BME0007

The Pedicle Screw Parameters Inserted Cervical Spine Affect Stress Transfer Parameter (STP)

Supagorn Ritddech[1], Promtpong Anuchitchanchai[2,*], Kitti Aroonjarattham[2], Chompunut Somtua[1,3] and Panya Aroonjarattham[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, Mahidol University, Nakornpathom, Thailand, 73170
[2] Department of Orthopaedics, Faculty of Medicine, Burapha University, Chonburi, Thailand, 20131
[3] Department of Mechanical Engineering, Faculty of Engineering, Bangkok Thonburi University, Bangkok, Thailand, 10170
[*] Corresponding Author: kittaroon@gmail.com
Tel: 66-3839-4850

Abstract

The pedicle screw fixation was used to fix the cervical spine for the patient, who had cervical disc problem to return the normal life. The screw has many characteristics and sizes such as outer diameter, core diameter, proximal root radius, distal root radius, pitch and thread width affect the pullout strength of pedicle screw when inserted in the patient. This study aims to compare the pullout strength of the popular nine pedicle screws fixation inserted eight Thai cervical spines (C3) by stress transfer parameter (STP). The three-dimensional finite element models were developed to investigate the failure behavior of the bone during the screw pull out and the effect of screw's parameters. The equivalent von Mises stress was calculated by use the stress transfer parameter to compare the pullout strength of the nine cervical screws. The result showed the TSRH I was the best of pedicle screw when inserted in cervical spine (C3) from stress transfer parameter analysis to resist the pullout force. The large outer diameter and core diameter were the main cause of the high pullout strength.

Keywords*:* Pedicle Screw Parameter, Cervical Spine and Stress Transfer Parameter.

1. Introduction

The pedicle screw fixation was used to fix the vertebra [1], which had a problem as:

- Spine loose, the screw fixation was used to tighten the loosen spine.
- Spinal disabilities, the screw fixation were used to straighten the spine to the nature position.
- Spine caused by accident.

The pedicle screw fixation had many sizes and characteristic such as outer diameter, core diameter, proximal root radius, distal root radius, pitch and thread width that affect the pullout strength when inserted in the patient. The highest risk of the screw insertion at the cervical spine was pull out from the pedicle region, may cause injury to the patient [2].

This study aims to evaluate the effect of screw parameters to pullout strength, inserted in eight Thai cervical spines (C3) by finite element analysis to prevent the failure of screw fixation endangers to the patient. Nine popular pedicle screws were compared by stress transfer parameter (STP) [3]

2. Materials and methods

2.1 Three-dimensional models of cervical spine (C3)

Eight cervical spines was scanned with computerized tomography (CT) scanner. The CT data was reconstructed with ITK-SNAP as shown in Fig. 1.

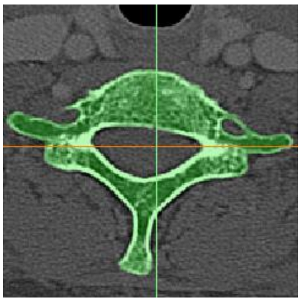

Fig. 1 The CT slice data of cervical spine.

Three-dimensional cervical spine model was shown in Fig 2.

Fig. 2 Three-dimensional models of cervical spine (C3).

2.2 The Screw Fixation

The CAD model of all screw fixation was constructed by SolidWorks 2010 package based on commercial screw fixation. The screws, was used in analysis had three types as Cotrel-Dubousset (CD) (Medtronic Sofamor-Danek, Memphis, TN), Texas Scottish Rite Hospital (TSRH) (Danek, Memphis, TN) and Moss Miami (DePuy Spine, Raynham, MA) were shown in Fig. 3. Each type of screws was varied with three sizes [4].

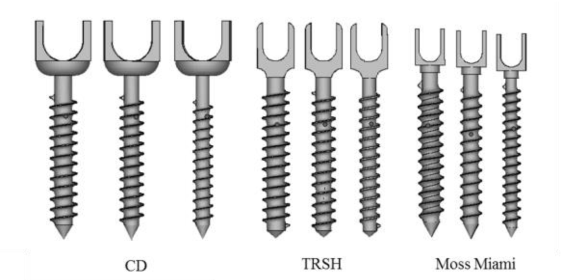

Fig. 3 Three types of screw fixation were used in the research.

The dimensions of the screw consist of outer diameter (OD), core diameter (CD), pitch (P), proximal root radius (PRR), distal root radius (DRR) and thread width (TW) as shown in Table. 1. All screws were defined the material property as titanium alloy.

Table. 1 The dimension of nine pedicle screws.

