Analecta Technica Szegedinensia

Vol. 18, No. 3 ISSN 2064-7964 2024

BIOMECHANICAL ANALYSIS AND MODELING OF DIFFERENT TRACTION PATTERNS IN ADOLESCENT IDIOPATHIC SCOLIOSIS

[1]Qiaolin Zhang, [2]István Bíró

[1] Doctoral School on Safety and Security Sciences, Obuda University, 1034, Budapest, Hungary
[2] Faculty of Engineering, University of Szeged, Mars ter 7, 6721, Szeged, Hungary
e-mail: zhangqiaolin123@gmail.com

Received: 2nd June	*Accepted: 19th September*

ABSTRACT

Objective: Traction is a valuable treatment for Adolescent idiopathic scoliosis; however, assessing its biomechanical effects, particularly with new methods, presents challenges. This study aims to explore the biomechanics using finite element analysis, with the goal of enhancing safety and effectiveness. Methods: Based on CT images, two different boundary and loads were applied to simulate two traction methods. The effects of these two traction methods on stress and deformation of lumbar vertebral bodies and intervertebral discs were compared. Results: Under two traction methods, the stress was concentrated on the posterior side. Multi-point traction resulted in higher stress and deformation, and concentrated stress on the convex side as well. However, there is some stress concentration on the vertebral arch, which may lead to injury. Conclusion: Compared to longitudinal traction, multi-point traction can better reduce stress on the vertebral bodies and intervertebral discs, focusing the pulling force on the concave side and achieving greater deformation. Multi-point traction might better suit specific patients needing more correction and pressure relief compared to longitudinal traction.

Keywords: Finite element, Adolescent idiopathic scoliosis, Lumbar stress, Traction methods, Multi-point traction

1. INTRODUCTION

Scoliosis is one of the most common types of spinal deformities, characterized by a lateral curvature of the spine in the coronal plane or a change in the sagittal plane curvature, or sometimes a combination of both, resulting in a three-dimensional spinal deformity [1]. The internationally recognized diagnostic criteria for scoliosis are established by the Scoliosis Research Society (SRS), which uses Cobb's method to measure the curvature of the spine on standing X-ray images, with an angle greater than 10° considered as scoliosis [2].
Idiopathic scoliosis is a subtype of scoliosis, and Adolescent idiopathic scoliosis (AIS) belongs to the idiopathic category. The prevalence of AIS varies widely in the general population. Qiu et al.[3] found a prevalence range of 0.6% to 2.0% for scoliosis in the Chinese population, with 90% of cases being AIS. Zheng et al.[4] reported a prevalence rate of 2.4% for AIS, with a higher incidence in girls. Several studies have reported the incidence of AIS to be within the range of 1% to 3% [5], with 2% to 3% being the most commonly reported values in the literature. AIS primarily affects adolescents aged 10 to 18 years and tends to progress during the second growth spurt [6]. AIS poses various risks to adolescents, including spinal deformity, restricted mobility, and significant impact on daily life. The physical deformity associated with AIS can also lead to psychological disorders in patients, making it an important risk factor for social and psychological problems as well as health impairments [7, 8]. Patients with idiopathic scoliosis may require lifelong treatment and monitoring, which significantly impacts their growth and development, particularly in adolescent patients.
The lumbar region is a significant part of the spinal column, consisting of five vertebrae located between the thoracic spine and the sacrum, and it bears the weight of the upper body. The development of the lumbar spine is closely related to the formation of spinal processes, which may influence its motion and function [9]. For instance, an excessively large or posteriorly protruding spinal process may compress the lumbar nerve roots or spinal cord, causing pain or neurological symptoms. Spinal processes can also lead to deformities or abnormalities in the lumbar spine [10]. Therefore, physicians may need to closely monitor the

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

condition of the lumbar spine in patients with spinal processes and devise appropriate treatment plans based on individual circumstances. Due to the unknown etiology of AIS, there is no standardized treatment approach. Generally, treatment options for AIS include surgical and non-surgical methods.

For adolescents with early-stage AIS who do not meet the criteria for surgery, a proactive conservative treatment approach is recommended [11, 12]. Extensive research and clinical studies have shown that non-surgical treatment options should be the first choice to prevent progressive changes in curvature [13].

Traction is the most commonly used non-surgical treatment for AIS, which effectively relaxes the muscles and releases adhesions in the lumbar region. And it also helps correct misalignment, reduce pressure within the spinal canal, improve blood supply to the lumbar region, alleviate lower back and leg pain, and restore muscle balance on both sides of the spine. Traction is considered an effective and non-invasive method for correcting lumbar scoliosis [14]. Additionally, traction can loosen the soft tissues surrounding the spine, increase ligament and facet joint mobility, enhance spinal flexibility, and improve spinal cord tolerance, thereby reducing postoperative complications. Preoperative traction is widely recognized as an effective adjunctive treatment for severe scoliosis correction [15, 16].

