A biomechanical study on post-scoliotic deformity correction

S Balamurugan¹, Kunal Pandey², Shraddha R Iyer², Appaji Krishnan¹ and Shantanu Patil¹
¹ Department of Mechanical Engineering, SRM Institute of Science and Technology, Chennai, India.
¹ Department of Translational Medicine and Research, SRM Institute of Science and Technology, Chennai, India.
¹ Consultant Spine Surgeon, SIMS Hospital Vada Palani, Chennai, India
² Students, Department of Mechanical Engineering, SRM Institute of Science and Technology, Chennai, India.

E-mail: balamurs3@srmist.edu.in

Abstract. Scoliosis is the deformity of the growing human spinal column such that the vertebral alignment is distorted in a corkscrew fashion. A person with severely deformed spine may find it difficult to breathe as the ribcage may press against the internal organs compromising the functions of the lungs and the heart. Due to the altered load transfer, these patients also suffer from back pain and early arthritis. The scoliotic deformity is surgically corrected by using implants which are screwed into the vertebra. In severe cases, complete correction may not be achievable. As a result, the loads experienced by the implants may not be optimal, leading to their early failure. The objective of this work is to study the effect on the deformity correction in a scoliotic spine. A three-dimensional model of the surgically corrected spine was segmented from the computed tomography scan and converted into a surface model. This model was imported into ANSYS for meshing and subjected to compression load to simulate weight bearing. The stress concentration and displacement across the entire spine, individual vertebrae and discs was analysed. The effect on the implants was separately analysed as well.

1. Introduction
Scoliosis is a deformity of the growing human spine [1]. It deforms the torso and also affects the shape of the body [2]. Sometimes the spine anomaly is present at the birth and sometimes it can be observed only when the child reaches adolescence. There are mainly three types of scoliosis suggested by American Association of Neurological Surgeons (AANS) namely neuromuscular, idiopathic and congenital [3]. In idiopathic scoliosis [4] the cause of deformation is unknown whereas in congenital scoliosis the cause of the spine deformation present in the foetus during spine development present during birth. There are different reasons for congenital anomaly [3].

1.1 Incomplete formation of vertebrae
Due to incomplete formation of a vertebra during gestation, a sharp wedge is formed at the spine. Such kind of vertebra is known as a hemivertebra. The angle at the spine can get even worse while reaching the adolescence. There are cases in which more than one hemivertebra has been formed in the spine which tries to neutralise each other to stabilize the spine hence giving it a sharper angle increasing the severity of the deformation.
1.2 Incomplete separation of vertebrae
During the intra-uterine gestation of the foetus, the spine is developed as a single column of tissue which in later stages get segmented into bony vertebrae but sometimes the separation is incomplete which leads to formation of partial fusion and joins two or more vertebrae [5]. Due to fusion the growth of spine is averted on one side and a curvature is developed.

1.3 Formation of a hemivertebrae and partial fusion
In such cases the deformation arises due to both aforementioned deformities. Such cases need early diagnosis and corrective measure to arrest the increased curvature of the spine [5]. The model used in the analysis was of a patient with congenital scoliosis due to development of a hemivertebrae. The patient underwent surgical correction of the deformity, excision of the hemivertebrae and spinal fusion with intervertebral cage [6, 7]. The correction was maintained with the help of twelve pedicular screws and two titanium rods stabilised with cross bars at one level.

2. Materials and Methods

2.1 Model Generation
A linear three-dimensional thoracolumbar model of the spine which consists of vertebrae from T1 to T12, L1-L5, implant rod and screws [5] was developed using a Computed Tomography (CT) scan which is a combination of the series of X-rays images taken from various angles of the human body. It generates the cross-sectional images of the bones, blood vessels and tissues using computer processing. CT scan of the patient post-surgery was procured from the SIMS Hospital, Chennai. The scan was imported to MIMICS 14.0 software. MIMICS is an image processing software used for 3D designing and modelling. It uses the image data obtained from CT scan to calculate the three-dimensional model through segmentation as shown in figure 1 & 2.

