Chapter 5
Finite Element Method Study: The Effect of Insertion Torque and Angle on Pedicle Screw Loosening

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Abstract Pedicle screws are widely used for the treatment of spinal instability by spine fusion. This treatment can be performed at any level in the spine (cervical, thoracic, or lumbar) and prevents any movement between the fused vertebrae. However, screw loosening is a major problem of spine fusion, contributing to delayed patient recovery. This appears to be a minor problem for fixation and fusion of healthy, non-osteoporotic bone. Screw loosening happens when insertion torque and angle are not suitable for the pedicle screw which affects the screw pullout strength. Based on the optimum torque and angle in finite element analysis, loosening of screw in spine fusion can be minimized by increasing the screw pullout strength. The highest pullout strength can minor the loosening of the screw. Four insertion angles of the pedicle screw were used which are 0°, 10°, 20°, and 30°. Besides that, the effect of insertion torque on pullout strength can be seen on the equivalent von Mises stress value when applied three values of moment to pedicle screw-bone with constant insertion angle. The lowest stress for pedicle screw can give a better fixation with bone and thus can increase the pullout strength. We found that the insertion angle of 10° gives higher pullout strength of pedicle screw-synthetic bone which indirectly will minimizing the effect of the screw loosening from bone. Besides that, insertion

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A. Ismail et al. (eds.), *Advanced Materials and Engineering Technologies*,
Advanced Structured Materials 162,
https://doi.org/10.1007/978-3-030-92964-0_5

torque with 1200 Nm gives a lower equivalent von Mises stress which causes a lower effect on fixation between screw and bone and thus has potential in minimizing the loosening to pedicle screw.

Keywords Pedicle screw · Finite element analysis · Screw loosening · Insertion torque and angle · Optimization

5.1 Introduction

Pedicle screw-rod constructs are commonly used for the treatment of fractures, tumors, and degenerative disease in the spine. When osteoporosis is present, gaining adequate screw purchase during these procedures can be challenging [1]. The weakened screw-bone interface can be explained by a direct correlation between bone mineral density and pedicle screw fixation [1]. Fusion is therefore more difficult to achieve than in healthy bone [2] causing a longer duration of loading on the instrumentation, [3] which increases the risk of construct failure. Position and numbers of radial holes, cement injection technique were also investigated to increase the pullout performance especially for osteoporotic vertebrae [4, 5]. Screw pullout is the standard method of testing screw fixation within bone. In the spine it gives information on the stability of a pedicle screw-rod construct via screw purchase. Pedicle screw failure, however, typically does not occur with simple pullout. Instead, loosening, due to fatigue, weakens the screw-bone interface leading to pullout. More attention is being paid to understanding the role of fatigue in pedicle screw failure [6]. Achieving optimal fixation of the screw-bone interface is vital to clinical outcome.

To determine the optimal fixation technique for pedicle screws, numerous studies have been undertaken to evaluate how specific factors affect loosening and pullout strength. Among others, researchers and physicians have evaluated insertion techniques, screw characteristics, augmentation, bone quality, and morphometry. Generally, a correlation between pullout strength and bone mineral density (BMD) has been noted by many researchers [6, 7]. This correlation separates bone quality into healthy and osteoporotic bone, and each type has unique needs that should be addressed in screw design and insertion technique. Trajectory, insertion technique, and screw design have a large effect on screw purchase and may provide a good alternative technique when a surgical limitation is present [1, 4, 6]. The extrapedicular technique, for example, may be a viable option for patients with morphometry that makes adequate screw purchase a challenge.

There is some debate whether an extrapedicular screw trajectory decreases fixation strength [8] or whether it remains the same [9]. The differences may be due to sample size, in which a small sample size increases the likelihood of a type II error. Insertion technique can be altered to optimize fixation strength. Lateral misdirection may increase the likelihood of fracturing the wall of the pedicle and therefore should be avoided. Single screw and pullout strength tests were carried out according to American Society for Testing and Materials F 543-07 on foam models to test the effect of insertion angle using polyaxial pedicle screws. Rigid polyurethane foams are widely used as a substitute for cadaver spinal bone because of their consistent and homogeneous structural properties. Grade 10 (160 kg/m^3) represents osteoporotic a block dimensions of 120 mm × 60 mm × 40 mm. For good results in osteoporotic bone, there is a benefit of using insertion angle in 10° to minimize screw loosening [6].

Many surgeons prefer a pedicle screw with high insertion torque because it gives good tactile feedback of bony purchase. By contrast, although there is a strong correlation between insertion torque and BMD, screw loosening is not objectively predicted by insertion torque in the clinical setting. But some journals reported that loosened screws are associated with decreased pullout strength and extraction or high torque [1, 4, 10, 11]. Therefore, the aim of this paper is to investigate the effect of insertion torque and angle on pedicle screw loosening by using the finite element method.

5.2 Methodology

Developing a screw with accurate thread style is crucial in achieving best results among the shape because the most popular size, shape, and pitch can vary with the supported specific anatomy. The pedicle screw was constructed using SolidWorks software with a diameter of 6.0 mm and a length of 45 mm (Fig. 5.1). This software was capable of performing 2D and 3D measurements of the bone's model, and these capabilities were used in order to make morphological measurements of individual talus bones as well as combination of bones as shown in Fig. 5.1.