With the increasing demand for disease treatment, an increasing number of new traction methods are being proposed. The evaluation of its therapeutic effectiveness can be assessed through pain evaluation, functional assessment, imaging evaluation, and other comprehensive measures [17]. The SOSORT and SRS Non-operative Management Committee consensus in 2014 suggested that reporting predicted outcomes and providing imaging results during non-surgical treatment studies in the growth phase are strongly recommended[18]. However, there is no ideal method to predict treatment outcomes and examine the changes in spinal stress and the effects of traction in advance. Traditional experimental methods are difficult to directly apply to the study and analysis of human biomechanics due to the complex physiological environment and load characteristics. Finite element analysis (FEA) overcomes the limitations of traditional mechanical experiments, as it offers accurate, objective, comprehensive, and repeatable mechanical performance testing. [19, 20].

Currently, FEA has made it an important methodology in the biomechanical research of idiopathic scoliosis. In the 1970s, FEA was introduced into biomedical and orthopedic biomechanics research. In light of the swift progress in modern computers, FEA has been used in traction analysis. Luis Cardoso [21] conducted FEA simulations on a commercially available thermal-mechanical massage bed capable of performing spinal posterior-anterior traction. Stress release generated by mechanical therapy was investigated on human subject models with different BMI levels. Sicong Wang [22] established models of the L1-L5 lumbar vertebrae and a vibration dynamics model to explore the biomechanical effects of head-down tilt (HDT) traction combined with vibration therapy on age-related degenerative changes in the lumbar spine. The study results demonstrated that the reduction in intradiscal pressure was more effective when vibration was combined with traction therapy. Zeinab Kamal et al. [23] used a combined musculoskeletal model and FEA to investigate the stress distribution changes in the growth plate of the trunk in adolescent idiopathic scoliosis after unilateral muscle paralysis and evaluated muscle strength based on stability in AIS spines.

Based on previous studies, using finite element simulation to assess the stress changes within the spine during traction is achievable.[24] Before its implementation, conducting finite element simulations to calculate the stress changes in the scoliotic spine can provide valuable insights into the safety and efficacy of the proposed traction method. Assuming that multi-point traction exerts greater and more concentrated tensile stress on the vertebral bodies and intervertebral discs (IVDs) compared to single longitudinal traction, it is hypothesized that multi-point traction may result in a greater overall deformation for the lumbar spine.

The usual axial traction may alter the normal anterior curvature of the spine and potentially lead to lower back pain [25, 26]. Due to the significance of the lumbar region within the spinal column, this study focuses on the lumbar to investigate the biomechanical differences between two non-invasive traction methods. The first method is multi-point traction, which involves applying axial traction to the lumbar spine while applying an additional lateral force at L2-L4. The second method is axial traction. The biomechanical changes in the lumbar spine segments under these two methods are examined. Unlike traditional beds that mainly pull

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

vertically, our study considers two directions. And we used computer simulations for its development, which is not only safer and more efficient compared to physical experiments but also aids in the development and validation of new traction techniques.

2. MATERIALS AND METHODS

2.1. Data acquisition

The subject of this study is a female （14 years old，45kg）with congenital scoliosis. When the subject was CT scanner, the participant was positioned in a supine posture without any external weight applied. A scanning interval of 0.75 mm was utilized, and the CT image was processed using Mimics software (Materialise, Leuven, Belgium) to generate a 3D model, as shown in Fig. 1. The Ethics Committee of Ningbo University approved this study (RH0020230607), and the participant demonstrated a comprehensive comprehension of the experimental objectives.

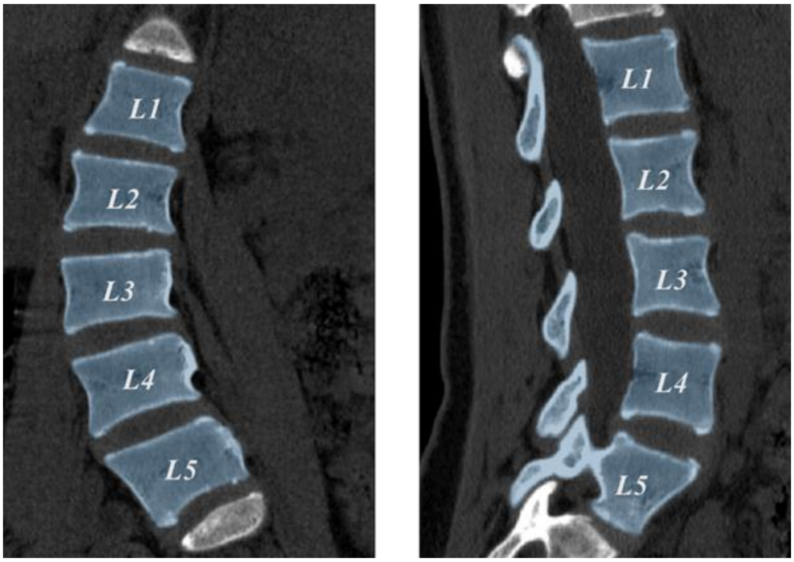

Figure 1. Frontal and sagittal plane of the scoliotic spine

The DIERS Formetric 3D evaluation system (DIERS Formetric, Diers Medical Systems, Chicago, IL) was used for assessment. During the evaluation, the patient removes the upper clothing, exposing the back and upper buttocks, stands naturally, facing the camera, and positioned within the focal point of the grid. Overlapping interference of the grid forms parallel bright bands with wave patterns projected onto the body surface, which vary with the contour of the body. The deformation of a single light beam corresponds to the three-dimensional shape of the back. These deformations are captured by the camera and used to generate a three-dimensional spinal reconstruction model for analysis. Multiple image data are obtained during this process as shown in Fig. 2, and the results indicate that the maximum vertebral rotation of the lumbar spine is -22° to the left at the second lumbar vertebra, and the maximum lordotic angle ITL-ILS is 16°.