![Figure 1. Scan model.](image1)

![Figure 2. Segmented Model segmented in different views.](image2)
The imported post correction model is segmented using this software to create a 3D surface model. 0.5 mm gap was created between each slice. The model is converted into a .stl file and imported to Geomagics Design. The imported model is then subdivided, smoothened, re-wrapped and the surface model was generated as shown in figure 3. The model is exported to ANSYS 18.0 for meshing and to assign the material properties, was shown in table 1 [6-8]. Beam element was created in the surgical region to represent the implant. The normal body load to simulate standing condition was applied on the spine in different locations (figure 4).

![figure 3. Surface generation in Geomagics.](image)

**Table 1.** Material properties of the FEM of thoracolumbar spine.

| Components          | Young’s Modulus (MPa) | Poisson’s Ratio | Cross-Sectional Area (mm²) | Element |
|---------------------|-----------------------|-----------------|----------------------------|---------|
| Cortical bone       | 1200                  | 0.26            | -                          |         |
| Cancellous bone     | 100                   | 0.2             | -                          | Solid 185 |
| Posterior elements | 3500                  | 0.25            | -                          |         |
| Disc                | 1                     | 0.499           | -                          |         |
| Nucleus             | 4.2                   | 0.45            | -                          | Link 10 |
| Ground Substance    | 0.3                   | 0.3             | 0.76                       |         |
| Fibre Ligament ALL  | 20                    | -               | 63.7                       | Link 10 |
| PLL                 | 20                    | -               | 20                         |         |
| TL                  | 58.7                  | -               | 3.6                        |         |
| LF                  | 19.5                  | -               | 40                         |         |
| ISL                 | 11.6                  | -               | 40                         |         |
| SSL                 | 15                    | -               | 30                         |         |
| CL                  | 32.9                  | -               | 60                         |         |
**Figure 4.** Meshed model of corrected spine with boundary condition.

*a. Boundary Conditions*

The L5 vertebra was constrained from all the degrees of freedom. Assuming the weight of the patient to be 800N (80kg), a compressive force of 50N along the Z-axis was applied on T1 vertebra. This load replicates weight of the human head. A load of 150N was applied on the T9 vertebra replicating the weight of the upper proximity of the human body. Another load of 200N was applied on T12 vertebra on the thoraco-lumbar junction (Figure 4).

**3. Results and Discussion**

Finite element meshed model of post-surgery scoliosis affected spine was developed and analysed for Maximum stress and vertical movement in vertebrae and disc. Static load was applied to the model to understand the severity of the surgical region in terms of stress concentration and deformation were investigated. After the surgical region, lumbar segments showed maximum stress concentration compare to thoracic region. The maximum stress and deformations were shown in figure 5 and 6.

Stress distribution in the vertebrae of post-operative condition for normal standing loading, followed the stress pattern similar to intact spine. This shows that the non-uniform deformity in the scoliosis affected spine were corrected in the spine curvature and mimicked the intact spine. While, comparing the displacement in the vertebrae, adjacent vertebrae of the surgical region T7 and T9 showed the maximum displacement compare to other vertebrae. Similarly, comparing the disc stress distribution and displacement the lumbar segment showed the maximum value. Further, the stress and displacement on L3 to L5 vertebrae and disc were high because this segment is below the surgical region. The maximum stress and displacement are shown in figure 7 and 8.
However, the stress distribution was more in the lumbar segment. L1 to L5 in vertebrae and L3 to L5 in disc showed high values, this showed that below the surgical region experience maximum stress. But, last three vertebrae and disc were showed the stress raiser. This proves that the stress concentration is maximum at the end of the lumbar region after post-surgery condition.

4. Conclusion
Three-dimensional model of post-surgery condition was modelled and analysed. After simulation, pre-surgery FE model helped to understand the stress and displacement patterns. The study revealed that high stress concentration on the vertebra and the disc comprised in the lumbar region. The extracted model was subject specific and studying the corrected spine curvature after surgery was critical and more complex. This study may pave pathways for future studies to be conducted in this field.

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