Type	OD (mm)	CD (mm)	P (mm)	PRR (mm)	DRR (mm)	TW (mm)
CD I	7.5	4.92	2.80	0.81	1.27	0.20
CD II	6.50	4.10	2.80	0.88	1.20	0.20
CD III	5.50	3.84	2.71	0.81	1.23	0.10
TSRH I	7.50	4.98	2.80	0.83	1.16	0.18
TRSH II	6.50	4.32	2.80	0.84	1.18	0.26
TSRH III	5.50	3.78	2.75	0.83	1.23	0.18
Moss Miami I	6.90	4.50	2.98	3.31	3.31	0.18
Moss Miami II	5.85	4.19	2.94	3.31	3.31	0.19
Moss Miami III	4.87	3.03	2.48	2.54	2.54	0.19

2.3 Material Properties

Linear elastic and isotropic material properties were assigned to pedicle screw and cortical bone. The material properties were shown in Table. 2 [5].

Table. 2 Material properties of cortical bone and pedicle screw.

Material	Modulus (MPa)	Poisson's Ratio	Yield Strength (MPa)
Cortical bone	14,000	0.3	100
Titanium Alloy	110,000	0.3	850

2.4 Virtual Simulation

The virtual simulation method was used to insert the pedicle screw into the cervical spine. All screw were placed by starting landmarks reported by Karaikovic *et al.* [6], which was lie on the center of pedicle region with the actual surgery position as shown in Fig. 4.

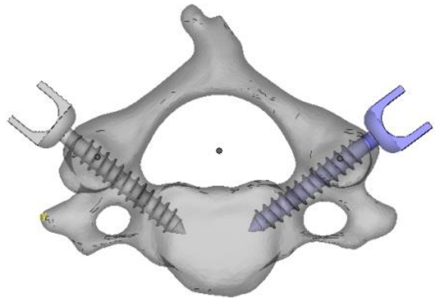

Fig. 4 The characteristic of pedicle screw inserted into the cervical spine

2.5 Mesh Generation

The four-node tetrahedral element was used to generate the mesh model by MSC Marc software. Ramos and Simones (2006) had compared the tetrahedral element with hexahedral element and the result was shown the similar result to the theory [7]. The cervical spine of C3 had a total of 37,282 nodes and 167,836 elements. The mesh model was shown in Fig. 5.

(a) (b)

Fig. 5 Mesh model: (a) Cervical spine and (b) Pedicle screw.

2.6 Boundary Condition

The cervical spine was fully fixed and received axial load at the top of the pedicle screw by using Multiple Point or MPC. The MPC pull out the screw to the vertical movement by creating the forced on several nodes. The force distribution on several nodes at the top of screw to control the equal vertical motion of each node was shown in Fig. 6. The contact between bone and screw was touching contact condition. The value of friction coefficient between the contact interface of screw and bone was selected 0.2 [8-11].

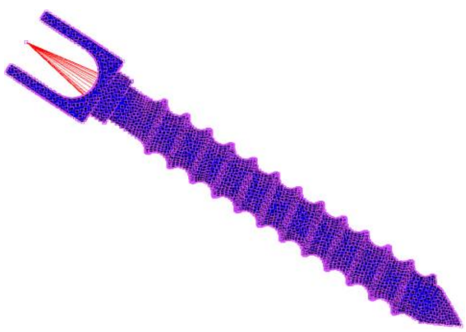

Fig. 6 The MPC pull out the screw to the vertical movement.

2.7 Stress Transfer Parameter (STP)

Stress transfer parameter was a dimensionless parameter and utilized to characterize the load transfer between the pedicle screw and cervical spine. The STP can be applied to test and compare the different types and parameters of screw. This parameter was evaluated the load sharing between the fixation screw and the bone surrounding it. Two different STP were defined as follow:

$$\alpha = \frac{\sigma_{fb}}{\sigma_{ft}} \quad (1)$$

$$\beta = \left(\frac{1}{N} \sum_{i=2}^{N} \sigma_{bi} \Big/ \frac{1}{N} \sum_{j=2}^{N} \sigma_{tj} \right) = \left(\sum_{i=2}^{N} \sigma_{bi} \Big/ \sum_{j=2}^{N} \sigma_{tj} \right) \quad (2)$$

The α was found from the stress distribution on the first thread (σ_{fi}) near the screw's cap to bear an average stress on the bone (σ_{fb}) over the first thread and the β was found from the stress distribution on the thread of the screw (σ_{tj}) (j ≥ 2) to bear an average stress on the bone (σ_{bi}) that found between theses thread. In this case, stress shielding will be eliminated [12-16].The Fig7 shows the behavior of screw and bone in the Two-dimensional model by shows the calculation STP follow (Eqs (1) and (2)).

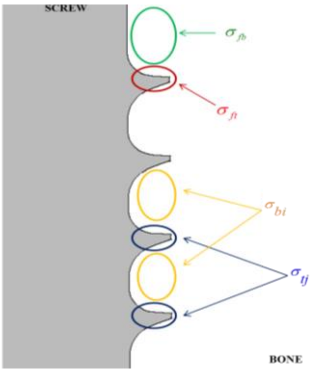

Fig. 7 The positions of stress distribution were used to evaluate STP.