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

Analecta Technica Szegedinensia
Vol. 18, No. 3 ISSN 2064-7964 2024

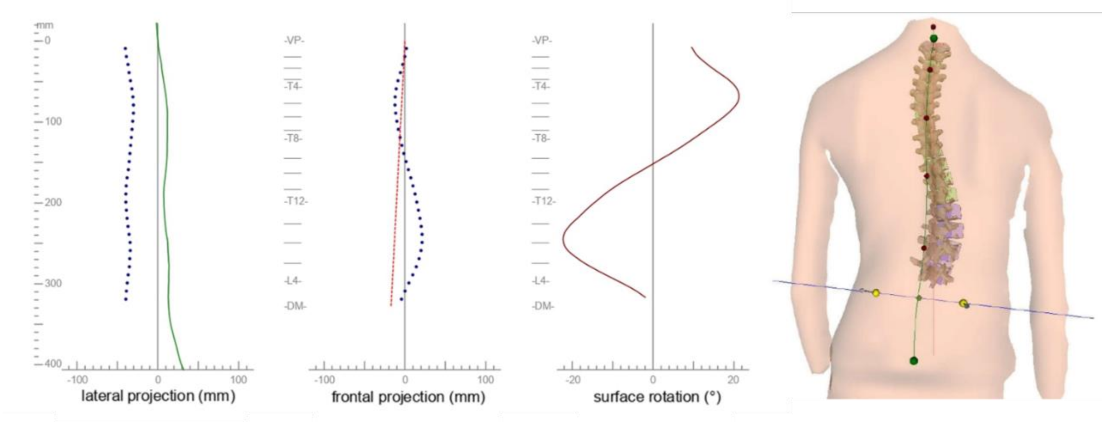

Figure 2. Frontal and sagittal plane of the scoliotic spine

2.2 Building of the three-dimensional solid model

The CT image underwent segmentation using Mimics 21.0 software (Materialise, Leuven, Belgium) to generate a 3D model. Subsequently, the model was imported into Geomagic Studio 2021 (Geomagic, Inc., Research Triangle Park, NC, USA) for smoothing and construction of the lumbar ligament. Finally, the model was assembled using SolidWorks 2021 software (SolidWorks Corporation, Waltham, MA, USA). Then, established the internal anatomy such as cancellous bone, IVDs, endplate, annulus fibrosis, and articular cartilage. In this study, the thickness of the endplate is 0.5mm and the thickness of the cortical bone is 0.4mm [27].

2.3 Material Parameters

The material parameters for the model in this study are presented in Tab. 1 [28]. An isotropic homogeneous linear elastic material is used to define cancellous bone, cortical bone, articular cartilage, endplate, and IVDs.

Table1. Material parameters of lumbar model.

	Young's Modulus (MPa)	Poisson ratio	Radius（r, mm）
Cortical bone	12000	0.3	
Cancellous bone	100	0.3	
Annulus fibrosis	4.2	0.453	
endplate	25	0.25	
Nucleus pulposus	1	0.499	
Articular cartilage	50	0.3	
Anterior longitudinal ligament	7.8	0.3	63.7(r4.5)
Posterior longitudinal ligament	10	0.3	20(r2.52)
Ligamentum flavum	17	0.3	40(r3.57)
Interspinous ligament	10	0.3	40(r3.57)

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

Supraspinous ligament	8	0.3	30(r3.09)
Intertransverse ligament	10	0.3	1.8(r0.76)
Capsule ligament	7.5	0.3	30(r3.09)

