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The Stress Distribution on Pedicle Screw Fixation System Inserted Cervical Spine

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Abstract

The screw fixation system was used to fix and share the load from equal or greater than two cervical spines, removed the intervertebral disc. The rod, was connected to the pedicle screw had share the load transfer from the bone. This research aims to evaluate the von Mises stress distribution on pedicle screw system, was fix between C3 to C5 and C4 to C6 that removed the intervertebral disc between C4 and C5 under the axial loading and the moment with flexion and extension to the superior on C3 vertebra. The result was shown the maximum von Mises stress on the pedicle screw system fix at C3 to C5 spine 59.62 MPa under flexion condition and fix at C4 to C6 spine 84.86 MPa under flexion condition. The maximum von Mises stress occurred at the first thread of upper pedicle screws in all cases. The surgeon should be inserted the first screw of pedicle screw system over the cervical spine without intervertebral disc to reduce the maximum von Mises stress 29.74%.

Keywords: Pedicle Screw Fixation, Screw Fixation System and Cervical Spine.

1. Introduction

The pedicle screw fixation was widely used to treat the patient, who had a problem with degenerative disc. In the spine surgery, the pedicle screw was inserted through the pedicle region, was the smallest region of cervical spine. When the pedicle screw system was inserted the cervical spine after intervertebral disc removal, the screw system was supported the skull's weight that was shared the load transfer from the cervical spine to the pedicle screw system. Seventy-five percentages of the patients had the screw brakeage on the caudal side by conducting retrieval analysis [1].

This study aims to evaluate the stress distribution on the pedicle screw system by finite element analysis under three different loading conditions, when varied the position of pedicle screw fixation on the cervical spine at C3 to C5 and C4 to C6 respectively and the intervertebral disc between C4 and C5 was removed.

2. Material and Methods

2.1 Three-dimensional Cervical Spine Model

The cervical spine was scanned by the computerized tomography (CT) scanner. The CT data was reconstructed by the reverse engineering process to three-dimensional model with ITK-SNAP as shown in Fig. 1.

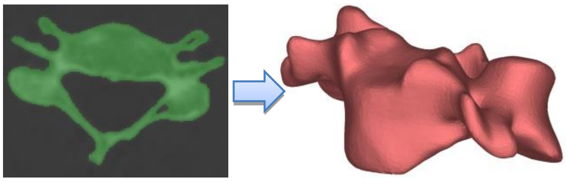


Fig. 1 CT image of cervical spine was converted to three-dimensional model.

Pedicle screw system was created by SolidWorks software as shown in Fig. 2. The model of pedicle screw was used the mono-axial type with Moss Miami. The diameter of pedicle screw was 4.87 mm. and 30 mm. length.

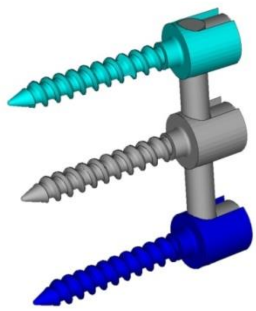
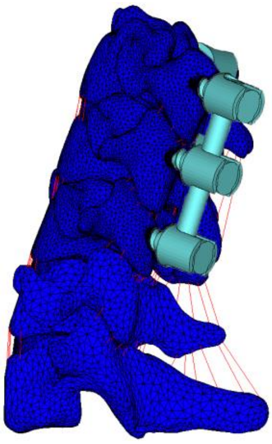
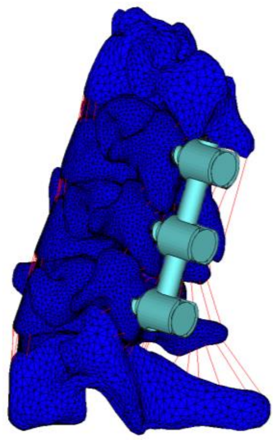


Fig. 2 The pedicle screw system.