3. Results

The equivalent von Mises stress of nine screws inserted C3 spines to compare the stress transfer parameter (STP) and the pullout strength of screws were shown in Table 3 - 10 for Model A, B, C, D, E, F, G and H respectively. The maximum stress distribution on C3 spine inserted TSRH I was shown in Fig. 8.

Table. 3 The stress transfer parameter on nine screws inserted C3 spine of Model A.

Type	STP
CD I	0.22
CD II	0.22
CD III	0.36
TSRH I	0.34
TSRH II	0.47
TSRH III	0.48
Moss Miami I	0.21
Moss Miami II	0.33
Moss Miami III	0.53

Table. 4 The stress transfer parameter on nine screws inserted C3 spine of Model B.

Type	STP
CD I	0.29
CD II	0.24
CD III	0.48
TSRH I	0.50
TSRH II	0.33
TSRH III	0.45
Moss Miami I	0.35
Moss Miami II	0.35
Moss Miami III	0.43

Table. 5 The stress transfer parameter on nine screws inserted C3 spine of Model C.

Type	STP
CD I	0.33
CD II	0.24
CD III	0.32
TSRH I	0.46
TSRH II	0.30
TSRH III	0.25
Moss Miami I	0.33
Moss Miami II	0.46
Moss Miami III	0.52

Table. 6 The stress transfer parameter on nine screws inserted C3 spine of Model D.

Type	STP
CD I	0.22
CD II	0.29
CD III	0.35
TSRH I	0.57
TSRH II	0.21
TSRH III	0.42
Moss Miami I	0.33
Moss Miami II	0.53
Moss Miami III	0.37

Table. 7 The stress transfer parameter on nine screws inserted C3 spine of Model E.

Type	STP
CD I	0.24
CD II	0.27
CD III	0.33
TSRH I	0.53
TSRH II	0.35
TSRH III	0.48
Moss Miami I	0.32
Moss Miami II	0.48
Moss Miami III	0.38

BME0007

Table. 8 The stress transfer parameter on nine screws inserted C3 spine of Model F.

Type	STP
CD I	0.34
CD II	0.28
CD III	0.54
TSRH I	0.49
TSRH II	0.49
TSRH III	0.33
Moss Miami I	0.25
Moss Miami II	0.50
Moss Miami III	0.47

Table. 9 The stress transfer parameter on nine screws inserted C3 spine of Model G.

Type	STP
CD I	0.22
CD II	0.24
CD III	0.22
TSRH I	0.35
TSRH II	0.32
TSRH III	0.40
Moss Miami I	0.37
Moss Miami II	0.29
Moss Miami III	0.28

Table. 10 The stress transfer parameter on nine screws inserted C3 spine of Model H.

Type	STP
CD I	0.24
CD II	0.20
CD III	0.39
TSRH I	0.32
TSRH II	0.53
TSRH III	0.42
Moss Miami I	0.35
Moss Miami II	0.40
Moss Miami III	0.50

Table 11 Shown the maximum strees transfer parameter (STP) of each model A-H

Model	Type	STP
Model A	Moss Miami III	0.53
Model B	TSRH I	0.50
Model C	TSRH I	0.46
Model D	TSRH I	0.57
Model E	TSRH III	0.48
Model F	CD III	0.54
Model G	TSRH III	0.40
Model H	Moss Miami III	0.50

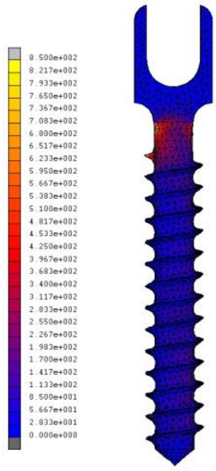

Fig. 8 maximum stress distribution on C3 spine inserted TSRH I.

4. Discussion

The maximum von Mises stress occurred at the first thread of pedicle screw because the load transfer was act on the cap and the first thread had less cortex bone to resist the pull out load that transfer from the cap. Each parameters of pedicle screw such as outer diameter, core diameter, pitch, proximal root radius, distal root radius and thread width affect the pullout strength. From the results, the highest STP occurred at TSRH I. The large outer diameter increased the thread area of pedicle screw to share more the load from the bone than the small diameter.

5. Conclusion

This study compared the nine pedicle screws, which had difference parameters for evaluate the pullout strength when inserted in C3 spine. All screw's parameter affected the pullout strength of pedicle screw. Finite element method was analyzed the failure of pedicle screw inserted cervical spine in screw pullout process and compared by stress transfer parameter (STP) of each screw to show the screw's parameter that affect the pullout strength. The TSRH I was the best of pedicle screw when inserted in C3 spine from stress transfer parameter analysis to resist the pullout force. The large outer diameter and core diameter was the main cause of the high pullout strength. The pedicle screw was designed based on the force disperse between bone and screw for a good performance [17].