2.4 Boundary and Loading Conditions

The mesh was generated using the Mesh tool in Ansys, employing free meshing. Through multiple attempts, the model element size was controlled at 0.5 mm, and the local element size was set to 0.3 mm, which provided a fine finite element model within the computational capabilities of the computer.
To examine the variations in the effects of two methods, multi-point traction, and longitudinal traction, a finite element model of the lumbar spine was developed., The model consisted of five lumbar vertebrae (L1-L5), each with pedicles and vertebral arche. The lower endplate of L5 was fixed as a boundary condition, and the contact surfaces between the vertebral body models and the IVDs models were defined as tied contacts. The interaction between the vertebral body and the facet joint was set to "friction" since sliding can occur under certain loads. A friction coefficient of 0.01 was determined considering the presence of synovial fluid [29]. Two loading conditions were applied in the model.
The magnitude of traction force is a direct and significant factor influencing the traction effect. A larger traction force can induce greater axial displacement of the IVDs, resulting in better therapeutic effects. However, the traction force should not be excessively high to avoid strain on muscles or soft tissues. Additionally, during traction treatment, patients usually lie on the traction bed, so the traction force needs to overcome frictional forces and the elastic resistance of muscle tissues. It must exceed a certain value to be effective. Based on previous studies, the longitudinal traction force was set at 35% of body weight, and the lateral pushing force was set at 15% [30, 31].
Control Group: A vertical traction force of 35% of body weight (154.35 N) was applied to L1 along the positive Z-axis to simulate the axial load in an upright position, as shown in Fig. 3A.
Simulation group: Firstly, a vertical traction force of 35% of body weight (154.35 N) was applied to L1 along the positive Z-axis to simulate the axial load in an upright position. Secondly, a lateral force of 15% of body weight (66.15 N) was applied to the model along the X-axis in the direction of the spinal curvature to simulate the lateral force acting on the spine in the case of spinal deformity. These loading conditions were simultaneously applied to the finite element model during the multi-point traction, as shown in Fig. 3B.
The differences between the two traction methods were analyzed by measuring the displacement of the vertebral bodies and the distribution of stress in the vertebral bodies and IVDs before and after spinal traction.

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

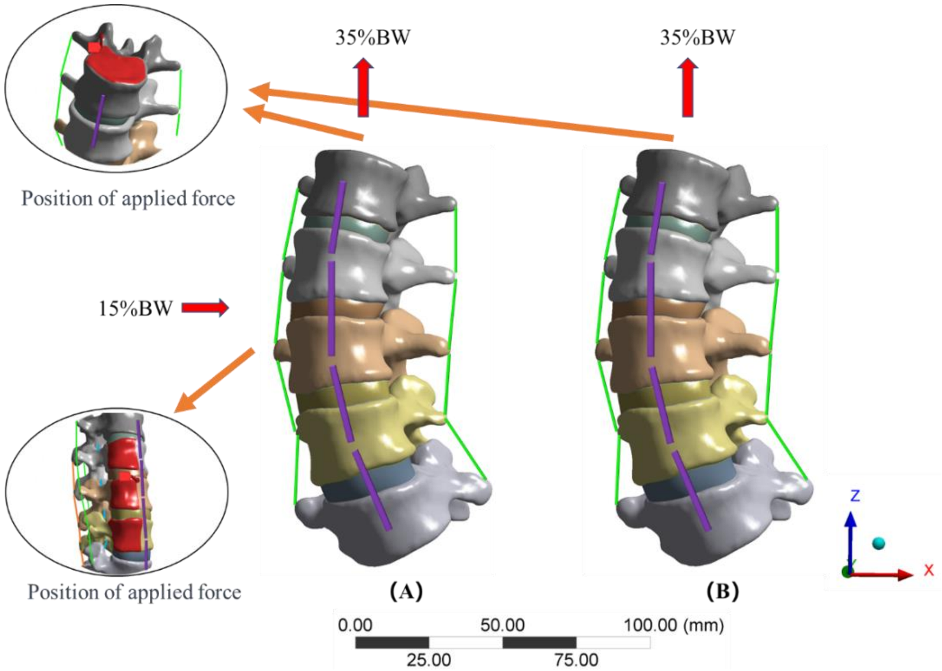

Figure 3. Loading condition of two different traction modes. A： Multi-point Traction, B: Longitudinal Traction.

2.5 Model Validation

Given the absence of universally accepted validation criteria for various angles of spinal scoliosis, model validation is implemented to assess the accuracy of the modeling procedure. As a result, if the normal lumbar spine model demonstrates efficacy, the scoliotic lumbar spine model is deemed valid as well. The L5 vertebra is completely fixed, restricting its degrees of freedom in six directions. A vertical load of 400 N is uniformly applied on the surface of the L1 vertebra to simulate the upper body mass, and an additional moment of 10 N ·m is applied to simulate six different conditions: flexion, extension, left lateral bending, right lateral bending, left rotation, and right rotation of the lumbar spine. The biomechanical characteristics of the lumbar spine under these conditions are calculated [32].

3. RESULTS AND DISCUSSION

3.1 Validation Results

To assess the range of intervertebral motion under varied loading conditions, the developed model was compared with in vitro experiments. This comparison aimed to evaluate the model's accuracy and reliability. The results were also compared with the experimental and theoretical data from previous studies, such as Yamamoto and Heth [33, 34], under the same loading conditions. As shown in Fig. 4, the average stiffness values of this model under flexion, extension, lateral bending, and rotation were in good agreement with the reported average stiffness values in the literature. Therefore, the developed three-dimensional finite element model is considered effective and reliable and can be applied in clinical research [35].