The synthetic bone is also constructed using the SolidWorks software. The material of the pedicle screw model was considered elastic and isotropic which requires two parameters to describe the properties which are E (elastic modulus) and ν (Poisson's ratio). There were two types of materials used in this project which are titanium alloy (grade 23) for the pedicle screw and polyurethane for the synthetic bone. Table 5.1 shows the properties of the titanium alloy and polyurethane.

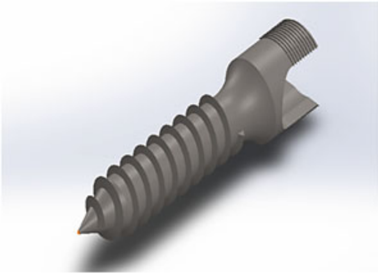

Fig. 5.1 3D model of cannulated pedicle screw

Table 5.1 Properties of titanium alloy (Grade 23) and polyurethane

Properties	Titanium alloy	Polyurethane
Young's modulus, E (GPa)	104.5	0.78
Tensile strength, σ_x (MPa)	860.0	33.0
Yield stress, σ_y (MPa)	820.0	133.0
Poisson's ratios, ν	0.3	0.3

5.2.1 Finite Element Method

A static structural load analysis performed using the ANSYS software. A static structural analysis determines the displacements and stresses in structures or components caused by loads that do not induce significant inertia and damping effects. The finite element analysis began with the 3D-model of implant that was prepared in the SolidWorks software and exported to the ANSYS software. Then the model was meshed using tetrahedral elements for the simulation. The element size has been taken 1 mm on the pedicle screw. In many regions tetrahedral meshes were generated and provided a bonded interface conditions.

5.2.2 Finite Element Model Validation

Validation method is a technique for assessing either the results of a structural analysis (model) are correct or not. It is mainly used in settings where the goal is prediction, and one wants to estimate how accurately a predictive model will perform in practice. FE models must be validated and updated to assess the quality of FE models and increase confidence in the results. The result of FEA (pullout strength) was compared to the experimental result done by previous researchers [6]. They did pullout test on the foam with the inserted screw using a BiSS Nano-25 universal testing machine. A tensile load of 5 mm/min was applied to the test specimen. The FE model is considered valid if the gap of compared results were less than 15%.

5.2.3 Insertion Angle

After the FE model was validated, the new insertion angles were assigned in getting the optimum angle which gives a higher pullout strength. Figure 5.2 shows insertion angles of 10°, 20°, and 30° which are based on the schematic representative of single screw pullout study configuration as reported by Venkatesh et al. [6].

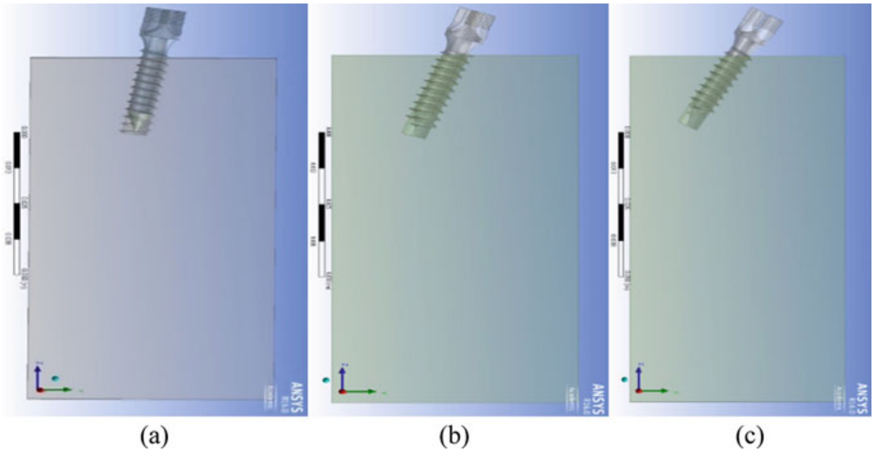

Fig. 5.2 Insertion angles **a** 10°, **b** 20°, **c** 30°

5.2.4 *Insertion Torque*

Some of the published journals prove that loosened screw was affected by decreased pullout strength and extraction or high torque. This means that low torque gives less loosening of the screw. The torque was represented by the moment of 1200, 1400, and 1600 Nm and applied in the FE to get the equivalent von Mises stress (EVM) value on the screw-bone interface. The EVM value can represent the pullout strength value since both are significantly correlated.

5.3 Result and Discussion

FEA revealed that the reaction force obtained to pull the pedicle screw for the insertion angle 0° was a similar value with the result obtained by previous researcher [6]. Table 5.2 shows the summary of the validation result with the percentage error between

Table 5.2 FE Model validation

	Experimental results by [6]	Result by FEM
Tensile load (mm/min)	5	5
Reaction force (N)	690	733.96
Present of error (%)	6.0%	

our prediction and previous experimental result, i.e., 6%. Thus, it proves that our FEA model is valid.

