The Comparison of Strain Distribution on Thai Scoliosis and Thai Scoliosis Adjust by Screw Fixation System

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Abstract
The secondary curve (S-shape) is one of the scoliosis deformity types. Scoliosis usually occurs in the thoracolumbar region of the adolescents, adulthood and the elderly. If the patient is not advised and treated by the surgeon, the patient will be in more pain and the curvature of scoliosis will be increased. The screw fixation system or pedicle screw system is popular in the treatment of spinal deformity. Because the surgical treatment is highly considered as successful, the postoperative of the pedicle screw system will become virtual homogeneous vertebral and movement together; however, there are few studies reporting the post-operative results in Thai scoliosis surgery. Therefore, this study aims to analyse the strain of Thai scoliosis (S-shape) as compared with normal Thai spine and Thai scoliosis adjusted by screw fixation system under the compressive load with a finite element method. The results showed the maximum strain occurred on Thai scoliosis, normal Thai spine and Thai scoliosis adjusted by screw fixation system respectively. It appeared that the strain occurred on the model of scoliosis adjusted by screw fixation system were more decreased/reduced than the scoliosis model and it is reasonable if compared with the normal model, due to the pedicle screw fixation system could be absorbed the strain occurred on the spinal very well. The center of scoliosis pre-operative was at T7 and L1 levels which had the maximum displacement before being adjusted by screw fixation system. It affects the strain occurred on the models by the reaction force. As mentioned above, the patient should be advised and treated by the surgeon as quick as possible in order to return to daily activities better than before the surgery.

Keywords: Strain, Scoliosis, Thoracic to Thoracolumbar, Screw fixation system and Finite element analysis.

1. Introduction
The most deformity of spinal cord is scoliosis, which is one of the spine curvature disorders, and usually occurs in an adolescent. The deformation is a disorder between and within vertebrae, too must curvature in the frontal plane [1]. Scoliosis can be divided into two types as a single primary curve (C-shape) and secondary curve (S-shape) [2] as shown in figure 1.
This research aims to analyze the strain dispersion on Thai scoliosis (S-shape) compared with normal Thai spine and Thai scoliosis adjusted by screw fixation system using finite element analysis. The scoliosis model measured the curvature of deformity by the Cobb method.

2. Materials and Methods

The three-dimensional models in this research were Thai scoliosis, normal Thai spine and Thai scoliosis adjusted by screw fixation system.

2.1 The three-dimensional models of Thai middle of thoracic to thoracolumbar (T5-L5)

Three-dimensional models of Thai spine recreated by ITK-SNAP program from the computerized tomography (CT) data. The middle of thoracic to thoracolumbar models was scoliosis and normal models as shown in figure 2.

2.2 The three-dimensional model of an intervertebral disc

The three-dimensional model of an intervertebral disc were created from SolidWorks software with the actual anatomical position. The intervertebral disc models consisted of nucleus pulposus and annulus fibrosus as shown in Figure 3.
2.3 The three-dimensional model of the screw fixation system
This model was created from SolidWorks software. The model of pedicle screw was the mono-axial type with Moss Miami. The diameter of the pedicle screw was 5 mm and 30 mm length as shown in figure 3.

![Figure 3](image)

**Figure 3.** Three-dimensional models: (a) The intervertebral disc and (b) The screw fixation system

2.4 Measurement of scoliosis
Cobb method was used to measure scoliosis curvature angle. Scoliosis in this study was the secondary curve (S shape) and the Cobb angle of the middle thoracic (T5-T10) were 20 degrees and 21 degrees of the thoracolumbar (T10-L5) as shown in figure 4.

![Figure 4](image)

**Figure 4.** (a) The measurement of scoliosis (Cobb angle) and (b) The virtual simulation model

2.5 Virtual Simulation
The virtual simulation was used to correct and adjust the scoliosis to a normal model, according to the anatomical human spine. In this process, the models have inserted the intervertebral disc and adjusted by screw fixation system as shown in figure 4.

2.6 Material properties
Material properties of cortical bone, annulus, nucleus and titanium alloy assume as homogeneous, isotropic material and linearly elastic. Anterior longitudinal ligament, posterior longitudinal ligament, ligamentum falvum, capsular ligament, interspinous ligament and supraspinous ligament were nonlinear properties. The specifications of all material properties were shown in table 1.
Table 1. The materials properties of the spine and ligament [3, 4, 5]

| Materials                     | Elastic modulus (MPa) | Poisson’s ratio |
|-------------------------------|-----------------------|-----------------|
| Cortical bone                 | 14,000                | 0.30            |
| Annulus                       | 8.4                   | 0.45            |
| Nucleus                       | 1.0                   | 0.499           |
| Titanium alloy                | 110,000               | 0.30            |
| Anterior Longitudinal Ligament| Nonlinear             | -               |
| Posterior Longitudinal Ligament| Nonlinear             | -               |
| Ligamentum Falvum             | Nonlinear             | -               |
| Capsular Ligament             | Nonlinear             | -               |
| Interspinous Ligament         | Nonlinear             | -               |
| Supraspinous Ligament         | Nonlinear             | -               |

2.7 Loading and boundary condition
The finite element (FE) models have represented an average sized Asian woman with the height of 150 cm and weight 50 kg. The models were compressed with axial load from the weight of the head 35.80 N at the top of the fifth thoracic vertebrae (T5) [6]. The End of the fifth lumbar vertebrae (L5) was fixed as shown in figure 5.

