium Alloy is highest, showed that material suitable used for cages and also for posterior instrument but lowest extension for this material. But had not much difference under axial rotation and lateral bending for all type of cages material properties.

Findings on total displacement at the human spine FE model for the load case of a 1000N in Figure 5 and Figure 6. Showed that relation between spinal fusion with posterior instrument and L3-L4 vertebrae are not much affected on displacement, cage is stable in the position and also the vertebrae.

Figure 5. Displacement for L3-L4 (unit: mm) at different materials of cages

PLA are most affected on displacement when apply the material properties on L3-L4 vertebrae model in simulation. However, these materials are cheaper material but give high quality of implant biomaterial. Cage from these categories must in complete set with posterior instrument for more stability. Usually, posterior material is from metal categories such as Titanium Alloy are used for pedicle screw and rod.

Figure 6. Translational Displacement of L3-L4 on 1000N compressive loading

The simulation study suggested that the different material properties of spinal fusion and posterior instrument important to get better stability and also less stress at the bone when doing physiology activity such as walking or climbing/jumping.
4. Conclusion
A computational modelling study was conducted to evaluate the effect of material properties for different cage material with pedicle screw and rod. However, the results of our study demonstrated that the posterior lumbar interbody fusion (PLIF) with different categories of implant material was important stabilization system with low stiffness not only produced desirable stabilization but also allowed near-intact motion. FE study has predicted changes in stress due to flexibility of stabilization systems. The FE result clearly showed that the vertebrae with hinged screw permit a better load sharing with lower stresses at the bone-implant interface. however, further analysis of the construct in the presence of follower compression pre-load and long-term assessment are essential for overall assessment of the stress and displacement of vertebrae in all condition of physiological motion.

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