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

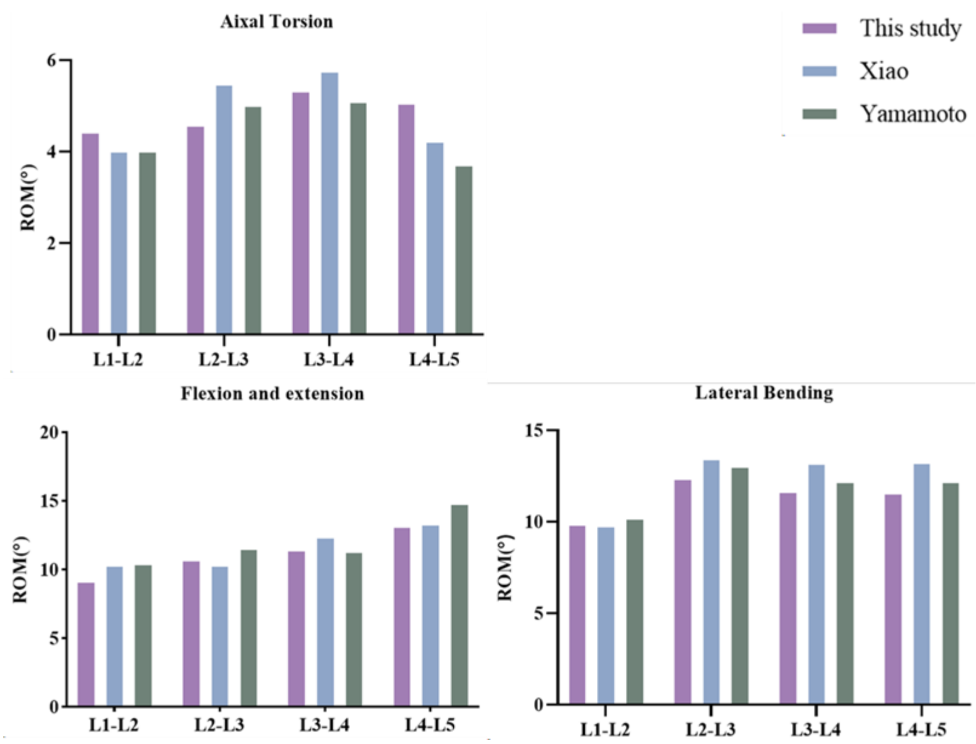

Figure 4. The relative range of motion of L1-L5 lumbar vertebrae under different working conditions.

3.2 Vertebral Stress and Deformation of lumbar

According to the results of the FEA, the equivalent stress values of each vertebral body in the L1-L5 region during lumbar traction using the two methods are shown in Fig. 5. It can be observed that under both traction methods, the equivalent stress values initially increase, then decrease, and then increase again from L1 to L5. The maximum stress value is observed at L5, while the minimum stress value during longitudinal traction is at L1, and for multi-point traction, it is at L3.

The stress distribution in the vertebral bodies of L1-L3 is similar. Under both traction loads, the stress variation in the scoliotic vertebral bodies is similar and mainly concentrated on the concave side of the vertebrae, as shown in Fig. 5.

The main difference in stress distribution between the two traction methods is observed at L4 and L5. Aside from the observed stress concentration on the concave side of the lumbar spine, multi-point traction also induces increased stress on the convex side of the lumbar spine.

Under different simulated traction methods, the displacement of the lumbar vertebrae also varies. As shown in Figure 6, both traction methods result in a similar decreasing trend of vertebral displacement from L1 to L5. Under longitudinal traction, the specific displacement values for L1 to L5 are 0.58 mm, 0.51 mm, 0.43 mm, 0.35 mm, and 0.02 mm, respectively. However, multi-point traction leads to greater vertebral displacement compared to longitudinal traction. Under multi-point traction, the specific displacement values for L1 to L5 are 1.83 mm, 1.54 mm, 1.21 mm, 0.85 mm, and 0.05 mm, respectively.

