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Effect of thread profile on bending strength of pedicle screw

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Abstract. Current pedicle screw designs have not achieved strong bending strength due to varying bone density among patients. Osteoporosis further presents complications in screw fixation and instrumentation failure due patients having less dense bones. We conducted this study to investigate the effect of thread profile on the bending strength of pedicle screw. The study also focus on the bending performance comparison between single threaded and dual threaded pedicle screw via finite element method. The finite element analysis (FEA) was apply to investigate the effect of thread design on the bending strength of pedicle screw (dual threaded, double dual threaded and the dual lead dual threaded screw designs) under normal and osteoporotic bone conditions. The FEA results obtained show that the thread profile does influence the bending strength of a pedicle screw in normal and osteoporotic bones. The dual lead dual threaded pedicle screw showed an improvement of 1.88% in its deflection due to bending. While for the osteoporotic condition, the dual lead dual threaded pedicle screw showed an improvement of 32.3% in term of deflection. Thus, this finding have potential in assisting the optimum pedicle screw design in future although further investigation needed to support this finding.

Keywords: Bending Strength; Pedicle Screw; Optimization; Osteoporosis.

1. Introduction

As our society becomes more advanced, humans are beginning to have longer lifespans. However, with this comes issues pertaining to caring for their health, as the human body ages our mental and physical abilities start to deteriorate and as many developed countries recently figuring out a lot of energy and care is required to take care of the elderly. One of the common issues faced by elderly people is osteoporosis in which is a bone disease that occurs when the bone density decreases. As a result, the bone strength decreases and may break from falling or, in more profound cases, from sneezing or minor bumps. It is indeed is a grim reality and many of the elderly do indeed have to go through procedures to ensure that they have a decent quality of life. Spinal fusion is one of the most common procedures used by the elderly. This is a procedure for combining two or more vertebrae into a single structure [1-4].

It works by preventing movement between the joined vertebrae, which reduces or prevents back pain. After the bones have fused, they do not move any more as they used to. This prevents the patient from stretching ligaments and nerves of surrounding muscles, which may have caused pain. Pedicle screws, which are often use in the spinal fusion process to provide additional support and strength to the fusion when healing. Pedicle screws are insert into the vertebrae, and a rod is use to connect the fused screws together. There have been issues on pedicle screw usage in surgery, which has become a standard for spinal surgery. Since its first usage in a surgery in the 1990s. Common problems that are face by this adjacent segment disease and instrumentation failure, which might be cause by biomechanical problems [5-7]. As mentioned earlier the decreasing bone density in the elderly has resulted in poorer performance of pedicle screws in spinal surgery. Current studies are gearing towards finding a more optimum screw design, which will have better bending strength [8-14]. One of the proposed designs is a dual threaded screw.

Pedicle screws commonly used to treat a variety of spinal conditions, such as fracture, tumour, infection, or spine degeneration. As society continues to enjoy longer life spans, surgeons commonly face complicating cases in treating spinal problems such as where patients are not only suffering osteoporosis which results weak bones but also require pedicle screw fixation for treatment [1-14]. Current issues faced by the industry are the current design of pedicle screws that still have not accomplished a strong bending strength due to the fact, that the density of the bone varies from person to person and the bone is significantly less dense in patients suffering osteoporosis. Thus, the purpose of this research is to investigate the bending strength of single and dual threaded pedicle screw, the effect of thread profile design on the bending strength of a pedicle screw either in normal bones or in osteoporotic bones.

2. Methodology

This project began with constructed 3D model of pedicle screw which focusing its thread profile in detail. The thread construction based on the parameters listed in table 1 and referred from report by Kao *et al.* [13].

Table 1. Thread design parameter.

Parameter	Value
Proximal Root Radius	0.4mm
Distal Root Radius	1.2mm
Thread Width	0.1mm
Proximal Half Angle	5°
Distal Half Angle	25°

To create the thread profile, we select the thread profile folder and an existing default thread profile is then edit to the specifications from table 1. Figure 1 shows the dimension of the thread profile while figure 2 shows the thread profile.

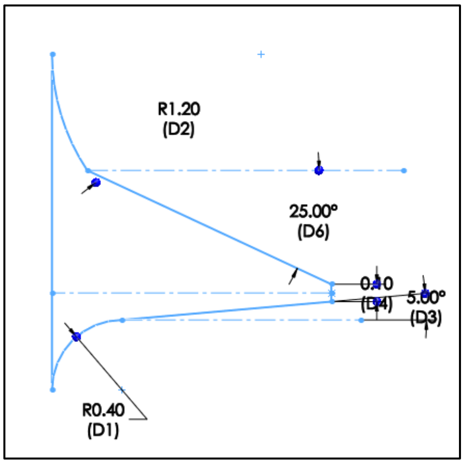

Figure 1. Thread profile dimensions for single threaded screw.

