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The Effect of Screw Parameters on Pullout Strength of Screw Fixation in Cervical Spine

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***Abstract*—**The pullout strength had an effect on the stability of plate screw fixation when inserted in the cervical spine. Nine different titanium alloy bone screws were used to test the pullout strength through finite element analysis. The result showed that the Moss Miami I can bear the highest pullout force at 1,075 N, which causes the maximum von Mises stress at 858.87 MPa, a value over the yield strength of titanium. The bone screw should have large outer diameter, core diameter and proximal root radius to increase the pullout strength.

***Keywords*—**Pullout strength, Screw parameter, Cervical spine, Finite element analysis.

I. INTRODUCTION

THE plate screw fixation is one of the most popular devices used to fix the instable bone resulted from trauma, tumors and infection. The bone screws are commonly used to fix the orthopaedic implant that converts the torque applied into a compressive force between the screws placed through two components. In spine surgery, a screw is used to stabilize between the degenerative two or more spinal levels. The bone screw insertion concerns the selection of correct size of the screw and the proper position to ensure good anchoring when inserting [1]. The purpose of stabilizing the inserted spine concerns the pullout strength of the screw that measures screw fixation strength [2]. The parameters of screw such as major and minor diameters, pitch and threads length affect the pullout strength of screw fixation. Many researchers had examined the pullout strength and other factors through experimental studies [3], [4] and finite element analysis, [5] but none of them had evaluated the results with actual spine geometry through finite element analysis.

This research aims to evaluate the pullout strength of the nine different bone screw fixations, inserted in cervical spine through finite element analysis. The stress distribution on the bone-screw joint contact during the screw pullout process was obtained.

II. MATERIALS AND METHODS

A. The Cervical Spine Model

The cervical spine was scanned with computerized tomography (CT) scanner (GE LightSpeed VCT; Chonburi, Thailand). The CT data was reconstructed with ITK-SNAP software (Version 2.4.0; Nov 21, 2012; grant R03 EB008200; USA). The completed three-dimensional cervical spine models, which were exported from the imaging program, were shown in Fig. 1.

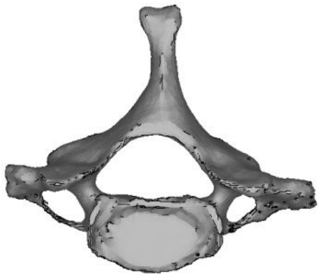

Fig. 1 Three-dimensional model of cervical spine

B. The Screw Fixation

The CAD model of all bone screws fixation was constructed using SolidWorks 2010 package (Version 2010; Mahidol University; Nakhon Pathom, Thailand) based on commercial screw fixation. The screws in this research were Cotrel-Dubousset (CD), Texas Scottish Rite Hospital (TSRH) and Moss Miami [6]. The dimensions of the bone screws are shown in Table I and the cross sectional of all bone screws are shown in Fig. 2.

TABLE I
DIMENSION OF THE BONE SCREW

Type	Outer diameter (mm)	Core diameter (mm)	Pitch (mm)	Proximal root radius (mm)	Distal root radius (mm)	Thread width (mm)
CD I	7.50	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
TSRH 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

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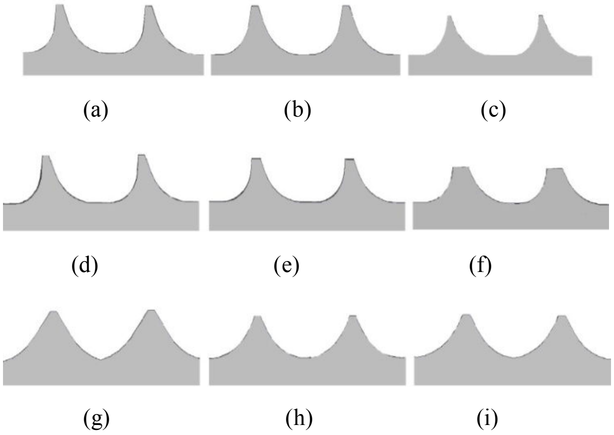

Fig. 2 Cross-sectional area of nine bone screws: (a) CD I, (b) CD II, (c) CD III, (d) TSRH I, (e) TSRH II, (f) TSRH III, (g) Moss Miami I, (h) Moss Miami II and (i) Moss Miami III

C. Virtual Simulation

All screws were positioned using the starting landmarks reported by [7], which lay in the center of pedicle region with actual surgery positions as shown in Fig. 3.