Analecta Technica Szegedinensia
Vol. 18, No. 3 ISSN 2064-7964 2024

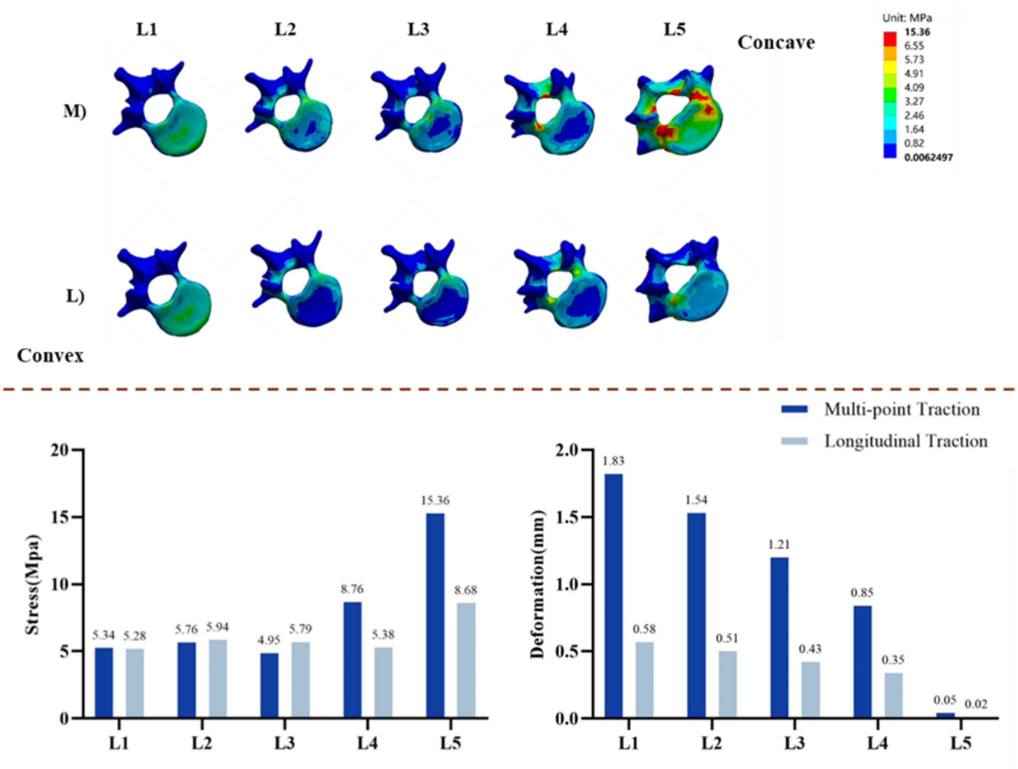

Figure 5. Stress distribution of vertebral in AIS lumbar under two different traction modes. M： Multi-point traction, L: Longitudinal traction.

3.3 Intervertebral Disc Stress

The maximum stress on the IVDs caused by the two traction methods is shown in Fig. 6. With both traction methods, the maximum stress on the IVDs occurs at IVD1, while the minimum stress occurs at IVD4.
The stress distribution on the IVDs caused by the two traction methods is shown in Fig. 6. The multi-point traction method results in higher stress on all four IVDs compared to the longitudinal traction method, and the stress is primarily concentrated on the posterior side of the IVDs.
Under longitudinal traction, the stress on IVD1 and IVD2 is primarily concentrated on the posterior side of the concave region. However, under multi-point traction, stress is concentrated on the posterior side of both the convex and concave regions. For both methods, there is stress concentration on the posterior side of IVD3 bilaterally, but under multi-point traction, there is also stress concentration on the anterior side of IVD3.

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

Analecta Technica Szegedinensia
Vol. 18, No. 3 ISSN 2064-7964 2024

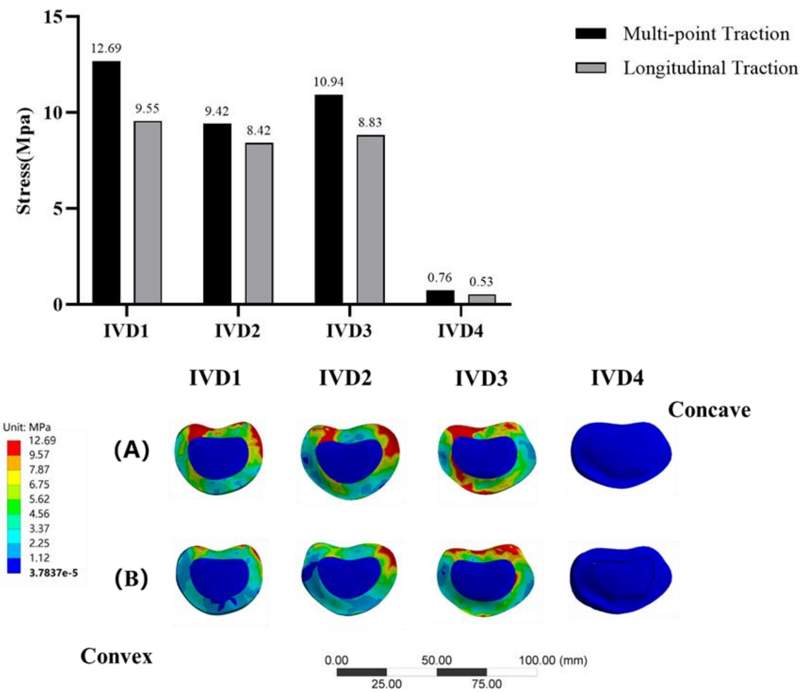

Figure 6. Equivalent Stress and Stress distribution of IVDs in AIS lumbar vertebrae under two different traction modes. A : Multi-point traction, B: Longitudinal traction.

3.4 Discussion

This study compared the stress levels and distribution in the lumbar vertebrae and IVDs, as well as the overall displacement of the lumbar spine, between multi-point traction and single longitudinal traction. It was found that multi-point traction is more effective in alleviating pressure on the concave aspect of the lumbar vertebrae and produces more corrective effects. The findings of the research suggest that multi-point traction may achieve better clinical outcomes compared to single longitudinal traction.

A stable mechanical environment of the vertebral bodies plays a crucial role in maintaining normal lumbar function [17] and bearing the majority of compressive loads from the upper body. When vertebral body injuries occur, it can lead to changes in the stress distribution of the corresponding IVDs annulus fibrosus, with decreased stress on the anterior side and increased stress on the posterior side [36]. The results of this study suggest that under multi-point traction, the FEA shows a concentrated distribution of stress in the posterior vertebral bodies and IVDs annulus fibrosus of the convex side of the scoliotic lumbar, while the stress distribution in the anterior vertebral bodies is more uniform, without concentration. This indicates that multi-point traction is more effective in relieving pressure on the convex side of the scoliotic lumbar. This may be because multi-point traction not only provides longitudinal tension but also provides lateral thrust, allowing for better relaxation of lumbar spine twisting and bending, thereby improving lumbar function [17]. However, the vertebral arch is a bony structure located on the dorsal side of the vertebral bodies, connecting the pedicles to form the vertebral arch. Due to its relatively thin structure, the vertebral arch is susceptible to fractures or injuries caused by external impact or excessive bending stress [37]. Under multi-point traction, there is a concentration of stress in the vertebral arch, which may potentially lead to vertebral body damage.