5.3.1 The Effect of Insertion Angle on Screw-Bone Performance

The result of the pullout strength of pedicle screw-bone using new insertion angle which is 10°, 20°, and 30° is shown in Fig. 5.3. Based on the result obtained, reaction force (can represent pullout strength) for insertion angle of 10°, 20°, and 30° is 776.87, 609.55, and 335.60 N. Figure 5.4 shows pullout strength distribution graph for all four insertion angles. From the graph, insertion angle of 10° gives a higher pullout strength than other angles.

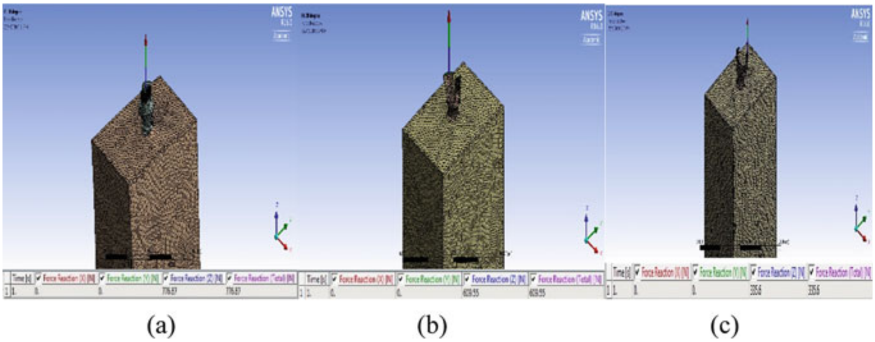

Fig. 5.3 **a** Reaction force for 10° insertion angle, **b** 20°, and **c** 30°

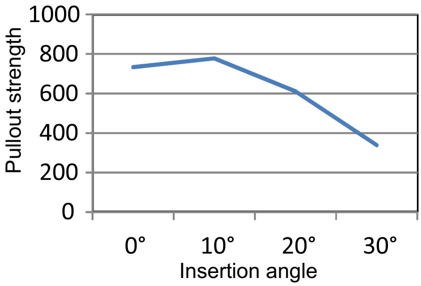

Fig. 5.4 Graph of reaction force (pullout strength) versus insertion angle

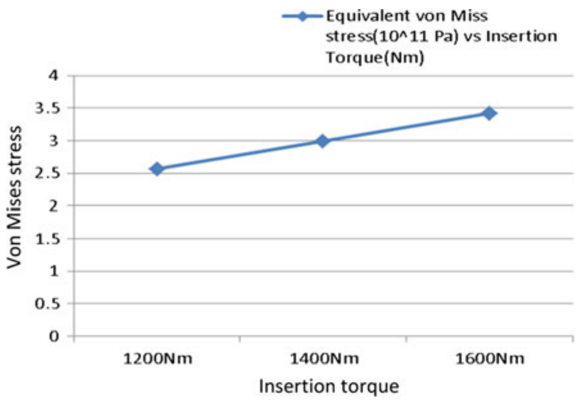

Fig. 5.5 Graph of von Mises stress versus insertion torque

5.3.2 The Effect of Insertion Torque on Screw-Bone Performance

The FEA results (von mises stress) distributed on pedicle screw due to three values of torque which are 1200, 1400, and 1600 Nm are shown in Fig. 5.5. The effect of insertion angle and torque for screw loosening can be predicted using the finite element method due to the fact that the validation error is only 6%. Thus, Fig. 5.4 shows that an insertion angle of 10° gives a higher pullout strength of pedicle screw-synthetic bone which indirectly will minimize the effect of the screw loosening from the bone. The effect of torque on stress value of pedicle screw are shown in Fig. 5.5 which the stress values of pedicle screw seem proportional with the values of torque. When a stress for pedicle screw is lower, the fixation of screw to bone is really fixed and gives minor loosening to pedicle screw.

5.4 Conclusion

In this paper, the investigation on the effect of insertion angle and torque on pedicle screw is done by doing finite element analysis. The FEA was done for four insertion angles of pedicle screw which are 0°, 10°, 20°, and 30° and also by applying three different moment of 1200, 1400, and 1600 Nm in the numerical simulation. Based on the FE results obtained, it is proven that the investigation on the effect of insertion angle and torque on pedicle screw can be done using the finite element method which also can be considered valid due to the gap of compared results between our FEA result and experimental result by previous researcher were less than 15%. Thus the optimum insertion torque and angle obtained also can be considered valid in minimizing pedicle screw loosening. The optimum value for insertion torque is 1200 Nm while 100 is the optimum insertion angle value. However, fabrication and further testing still need to be conducted in order to evaluate this optimum design of

AFO since depending on the FEA results alone it cannot give high confidence for the surgeon to apply the obtained optimum value of insertion angle and torque on pedicle screw during pedicle screw-spine surgery.

Acknowledgements The authors would like to thank Ministry of Higher Education for providing financial support under Fundamental Research Grant Scheme (FRGS) No. FRGS/1/2018/TK03/UMP/02/5 (University reference RDU190114) and Universiti Malaysia Pahang for laboratory facilities as well as additional financial support under Internal Research Grant RDU190327.

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