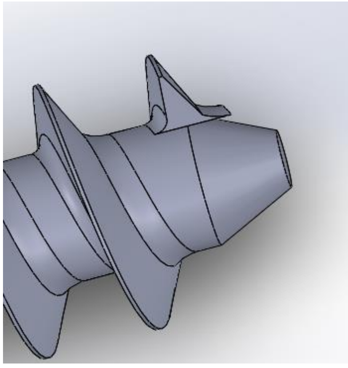

Figure 2. Thread profile of pedicle screw.

After the module has been selected the data for the material that represents the bone and screw must be inputted. The mechanical properties listed in the table 2 where the shear modulus and bulk modulus were derive by the software from the elastic modulus.

Table 2. Mechanical properties of the model.

Type	Screw (Titanium alloy)	Bone
Elastic Modulus	110 GPa	2.6 GPa
Poisson Ratio	0.3	0.3
Shear Modulus	4.2308 x 10^10 Pa	1 x 10^9 Pa
Bulk Modulus	9.16667 x 10^10 Pa	2.1667 x 10^9 Pa

2.1 Finite element model (FEA) validation

In order to validate the FEA model, the maximum deflection and the tensile stress of the single threaded screw compared to the FEA result obtained by Kao *et al.* [13]. The detail of the comparisons are as shown in table 3.

Table 3. FE model validation.

Type	Reference [12]	Our Model	Percentage Error (%)
Maximum Deflection (mm)	2.13	2.11	0.93
Maximum Tensile Stress (MPa)	2726	3028.7	11.10

Based on the low percentage error (0.93 & 11.10%), our FE model can be considered valid and acceptable. Once the model was validate, the finite element analysis was run under normal and osteoporotic bone conditions for the proposed models (dual threaded, double dual threaded and the dual lead dual threaded screw designs). This FEA done to investigate the effect of thread design on the bending strength. For the bending test, the head of the screw was fully constrained and the contact between the screw and bone was set as frictionless. A force of 220N was set at distance of 40mm from the head of the screw. The finite element analysis results such as the maximum principal stress and deformation obtained was use to represent the bending strength performance of the proposed pedicle screw. Proposed pedicle screw are consisted of three models which is the dual threaded, double dual threaded and the dual lead dual threaded screw designs. While for the reference model is single threaded screw (currently available in the market).

2.2 Dual threaded screw design

The parameters of the screw were maintained as the same as the single threaded screw the only difference being that the shaft screw was divided into two portions of 19mm each not including the tip of the screw. The pitch was 3mm and 1.95mm portions as shows in in figure 3.

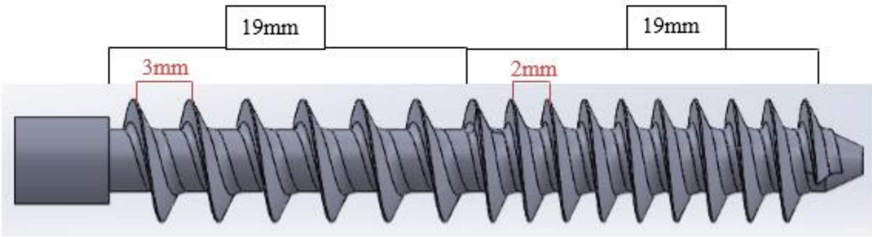

Figure 3. Dual threaded pedicle screw design.

2.3 Double dual threaded screw design
In a double dual threaded screw, there are two different thread profiles (buttress thread and V thread profile). Figure 4 shows the double dual threaded pedicle screw. The upper portions use the same thread profile as used in the single threaded screw while the lower portion uses the thread seen in figure 4. The thread was construct using the holes wizard feature in SOLIDWORKS and aligned with each other. The bone model was construct the same way as the dual threaded pedicle screw.

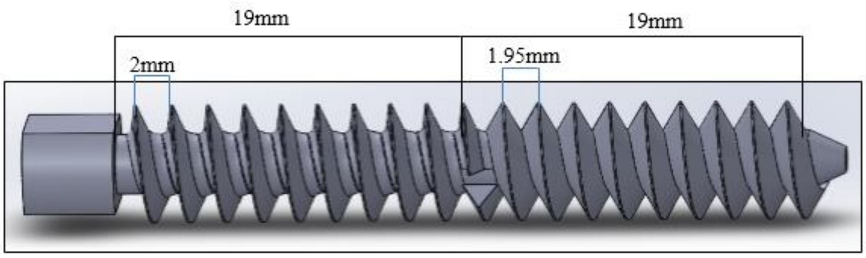

Figure 4. Dual threaded pedicle screw design.

