A biomechanical study of T12-L2 in thoracolumbar region of spine affected by tuberculosis

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Abstract. Pott's disease or tuberculosis spondylitis is the occurrence of tuberculosis in spine. It is caused by mycobacterium tuberculosis. Due to this infection vertebral compression fracture occurs leading to collapse of the vertebral column resulting in kyphosis. Tuberculosis mostly affects the thoracolumbar region (T12-L2) of spine. Several minimally invasive surgeries are available to treat the fractured vertebra. After the treatment subsequent adjacent fractures occur in certain people. This study deals with the biomechanical behavior of tuberculosis affected vertebrae after fracture. The surface model of T12–L2 spine segment of the thoracolumbar region is to be segmented from CT scan data of a healthy subject using MIMICS. The obtained surface model is meshed and analysis is carried out using Ansys and validated with literature. The validated model is modified to tuberculosis condition to study the biomechanical behaviour of affected vertebrae in comparing with healthy model.

Keywords: Tuberculosis, Vertebral compression fracture, Finite element analysis.

1. Introduction

Tuberculosis spondylitis in the vertebral column is very common in India [1]. It is caused by the bacteria mycobacterium tuberculosis and is more common in children and in young adults [2,3,4]. The bacteria cause lytic destruction on the vertebral body thus weakening it. The intervertebral disc is not affected if only one vertebral body is infected but there is increased anterior wedging on the vertebra leading to vertebral compression fracture [5,6,7]. If two or more vertebral bodies are infected the intervertebral disc between them will not be able to get nourishment from the nutrients therefore the disc tissue dies leading to vertebral narrowing and collapse resulting in spinal damage and kyphosis [8,9]. The areas which are mostly affected by tuberculosis are the lower thoracic and upper lumbar region in the vertebral column.
Several minimally invasive surgeries like kyphoplasty and vertebroplasty are available as a remedy for compression fractures in order to bring back the height of the vertebral body. But despite these surgeries further subsequent fractures occur. The causes of these subsequent adjacent fractures is due to the leakage of cement into the intervertebral disc while performing the surgery and also the extent to which the cement has leaked morphologically [10,11,12]. Finite element analysis is very useful for studying irregular geometries. This method can be used to analyze the vertebral column and appropriate solutions for problems can be obtained computationally thereby saving time and money when compared to the methods with cadaveric specimens [13].

This paper deals with the creation of a 3D surface model of the thoracolumbar region (T12-L2) from the CT scan of a normal person using MIMICS. The developed FE model was validated with literature and the same model was modified to tuberculosis condition. The biomechanical behaviour of the affected vertebrae was studied in comparison with a healthy model.

2. Methodology

To develop the surface model CT scan of a normal 26 year old male was used with slice thickness of 1.25 mm and 1229 in number. These 2D images of spine are then converted into a 3D model using MIMICS [14]. Thoracolumbar region (T12-L2) alone was segmented from the entire vertebral column and was smoothened to fill holes and cavity in order to refine and improve the surface. Intervertebral discs and ligaments were added and for the latter link 180 elements were used. Figure 1 shows the methodology to obtain the FE model.

![Figure 1: Methodology.](image)

The various vertebral bodies and the discs were first meshed using the 2D element tria. Quality check of these two dimensional elements was done before converting them into three dimensional tetramesh. Quality check of the 3D elements was also performed to ensure accuracy and correctness of the mesh.

Validation of the intact meshed model was done by first assigning the material properties of a normal spine to the model and a standing load of 720N was applied to check for compression. The range of motion for flexion plus extension was found out for the condition of flexion plus extension with no load in hand and the results obtained were compared with the in-vitro range of motion from literature [15].
The present work focuses on the study of the adult thoracolumbar region under TB condition. Two stages of TB were considered. Stage one comprises of degradation and structural change of the endplate and the disc. The disc components were decreased to 50% and the Young’s modulus of the end plate was decreased to 5MPa. Stage two is the erosion of disc and puss like infection of the total disc. In this stage for all the components above the Young’s modulus was reduced to 0.1MPa. Table 1 shows the various material properties of spine in normal and in tuberculosis condition [16, 17, 18, 19, 20].