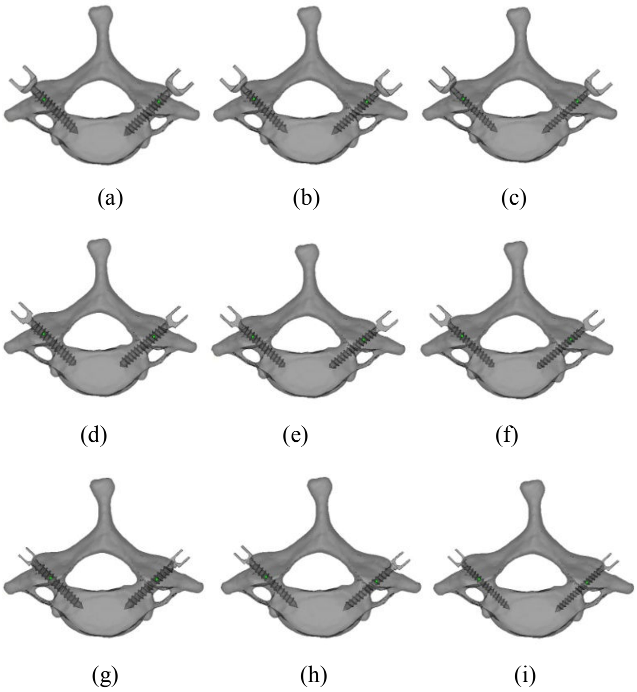

Fig. 3 The position of screw in the bone: (a) CD I, (b) CD II, (c) CD III, (d) TSRH I, (e) TSRH II, (f) TSRH III, (g) Moss Miami I, (h) Moss Miami II and (i) Moss Miami III

D. Material Properties

Linear elastic and isotropic material properties were assigned to all materials in this research. The material properties are shown in Table II [8].

TABLE II
MATERIAL PROPERTIES OF BONE AND SCREW

Material	Modulus (MPa)	Poisson's ratio
Cortical bone	14,000	0.3
Bone screw	110,000	0.3

E. Mesh Generation

The four-node tetrahedral element was used to generate the mesh model using MSC Marc (Version 2010, Mahidol University, Thailand). According to Ramos and Simones's experiment, the results from both tetrahedral element and hexahedral element were similar [9]. The bone-implant model had a total of 46,469 nodes and 202,760 elements. The spine-implant models are shown in Fig. 4.

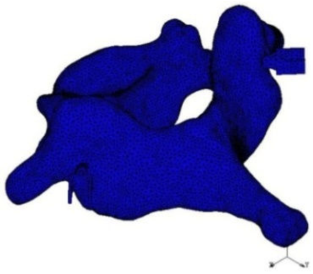

Fig. 4 Mesh model of spine-implant

F. Boundary Condition

The cervical spine was fully fixed and received axial load at the top of bone screws, which is shown in Fig. 5. The contact between bone and screw was set to touch contact condition in order to simulate the friction force occur at the region. The value of friction coefficient between the contact interface of screw and bone was set to 0.2 [5]-[11].

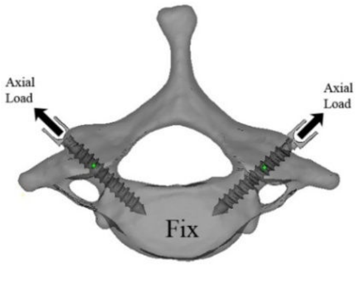

Fig. 5 Axial load act on top of bone screw

III. RESULTS

During the pullout test, the bone screws received the axial load until the maximum von Mises stress equaled or exceeded the yield strength of titanium alloy, which caused screw failure. The maximum von Mises stresses of all bone screws are shown in Table III.

The yield strength of titanium alloy is 850 MPa [12]. The peak von Mises stress on the bone screws occurred at the region near the cap of all screws. These values were higher than the yield strength of titanium alloy. The axial force cause by pulling the cap of the screw, together with the thread of the screw stuck in the cervical spine, caused the highest von Mises stress near the screw-cap as shown in Fig. 6.

