Stress analysis in pedicle screw and bone interface by various contact models in scoliotic spine fixation

M Rusli¹*, H Dahlan¹, R E Sahputra² and M Bur¹

¹ Mechanical Engineering Department, Faculty of Engineering, Andalas University, Kampus Unand Limau Manis, Padang 25163, Indonesia
² Orthopaedics Department, Faculty of Medicine, Andalas University, Jalan Perintis Kemerdekaan, Sawahan Timur, Padang 25171 – Indonesia

*meifal@eng.unand.ac.id

Abstract. Scoliosis is a musculoskeletal condition that has an abnormal lateral spinal curvature as its main feature. By a level curvature condition, the scoliotic spine has to treat by surgery process to install an instrument or implant consists of pedicle screws, rods, and connectors in fixation of the spinal curvature. However, it is observed in many cases that several types of failure occur in the instrument and the bone - pedicle screw interface. One of the problems was related to screw loosening and pulled out from the spine. This paper observes and discusses the stress distribution numerically in the screws and bone interface in scoliotic spine fixation using finite element analysis. The contact interface is modeled variously by bonded contact and friction contact. It is found that in bonded connection between screws and bone generates lower maximum stress than friction contacts. The maximum stress is working in the screw and the stress distribution is more uniform along the contact surface. Therefore, the risk of pulling out the screws will be minimized. On the other hand, friction contact with low friction coefficients makes the stress distribution is concentrated in a specific region and increase the maximum stress in bone.

1. Introduction

Scoliosis is defined as a musculoskeletal condition that has an abnormal lateral spinal curvature as its main feature. One of the medical treatments for spinal curvature fixation is by installing an instrument or implant that consists of rods, pedicle screws, and connectors by surgery process. However, some types of failure occur in the implants and the screw-bone interface during or after the operation. The problems were in the form of the loosening, pulling out the screw from the spine due to by high pull-out load [1,2], and osteoporosis [3]. There were also found the case of fatigue failure and fretting in pedicle screw [4,5], releasing rod from the screws[6], fracture of the rod and distal end screw [7,8].

Many researchers investigated the failure related to the screw-bone interface. Some researchers found that broken pedicle screws occur not only at the screw’s neck but also at the bone union in the bone graft that did not warrant the screw breakage prevention [4]. Moreover, it was observed that pullout strengths depend on thread type and design [9], and material properties of bone and screw [3]. To improve the resistance of loosening and pulled out the screws some ideas also have been proposed, such as the using of hydroxyapatite-coated and titanium-coated screws [10], and posterior fixation with transfacet pedicle screws [11]. The ideas provide increasing the resistance of loosening screws.
Based on the ideas of changing the contact interface by coating and any treatment of screw surface to increase the pulling out resistance, this paper will observe and discuss the stress distribution numerically in the screw-bone interface in scoliotic spine fixation using finite element analysis. The contact interface is modeled by bonded contact and friction contact with various friction coefficient.

2. Finite element model
A human backbone or spine generally consists of several main parts; seven segments of cervical spines, 12 thoracic spines, five lumbar spines, sacrum, and coccyx. The spines segments made of cortical bone in each are connected by discus. A finite element model of the spine and the scoliotic instrument is shown in figure 1. In this paper, stress analysis in the first lumbar spine (L1) implanted by 4.5 mm diameter of the pedicle screw will be done. The L1 and pedicle screw is depicted in figure 1.

Some researchers found that the external forces working to the pedicle screw are varied based on the position and number of the screws [12,13]. In this investigation, fifty Newton of pull out force is applied in the axial direction of the pedicle screw. The pedicles screw is made of titanium alloy with 110 GPa modulus elasticity (E). The lumbar is consist of Cortical Bone (E = 12 GPa), and Cancellous Bone (E = 100 MPa). The constraint of the lumbar model are fixed in lower and upper surfaces. The contact model is varied by bonded model and friction model with 0.2 and 0.3 friction coefficient. The stress analysis is done using ANSYS. Because of the convergence problem, the size of mesh in the finite element model is kept at a minimum of 2 mm; otherwise, the calculation process will not convergence.

![Figure 1. The finite element model of spine and instruments (left), Lumbar (L1) and pedicle screw and its pull out force (middle and right).](image)

3. Result and discussion
The maximum stress working in the screw-bone interface by various contact model is depicted in figure 2. It is shown that reducing the friction coefficient will increase the maximum working stress in the interface. The model with the friction coefficient 0.3 has the highest value of working stress and much higher than the bonded model or the others model. The author so far has not been able to use the lower friction coefficient caused by the convergence problem.

Furthermore, the stress distribution in each contact model is illustrated in figure 3. When the interface is bonded, the maximum stress in the pedicle screw is located near the screw neck or almost reaches the outer surface. By this model, the pedicle screw is contacted and bonded to the cortical bond without any relative motion. Therefore the stress well distributed the all surface and volume of the screw and the cortical bone, and the maximum stress will occur when the cross-sectional area is minimum at the neck of the screw. Moreover, when contacting in low friction coefficient, the maximum stress increases and located at the bone contact surface. The stress distribution in the bone near the contact interface then also increases.
Figure 2. The maximum stress in the various contact model.

When the friction coefficient decreases, the maximum stress increases, and the position of the maximum stress then moves to the deeper contact position. Furthermore, the maximum stress is not allocated in the screw but working at the cortical bone. The consequence of the maximum stress at the bone is the risk of the pedicle screw pulled out increases. By this analysis, it can be explained that by modifying the contact interface of the screw and the cortical bone, the pulled out strength of the screw will change. Increasing friction coefficient will improve the interface strength of the screw and bond. The maximum stress by the various value of pull out load is shown in figure 4.

Figure 3. Stress distribution by two contact model.

Figure 4. The maximum stress at various loads.
Figure 4 shows that by decreasing pull out load, the maximum stress in low friction contacts almost similar. The highest maximum stress occurs at the point with high-stress concentration, as shown in figure 5. The maximum stress position is working at nearly in the same location, although the pull-out force is much different. On the other hand, at the bonded contact model, working stress decreases by reducing the pull out force.

![Figure 5](image1.png)

**Figure 5.** Stress distribution at bone by 0.2 of friction coefficient contact model.

By this illustration, it is shown that by changing the contact interface between bone and screw will influence the working stress distribution at the bone. Coating screw by another material, especially with the material the has almost similar characteristic with the bone will decrease the maximum working stress at the bone, increase the resistance of the screw and reduce the risk of the pulled out screw.

### 4. Conclusion

In this paper, the effect of the contact model of the pedicle screw and lumbar to the stress distribution is investigated. It is found that reducing the friction coefficient will increase the maximum working stress in the interface. When the friction coefficient decreases, the maximum will stress increase, and the position of the maximum stress then moves to the deeper contact position. Furthermore, the maximum stress is not located in the screw but working at the cortical bone. The consequence of the maximum stress at the bone is the increase of the risk of the pedicle screw pulled out. To improve the pulled out strength of the pedicle screw, modification of contact interface can be essential to be developed.

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