Table 1: Material properties of spine in normal and in tuberculosis condition [16, 17, 18, 19, 20].

| Bones                        | Young’s Modulus(MPa)/Poisson’s ratio(Normal) | Young’s Modulus(MPa)/Poisson’s ratio(Stage 1 TB) | Young’s Modulus(MPa)/Poisson’s ratio(Stage 2 TB) |
|------------------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Cortical bone                | 12,000/0.3                                    | 5/0.4                                           | 0.1/0.49                                        |
| Cancellous bone              | 100/0.2                                       | 2/0.495                                         | 0.1/0.49                                        |
| End plate                    | 3000/0.25                                     | 0.5/0.49                                        | 0.1/0.49                                        |
| Anulus fibrosus              | 4.2/0.45                                      | 0.5/0.49                                        | 0.1/0.49                                        |
| Nucleus pulposus             | 1/0.4999                                      | Cross-section (mm²)                             |                                                  |
| ALL                          | 7.8 ( □ < 12%) 20 ( □ > 12%)                  | 63.7                                            |                                                  |
| PLL                          | 1.0 ( □ < 11%) 2.0 ( □ > 11%)                 | 20                                              |                                                  |
| LF                           | 1.5 ( □ < 6.2%) 1.9 ( □ > 6.2%)               | 40                                              |                                                  |
| TL                           | 10(□ < 69%) 59 ( □ > 69%)                     | 1.8                                             |                                                  |
| ISL                          | 1.0(□ < 14%) 1.2 ( □ > 14%)                   | 40                                              |                                                  |
| SSL                          | 3.0(□ < 20%) 5.0 ( □ > 20%)                   | 30                                              |                                                  |

3. Results and discussions

A FE model of the thoracolumbar region from T12-L2 was created and material properties for a normal spine and analysed for flexion plus extension to predict range of motion. A standing load of 720N was given along with flexion and extension under no load in hand condition and the range of motion for both the levels was calculated. Figure 2 shows the comparison of the range of motion for flexion plus extension of the present work with literature [15].
The results were compared with the *in vitro* and *in vivo* studies reported in the literature. The range of motion for T12-L1 in the present model was 8° and for L1-L2 it was found to be 16° which lies between the ranges given in literature [15]. In addition to this, the range of motion obtained for flexion plus extension for stage 1 TB is 12 and 40° which is higher than the intact model. Similarly the range of motion obtained for flexion plus extension for stage 2 TB is 27 and 116°, which is higher than both the intact and stage 1 TB model. Figure 3 shows the comparison of range of motion for flexion plus extension of the intact with two stages of TB.

**Figure 3** Comparison of Range of motion for flexion plus extension of the intact with the two stages of TB.

The maximum von Mises stress observed in the intact model for a standing load of 720N was 33.114 MPa. Similarly, maximum stress for Stage 1 TB was 54.2396 MPa and for stage 2 TB was 303.193 MPa which was higher than stage 1 TB and intact condition. Figure 4 shows the comparison of the maximum von Mises stress of the intact with the two stages of TB.

**Figure 4** Comparison of Maximum von Mises stress of the intact with the two stages of TB.
Figure 4 Comparison of maximum von Mises stress of the intact with the two stages of TB. Displacement of the discs of the intact model under a compressive load of 720N was 0.42mm. The displacement for the discs of stage 1 and stage 2 TB for the same loading condition was 1.71mm and 20.46mm respectively. Figure 5 shows the comparison of the displacement undergone by the intact and the two stages of TB.

Figure 5 Comparison of the displacement undergone by the intact and the two stages of TB.

It is observed that the range of motion for T12-L1 in stage 2 TB was 125% higher than the stage 1 TB range of motion and was 237% higher than the intact value. Similarly the range of motion for L1-L2 in stage 2 TB was 190% higher than the stage 1 TB range of motion and was 625% higher than the intact value. The maximum von Mises stress in stage 2 TB was 459% higher than stage 1 TB and is 816% higher than the intact condition. The displacement of the intervertebral discs in stage 2 TB is 1096% higher than stage 1 TB and 4698% more than the intact condition.

This study was restricted to only two stages of TB which is the initial stage for tuberculosis and only thoracolumbar region was chosen for study as it is more prone to fractures and most of the
TB lesions affect this area and also the lumbar region [21]. Range of motion of flexion and extension alone were studied as the other parameters were not important as the collapse of vertebrae occurs mostly during flexion and rarely in extension.

4. Conclusions

The present work involves the development of a finite element model of the thoracolumbar region (T12-L2) of an adult and was validated with literature. The model was simulated for two stages of TB to study the behaviour of the spine under those conditions. In stage 2 the thoracolumbar region (T12-L2) underwent a higher range of motion when compared to intact and stage 1 TB in both the levels. The lower level L1-L2 in stage 2 was more prone to fractures as the disc was completely eroded and was unable to distribute the loads to the other levels. High displacement and stress level in stage 2 TB may initiate compression fractures in the adjacent segments resulting in collapse of vertebrae. Hence immediate clinical support is required for the patient affected by stage 2 TB to restore the normal function of the spine thereby preventing pain and damage to the spinal cord. Future works may involve the study of lateral bending, axial rotation and also other parameters. The entire vertebral column of an adult can be modelled and TB can be simulated for various stages and the behaviour of the human spine can be studied for different loading conditions and the mechanism of collapse can also be analysed.

5. References

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