TABLE III
THE MAXIMUM VON MISES STRESS ON BONE SCREW

Type	Maximum von Mises stress (MPa)	Pullout force (N)
CD I	869.13	550
CD II	865.32	505
CD III	881.60	452
TSRH I	869.15	950
TSRH II	859.04	880
TSRH III	863.91	720
Moss Miami I	858.87	1,075
Moss Miami II	862.65	970
Moss Miami III	871.84	925

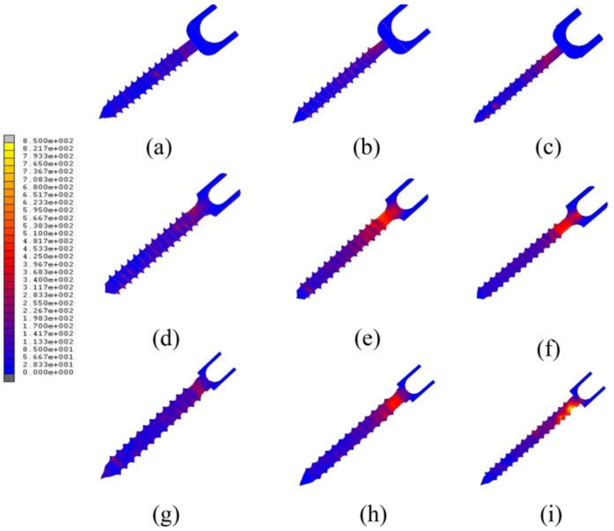

Fig. 6 The von Mises stress distribution on the bone screw: (a) CD I, (b) CD II, (c) CD III, (d) TSRH I, (e) TSRH II, (f) TSRH III, (g) Moss Miami I, (h) Moss Miami II and (i) Moss Miami III

The von Mises stress that occurred on the contact region between cervical bone and the thread of screw exceeded the yield strength of the cervical spine (100 MPa) [13], resulting in bone failure as shown in Fig. 7.

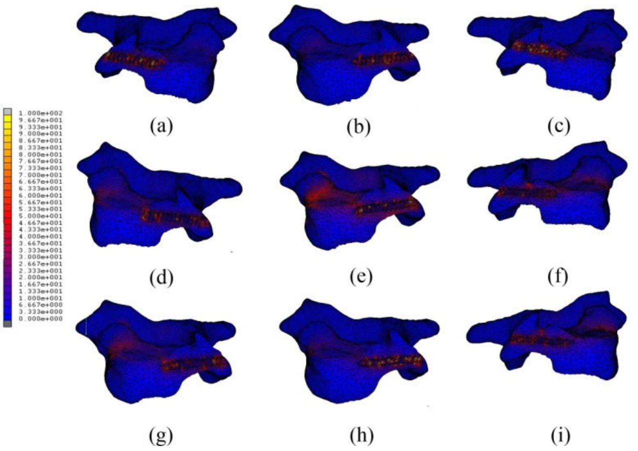

Fig. 7 The von Mises stress distribution on the cervical spine: (a) CD I, (b) CD II, (c) CD III, (d) TSRH I, (e) TSRH II, (f) TSRH III, (g) Moss Miami I, (h) Moss Miami II and (i) Moss Miami III

IV. DISCUSSION

The purpose of plate and screw fixation is to reinforce the stability of fractured bone throughout the healing process. The pullout strength is an important biomechanics parameter that should be optimized for screw design [14]. Pullout strength of bone screw had been extensively studied using cadaver bone [15], animal bone [16] and artificial materials [17]. The purpose of this study was to characterize the failure of bone screw during screw pullout process using finite element analysis. This study investigated the different screw parameters affecting screw pullout strength:

Firstly, the outer diameter and core diameter of the same type of bone screw affect the pullout force and maximum von Mises stress. Larger outer diameter and core diameter enable the screw to bear more pullout force since they increase the area to bear the load.

Secondly, the larger proximal root radius affects the larger contact area between the thread and the bone to increase the load bearing capacity of the bone screw.

V.CONCLUSION

The bone screws, which resist the high pullout strength, should

- have large outer diameter to increase the blade area to bear the load
- have large core diameter to increase the area to bear normal stress on the screw
- have the large proximal root radius to increase the contact area between the thread and the bone

Titanium alloy has the most biocompatibility of all metals due to its resistance to body fluids, high strength and low modulus. It is widely used for implants, surgical devices, pacemaker cases and centrifuges [18].

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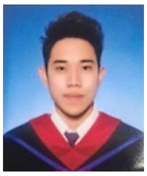

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