Two finite element models were used in this study as shown in Fig. 3, which removed the intervertebral disc between C4 and C5. The first model was inserted the pedicle screw system at C3 to C5 vertebra and the second model was fixed the pedicle screw system at C4 to C6 vertebra. The MSC software was used to evaluate the stress distribution on the pedicle screw system. The mesh model was generated by the four-node tetrahedral element. The four-node tetrahedral element was chosen in this research in order to reduce the calculating time. Ramos and Simones (2006) had compared experiment mesh element form tetrahedral element with hexahedral element and the result showed that the tetrahedral element form 4 nodes is similar to the that of the theory [2]. The bone-implant of pedicle screw system at C3 to C5 had 232,883 nodes 1,028,375 elements and pedicle screw system at C4 to C6 had 113,258 nodes and 1,026,218 elements.



(a)



(b)

Fig. 3 Finite element models: (a) Pedicle screw system at C3 to C5 and (b) Pedicle screw system at C4 to C6.

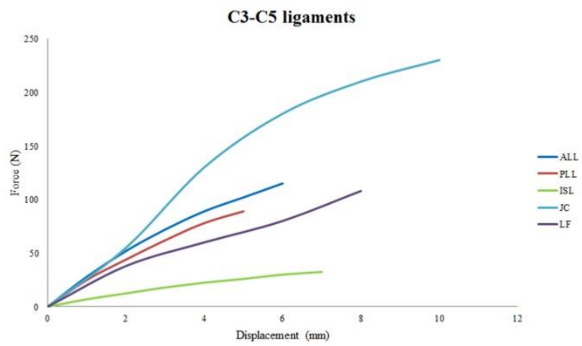
2.2 Material Properties

All materials were defined as linear elastic and isotropic properties in this study. The pedicle screw system was assumed as titanium alloy. The vertebral body and intervertebral disc were used to define only cortical bone and disc-nucleus. The material properties of the cervical spine, intervertebral disc and pedicle screw system were shown in Table. 1.

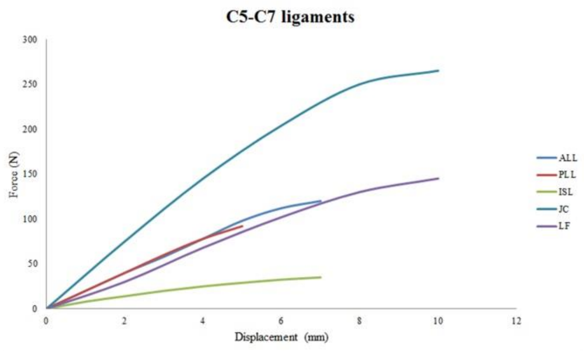
Table. 1 Material properties of finite element model [3,4].

Material	Young’s modulus (MPa)	Poisson’s ratio
Cortical bone	14,000	0.3
Disc-nucleus	3.4	0.4
Titanium alloy	110,000	0.3

The cervical spine connected with five ligaments as anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), interspinous ligament (ISL), ligament flavum (LF) and face joint capsular ligament (JC) that had the nonlinear property [5,6] as shown in Fig. 4.



(a)

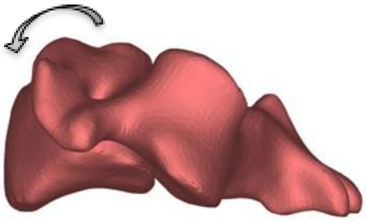


(b)

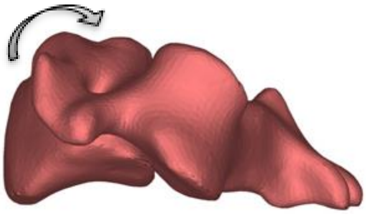
Fig. 4 Force-displacement properties of five ligaments: (a) Force-displacement properties for the C3-C5 group and (b) Force-displacement properties for the C5-C7 group.

2.3 Boundary Condition

The inferior endplate of C7 spine was fixed in all degrees of freedom. A compressive load of 74 N and a moment of 1.8 N.m with flexion and extension [7] were applied to the top of C3 vertebra as shown in Fig. 5. Axial load had only compressive load that applied as the skull’s weight in a stand position. Axial, flexion and extension load were simulated.



(a)



(b)

Fig. 5 The direction of moment on C3: (a) Flexion and (b) Extension.

3. Result and Discussion

This research was focused on the stress distribution on the pedicle screw system under three conditions. The peak values of the maximum von Mises stress due to three loading conditions was shown in Table. 2 for fix the pedicle screw system at C3 to C5 and Table. 3 for fixed the pedicle screw system at C4 to C6.