2.4 Dual lead dual threaded screw design
The third proposed screw design is dual lead dual threaded; the screw uses the buttress thread as shown in figure 5, the upper portion is a dual lead with a pitch of 3mm while the lower portion is 1.7mm. The thread was create using the holes wizard feature and made to align each other using Solidworks software. This proposed design is like a combination between the proposed design 1 (dual threaded pedicle screw) and proposed design 2 (dual threaded pedicle screw).

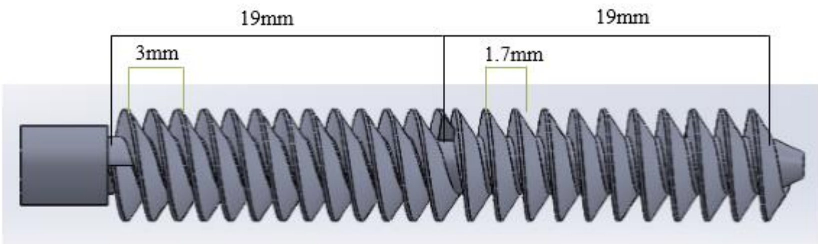

Figure 5. Dual lead dual threaded pedicle screw design.

2.5 Osteoporotic bone condition
To simulate the conditions of an osteoporotic bone the value for the elastic modulus is changed to mimic the loss of bone density from aging and a reduction from mechanical performance. The value of the young’s modulus is choose to be half of the amount of the normal healthy bone base on the published journal by Jimenez *et al.* [5]. Therefore, since the elastic modulus for the

normal healthy bone is assumed to be 2.6 GPa, the osteoporotic condition is set at 1.3 GPa to represent the decline in mechanical performance, the Poisson ratio is maintained constant at 0.3.

2.6 Meshing

The finite element mesh used in the present study consisted of solid elements (hexahedral and tetrahedral) with reduced integration. The models (three proposed design of pedicle screw models) are comprised of 9000 to 11000 elements and 17000 to 21000 nodes. One of assumption made in our Finite Element Analysis (FEA) was that the mesh used was not too course or too fine but it is still converged. Other assumptions that did in our FEA are such as materials were consider as linear and forces are being applied slowly and did not change direction in time.

3. Results and discussion

3.1 Comparison of maximum deflection of pedicle screw in normal bone

Based on the table 4, the proposed design 3 (dual lead dual threaded design) shows the best improvement since its maximum deflection, 1.94mm compared to the single threaded which is 2.11mm. This indicates that the proposed design 3 can withstand a higher force before starting to undergo deformation. Figure 6 shows the deflection of the dual lead dual threaded screw.

Table 4. Maximum deflection in normal bone.

Type	Single Threaded	Dual Threaded	Double Dual Threaded	Dual Lead Dual Threaded
Maximum Deflection (mm)	2.11	2.13	2.02	1.94

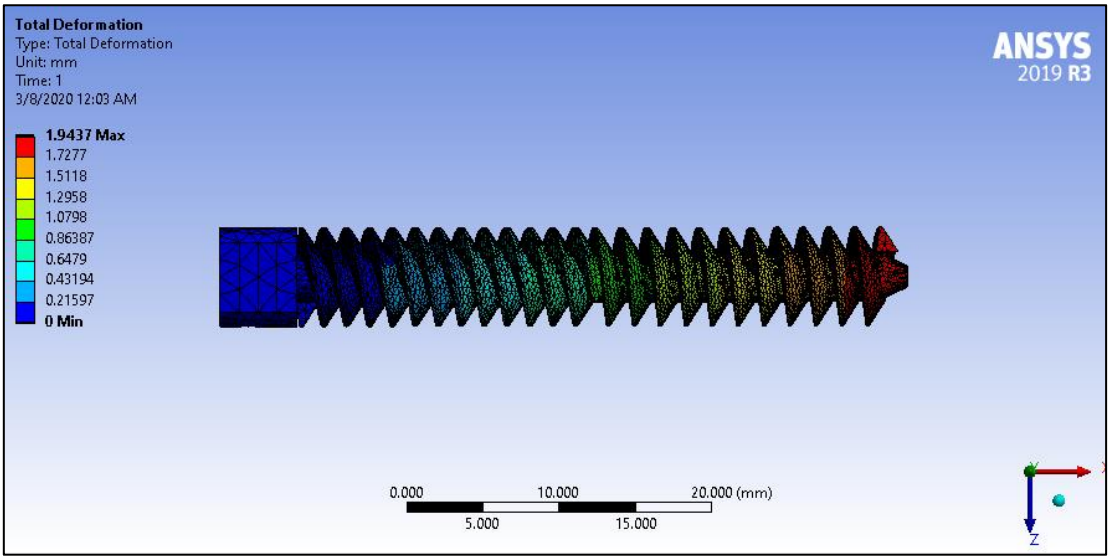

Figure 6. Deflection of dual lead dual threaded pedicle screw in normal bone.