2.8 Mesh Generation
The element type used to generate the mesh model was the four-node tetrahedral element. All mesh models were generated by MSC Marc software. The scoliosis model had a total of 72,584 nodes and 277,038 elements, the normal model had a total of 73,939 nodes and 281,780 elements and the scoliosis adjusted by screw fixation system had a total of 1,087,751 nodes and 4,892,176 elements. The finite element models are shown in figure 5.

Figure 5. The position of loading and boundary condition act on the middle of thoracic to thoracolumbar mesh model: (a) Scoliosis model and (b) Normal model

3. Validation Model
The validation model constructed the experimental test kit by 3D printing machine to determine the mechanical properties for validating the finite element models. The test kit was tested with Universal Testing Machine (UTM) for evaluating stress and strain distribution compared with finite element models.
as shown in figure 6 and the reliability of the validation was 90.83%. Therefore, the percentage error obtained in this study is “acceptable” and the finite element model is reliable [7].

![Validation Model](image)

**Figure 6.** Graph of stress-strain relationship between experimental testing and numerical simulation

### 4. Results and Discussion

Based on the results, we make the following observations:

The maximum equivalent of total strain on Thai scoliosis, normal Thai spine and Thai scoliosis adjusted by screw fixation system under compressive load are shown in table 2.

| Thoracic to Thoracolumbar | The Maximum equivalent of total strain (µε) |
|----------------------------|------------------------------------------|
|                            | Normal       | Scoliosis  | Scoliosis adjusted by screw fixation system |
| T5                         | 47.163       | 157.229    | 26.657                                      |
| T6                         | 36.099       | 265.898    | 37.676                                      |
| T7                         | 39.061       | 185.619    | 74.100                                      |
| T8                         | 49.743       | 158.349    | 43.753                                      |
| T9                         | 34.503       | 181.880    | 31.633                                      |
| T10                        | 52.649       | 70.393     | 44.104                                      |
| T11                        | 53.838       | 103.081    | 35.572                                      |
| T12                        | 87.918       | 165.563    | 8.943                                       |
| L1                         | 85.516       | 50.505     | 83.456                                      |
| L2                         | 111.181      | 70.133     | 53.312                                      |
| L3                         | 80.168       | 67.148     | 64.323                                      |
| L4                         | 60.147       | 92.830     | 26.566                                      |
| L5                         | 107.979      | 78.784     | 79.503                                      |

The maximum equivalent of total strain occurred on scoliosis adjusted by screw fixation system tended to be less than scoliosis and normal spine models as shown in figure 7. The screw fixation system could be absorbed the strain occurred on the middle thoracic to thoracolumbar. In addition, the results show that the maximum equivalent of total strain of scoliosis adjusted by the screw fixation system model is less than the normal and scoliosis models at 27.94% and 63.00%, respectively.
Figure 7. The maximum equivalent of total strain on Thai the middle of thoracic to thoracolumbar under compressive load conditions ($\mu\varepsilon$)

Figure 8 illustrates the maximum equivalent of total strain occurred at the center of scoliosis (T7 and L1) of normal, scoliosis and scoliosis adjusted by screw fixation system models. From figure 8(a) and 8(d), the maximum equivalent of total strain occurred around the body to spinous process, according to the axial force transmission from the weight of the head. The figure 8(b) and 8(e) show the maximum equivalent of total strain occurred around the body to the spinous process more than figure 8(a) and 8(d). As the result of the scoliosis deformity, cause the axial force not transmission along the axis. The last one, the strain concentration occurred at the area around the hole of a pedicle screw, especially when T7 and L1 levels were the center of scoliosis. Because the area was the connection between the vertebrae to the screw fixation.

Figure 8. The maximum equivalent of total strain occurred at T7 and L1: (a) T7 of normal, (b) T7 of scoliosis, (c) T7 of scoliosis adjusted by screw fixation system, (d) L1 of normal, (e) L1 of scoliosis and (f) L1 of scoliosis adjusted by screw fixation system.
5. Conclusion
In conclusion, the findings of this study show that the center of scoliosis pre-operative was T7 and L1 levels which had the maximum displacement before being adjusted by screw fixation system. It affects the strain occurred around the models by the reaction force. However, the patient had the Cobb angle less than 40 degrees and the maximum equivalent of the total strain of scoliosis adjusted by implant less than normal spine lightly. So, the surgeon should advise the patient to find a suitable treatment, such as wearing “a brace” [8, 9].

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References
[1] White A A Panjabi M M 1990 Clinical biomechanics of the spine (Philadelphia:Lippincott) 2 128-155
[2] Janicki J A Alman B 2007 Paediatrics & child health 12(9) 771-776
[3] Niinomi M Liu Y Nakai M Liu H Li H 2016 Regenerative biomaterials 3(3) 173-185
[4] Shin D S Lee K Kim D 2007 Computer-Aided Design 39(7) 559-567
[5] White A A Panjabi M M 1990 Clinical biomechanics of the spine (Philadelphia:Lippincott) 2 22
[6] Okamoto Y Murakami H Demura S Kato S Yoshioka K Hayashi H Sakamoto J Kawahara N Tsuchiya H 2015 The Spine Journal 15(4) 713-720
[7] Lin C L Chang Y H Liu P R 2008 Journal of dentistry 36(3) 194-203
[8] Weiss H R 2008 Disability and rehabilitation 30(10) 799-807
[9] Kuroki H 2018 Journal of clinical medicine 7(6) 136