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

Analecta Technica Szegedinensia
Vol. 18, No. 3 ISSN 2064-7964 2024

Multi-point traction can utilize combined force traction to reduce the weight force of longitudinal traction, thereby decreasing the discomfort associated with traction. In comparison to commonly used clinical methods such as self-suspension traction, where the patient's body weight is used as the traction force, or other methods like cranial gravity traction, halo pelvic traction, or skull traction on the greater trochanter, which apply traction forces at 50% to 70% of the patient's body weight, multi-point traction reduces the longitudinal traction force to only 25% to 35% of the patient's body weight. This reduction in force helps alleviate discomfort caused by excessive longitudinal traction, including soreness in the upper limbs, shoulder fatigue, lumbar discomfort, breathing difficulties, abdominal pain, nausea, vomiting, and abnormal sensations in the lower limbs [38].

In this study, a low traction force was used, which compared to a high traction force, the small force combined traction exerted a milder tension on the ligamentous tissues. This gentle approach is less likely to trigger muscle tension responses and can better facilitate the relaxation of spasmodic or tense muscles, maintaining relative stability and balance of the spine. It allows patients to undergo treatment in a relaxed state, which is more conducive to muscle spasms and pain relief, thereby improving the effectiveness of the treatment. Moreover, the comprehensive relaxation of the muscles in the lumbar region is an important factor affecting the effectiveness of traction therapy. In clinical practice, many patients experience aggravated pain symptoms during and after traction due to muscle spasms and excessive traction force. The use of high-force intermittent traction can excessively stretch the ligamentous tissues, disrupting the relative stability and balance of the spine, and potentially causing strain to soft tissues such as the paraspinal muscles and fascia, leading to discomfort.

However, this study has several limitations. The single-subject approach is a commonly used research design in FEA, as the finite element model is based on the anatomical structure of a single subject and may not accurately represent anatomical variations among different individuals. Therefore, further research is needed to develop more robust modeling techniques that can account for individual anatomical differences and better capture the complexity of the human body. Additionally, the finite element model did not consider the influence of muscles on the spine [39], and the material properties used were based on linear material behavior. Thus, further improvements are necessary in terms of finite element material data and muscle simulation to enhance the accuracy of the FEA [40].

4. CONCLUSIONS

Compared to single longitudinal traction, multi-point traction can concentrate the pulling force more on the concave side of the lumbar vertebrae, reducing the pressure on the vertebral bodies and IVDs, and resulting in greater deformation. However, there is also some stress concentration on the vertebral arch, which may lead to injury. Therefore, multi-point traction may be more suitable for patients who require greater corrective.

REFERENCES

[1] Roach JW (1999) Adolescent idiopathic scoliosis. Orthop Clin North Am 30:353-65, vii-viii. doi: 10.1016/s0030-5898(05)70092-4
[2] Kane WJ (1977) Scoliosis prevalence: a call for a statement of terms. Clin Orthop Relat Res:43-6.
[3] Qiu GX (2017) Scoliosis in China: History and Present Status. Chin Med J (Engl) 130:2521-2523. doi: 10.4103/0366-6999.217081
[4] Zheng Y, Dang Y, Wu X, Yang Y, Reinhardt JD, He C and Wong M (2017) Epidemiological study of adolescent idiopathic scoliosis in Eastern China. J Rehabil Med 49:512-519. doi: 10.2340/16501977-2240
[5] Dunn J, Henrikson NB, Morrison CC, Blasi PR, Nguyen M and Lin JS (2018) Screening for Adolescent Idiopathic Scoliosis: Evidence Report and Systematic Review for the US Preventive Services Task Force. Jama 319:173-187. doi: 10.1001/jama.2017.11669