3.2 Comparison of maximum deflection of pedicle screw in osteoporotic bone

For the osteoporotic bone condition in which the mechanical properties of the bone were greatly the test were conduct in the exact same condition. Figure 7 shows the deflection of the single threaded pedicle screw in osteoporotic bone. The maximum deflections of the dual threaded, double dual threaded and dual lead dual threaded pedicle screw are listing in table 5.

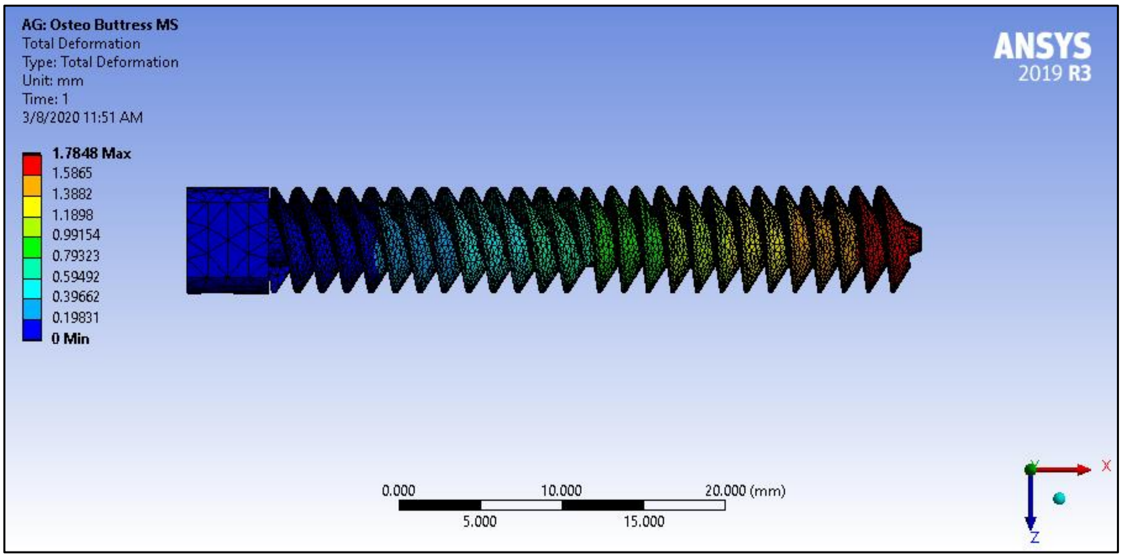

Figure 7. Deflection of dual lead dual threaded pedicle screw in osteoporotic bone.

Table 5. Maximum deflection in osteoporotic bone**.**

Type	Single Threaded	Dual Threaded	Double Dual Threaded	Dual Lead Dual Threaded
Maximum Deflection (mm)	2.63	2.65	2.52	1.78

The dual lead dual threaded design shows the lowest maximum deflection in the osteoporotic condition and 32.31% improvement when compared to the single threaded design (reference thread profile of pedicle screw that currently available in market). While the dual threaded did not show any significant improvements over the single threaded in terms of bending performance. While the double dual threaded performed slightly better than the single threaded design with an improvement of 4.18%. After comparing the performance of the three proposed screw design to the single threaded screws performance, dual lead dual threaded shows the most improvement over the single threaded pedicle screw performance. In the normal bone condition, it showed an improvement of 8.4% in terms of maximum deflection and improvement of 32.31% in osteoporotic bones.

4. Conclusion
Based on the finite element analysis result, the dual threaded pedicle screw did provide significant improvements over the single threaded pedicle screw in terms of bending performance in both normal and osteoporotic bone. The thread design seem to have an effect on the bending strength of the pedicle screw in which the dual lead dual threaded screw showed an improvement of 8.4% in the maximum deflection. In the osteoporotic bone, the dual lead dual threaded screw also showed an improvement 32.31% improvement. Thus, this finding have potential in assisting the optimum pedicle screw design in future although further investigation needed to support this finding.

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