6. Acknowledgement

The authors wish to thank the Faculty of Medicine, Burapha University and Biomechanics Analysis and Orthopedic Device Design Laboratory (B-AODD LAB), Department of Mechanical Engineering, Faculty of Engineering, Mahidol University for their support with facilities.

BME0007

7. References

[1] T.A. Mattei, M.S. Meneses, J.B. Milano and R. Ramina. "Free-hand" technique for thoracolumbar pedicle screw instrumentation: critical appraisal of current "state of art" *Neurol India*. 2009 vol. 57(6), pp. 715-721.

[2] J. D. Thompson, J.B. Benjamin and J.A. Szivek "Pullout strengths of cannulated and non-cannulated cancellous bone screws" *Clinical Orthopaedics and Related Research* 1997 vol. 341, pp. 241-249.

[3] S. Ritddech, P.Aroonjarattham, K. Aroonjarattham. "The effect of screw parameters on pullout strength of screw fixation in cervical spine" *World Acadamy of Science, Engineering and Technology* 2015 vol. 9, No:3.

[4] C. H. Ching, K.C. Ching, L.W. Jaw, M.H. Sheng, T.T. Ying and L. Jinn. "Increase of pullout strength of spinal pedicle screws with conical core: biomechanical tests and finite element analyse" *J. Orthopaedic Research* 2005 . 23, pp. 788-794.

[5] A. Perez, A. Mahar, C. Negus, P. Newton and T. Impelluso. "A computational evaluation of the effect of intramedullary nail material properties on the stabilization of simulated femoral shaft fractures" *J. Med Eng & Phy* 2007 vol. 20, pp. 755-760.

[6] E.E. Karaikovic, S. Kunakornsawat, M.D. Daubs, R. Madsen and R.W. Jr. Gaines. "Surgical anatomy of the cervical pedicles (landmarks for posterior cervical pedicle entrance localization)" *J. Spinal Disord* 2000 vol. 13, pp. 63-72.

[7] A. Ramos and J.A. Simoes. "Tetrahedral versus hexahedral finite elements in numerical modeling of the proximal femur" *J. Med Eng&Phy* 2006 vol. 28, pp. 916-924.

[8] Q.H. Zhang, S.H. Tan and S.M. Chou. "Investigation of fixation screw pull-out strength on human spine" *J. Biomechanics* 2004 vol. 37, pp. 479-485.

[9] Z. Paul, B. David, E.G. Allan and P. Marcello. "Nothching of the Anterior Femoral Cortex during Total Knee Arthoplasty" *J. Arthroplasty* 2006 vol. 21, pp. 737-743.

[10] Chazistergos, P., Ferentinos, G., Magnissalis, E. A., & Kourkoulis, S. K. "Investigation of the Behaviour of the Pedicle Screw-Vertebral Bone Complex, When Subjected to Pure Pull-Out Loads" *International ANSYS Conference Proceedings Pittsburgh, USA: ANSYS* 2006, pp. 1-13.

[11] S.-I.Chen., R.-M. Lin., C.-H.Chang. "Biomechanical investigation of pedicle screw-vertebrae complex: a finite element approach using bonded and contact interface conditions" *Med Eng Phys* 2003 *25(4),* pp. 275-282.

[12] Solehuddin Shuib., M.I.Z. Ridzwan., M.N. Mohamad Ibrahim. "Analysis of Orthopedic Screws for Bone Fracture Fixations with Finite Element Method" *Journal of Applied Sciences* 2007 *7(13),* pp. 1748-1754.

[13] A. Gefen."Dynamic simulations of cancellous bone resorption around orthopaedic fixative implants" *Proceedings – 23rd Annual Conference – IEEE/EMBS Oct.25-28, 2001,* Istanbul, TURKEY

[14] A. Gefen. "Computational simulations of stress shielding and bone resorption around existing and computer- designed orthopaedic screws" *Med. Bio. Eng. Comput* 2002, pp. 337-347.

[15] A. Gefen. "Optimizing the biomechanical compatibility of orthopedic screws for bone fracture fixation" *Medical Engineering and Physics* 2002, pp. 337-347.

[16] Haase,K., Rouuhi,G."Finite element optimization of plate and screw parameters to reduce stress shielding" *55th Annual Meeting of the Orthopaedic Research Society,* Poster No. 760

[17] C. Altieri, J. Flores, V. Gonzalez and A. Rodriguez. "Biomechanics of orthopaedic fixations" 2003 *Mechanics of Materials I*. University of Puerto Rico.