The results were shown the maximum von Mises stresses on the pedicle screw systems to fix at C3 to C5 and C4 to C6 were 59.62 and 84.86 MPa respectively. Yield strength of Titanium alloy is 870 MPa [8-11].

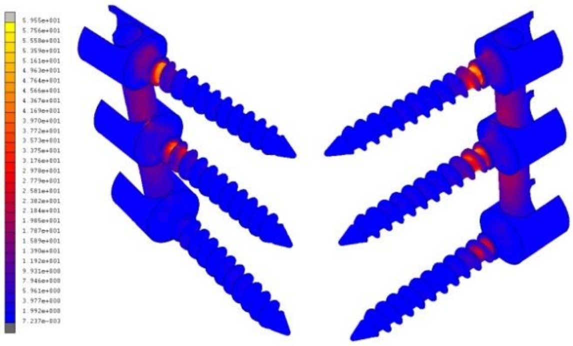


Fig. 6 The stress distribution on the pedicle screw systems fixed at C3 to C5 spine.

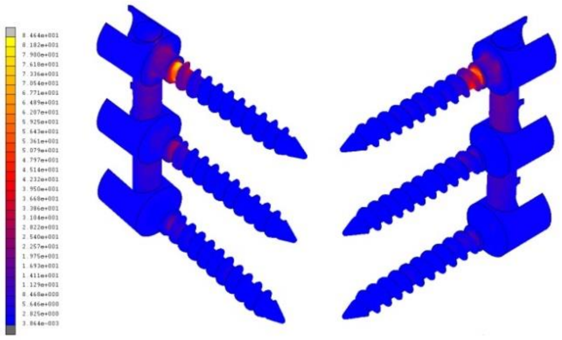


Fig. 7 The stress distribution on the pedicle screw systems fixed at C4 to C6 spine.

Comparing the stress distribution between different loading conditions, the maximum von Mises stress on the screw fixation system occurred at flexion condition in all implantation models. The stress distribution on the pedicle screw system, fix between C3 to C5 and C4 to C6 were shown in Fig. 6 and 7 respectively. The maximum von Mises stress occurred at the first thread of C3 and C4 pedicle screws in case of fix at C3 to C5 spine and at the first thread of C4 pedicle screws in case of fix at C4 to C6 spine.

Table. 2 Maximum von Mises stress on the pedicle screw system to fix the spines at C3 to C5 due to three different loading conditions.

Load	Maximum von Mises stress (MPa)							
	Right C3 screw	Right rod	Right C4 screw	Right C5 screw	Left C3 screw	Left rod	Left C4 screw	Left C5 screw
Axial load	50.27	18.27	47.39	9.56	57.86	21.58	59.55	28.83
Flexion	50.36	18.29	47.47	9.63	57.91	21.60	59.62	28.81
Extension	50.19	18.25	47.32	9.50	57.81	21.56	59.48	28.86

Table. 3 Maximum von Mises stress on the pedicle screw system to fix the spines at C4 to C6 due to three different loading conditions.

Load	Maximum von Mises stress (MPa)							
	Right C4 screw	Right rod	Right C5 screw	Right C6 screw	Left C4 screw	Left rod	Left C5 screw	Left C6 screw
Axial load	84.64	19.01	28.63	20.79	66.67	23.70	17.51	17.81
Flexion	84.86	19.03	28.69	20.75	66.84	23.73	17.53	17.77
Extension	84.43	18.98	28.58	20.87	66.49	23.67	17.49	17.84

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The pedicle screw system, which was fix the cervical spine without intervertebral disc between C4 and C5 had the less maximum von Mises stress when inserted the first screw upper the cervical spine without intervertebral disc to reduce the maximum von Mises stress 29.74%.

4. Conclusion

The pedicle screw fixation system fix at C3 to C5 and C4 to C6 can be considered as follows:

- All model had the maximum von Mises stress under flexion condition that showed the patient should be careful about flexion in daily activity.
- To fix the first screw upper the cervical spine without intervertebral disc can reduce the von Mises stress on all screw in the system.
- The other condition as right lateral bending, left lateral bending, right torsion and left torsion should be used to evaluate the von Mises stress on the implant.
- The surgeon can be used the result from this study to suggest the patient's activities after surgery.

5. Acknowledgement

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