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

[6] Weinstein SL, Dolan La Fau - Cheng JCY, Cheng Jc Fau - Danielsson A, Danielsson A Fau - Morcuende JA and Morcuende JA Adolescent idiopathic scoliosis.
[7] Weinstein SL, Zavala DC and Ponseti IV (1981) Idiopathic scoliosis: long-term follow-up and prognosis in untreated patients. J Bone Joint Surg Am 63:702-12.
[8] Payne WK, 3rd, Ogilvie JW, Resnick MD, Kane RL, Transfeldt EE and Blum RW (1997) Does scoliosis have a psychological impact and does gender make a difference? Spine (Phila Pa 1976) 22:1380-4. doi: 10.1097/00007632-199706150-00017
[9] Zhang L, Zhang Q, Zhang Y, Arthur M, Teo EC, Bíró I and Gu Y (2022) The Effect of Concave-Side Intertransverse Ligament Laxity on the Stress of AIS Lumbar Spine Based on Finite Element Method. Bioengineering (Basel) 9. doi: 10.3390/bioengineering9120724
[10] Bleck EE (1991) Adolescent idiopathic scoliosis. Dev Med Child Neurol 33:167-73. doi: 10.1111/j.1469-8749.1991.tb05097.x
[11] Weinstein SL (2019) The Natural History of Adolescent Idiopathic Scoliosis. J Pediatr Orthop 39:S44-s46. doi: 10.1097/bpo.0000000000001350
[12] Dayer R, Haumont T, Belaieff W and Lascombes P (2013) Idiopathic scoliosis: etiological concepts and hypotheses. J Child Orthop 7:11-6. doi: 10.1007/s11832-012-0458-3
[13] Negrini S, Donzelli S, Aulisa AG, Czaprowski D, Schreiber S, de Mauroy JC, Diers H, Grivas TB, Knott P, Kotwicki T, Lebel A, Marti C, Maruyama T, O'Brien J, Price N, Parent E, Rigo M, Romano M, Stikeleather L, Wynne J and Zaina F (2018) 2016 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. Scoliosis Spinal Disord 13:3. doi: 10.1186/s13013-017-0145-8
[14] Chou R and Huffman LH (2007) Nonpharmacologic therapies for acute and chronic low back pain: a review of the evidence for an American Pain Society/American College of Physicians clinical practice guideline. Ann Intern Med 147:492-504. doi: 10.7326/0003-4819-147-7-200710020-00007
[15] Cheung KM, Kwan EY, Chan KY and Luk KD (2003) A new halo-pelvic apparatus. Spine (Phila Pa 1976) 28:305-8. doi: 10.1097/01.Brs.0000042322.78033.32
[16] Huang MJ and Lenke LG (2001) Scoliosis and severe pelvic obliquity in a patient with cerebral palsy: surgical treatment utilizing halo-femoral traction. Spine (Phila Pa 1976) 26:2168-70. doi: 10.1097/00007632-200110010-00026
[17] Tadano S, Tanabe H, Arai S, Fujino K, Doi T and Akai M (2019) Lumbar mechanical traction: a biomechanical assessment of change at the lumbar spine. BMC Musculoskelet Disord 20:155. doi: 10.1186/s12891-019-2545-9
[18] Negrini S, Hresko TM, O'Brien JP and Price N (2015) Recommendations for research studies on treatment of idiopathic scoliosis: Consensus 2014 between SOSORT and SRS non-operative management committee. Scoliosis 10:8. doi: 10.1186/s13013-014-0025-4
[19] Zhang Z, Li Y, Liao Z and Liu W (2016) [Research Progress and Prospect of Applications of Finite Element Method in Lumbar Spine Biomechanics]. Sheng Wu Yi Xue Gong Cheng Xue Za Zhi 33:1196-202.
[20] Kumaresan S, Yoganandan N, Pintar FA, Maiman DJ and Kuppa S (2000) Biomechanical study of pediatric human cervical spine: a finite element approach. J Biomech Eng 122:60-71. doi: 10.1115/1.429628
[21] Cardoso L, Khadka N, Dmochowski JP, Meneses E, Lee K, Kim S, Jin Y and Bikson M (2022) Computational modeling of posteroanterior lumbar traction by an automated massage bed: predicting intervertebral disc stresses and deformation. Front Rehabil Sci 3:931274. doi: 10.3389/fresc.2022.931274
[22] Wang S, Wang L, Wang Y, Du C, Zhang M and Fan Y (2017) Biomechanical analysis of combining head-down tilt traction with vibration for different grades of degeneration of the lumbar spine. Med Eng Phys 39:83-93. doi: 10.1016/j.medengphy.2016.10.004

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

[23] Kamal Z and Rouhi G (2020) Stress distribution changes in growth plates of a trunk with adolescent idiopathic scoliosis following unilateral muscle paralysis: A hybrid musculoskeletal and finite element model. J Biomech 111:109997. doi: 10.1016/j.jbiomech.2020.109997
[24] Herrera A, Ibarz E, Cegoñino J, Lobo-Escolar A, Puértolas S, López E, Mateo J and Gracia L (2012) Applications of finite element simulation in orthopedic and trauma surgery. World J Orthop 3:25-41. doi: 10.5312/wjo.v3.i4.25
[25] Lee CH, Heo SJ and Park SH (2021) The Real Time Geometric Effect of a Lordotic Curve-Controlled Spinal Traction Device: A Randomized Cross Over Study. Healthcare (Basel) 9. doi: 10.3390/healthcare9020125
[26] Ozturk B, Gunduz OH, Ozoran K and Bostanoglu S (2006) Effect of continuous lumbar traction on the size of herniated disc material in lumbar disc herniation. Rheumatol Int 26:622-6. doi: 10.1007/s00296-005-0035-x
[27] Gómez FS, Lorza RL, Bobadilla MC and García RE (2017) Improving the Process of Adjusting the Parameters of Finite Element Models of Healthy Human Intervertebral Discs by the Multi-Response Surface Method. Materials (Basel) 10. doi: 10.3390/ma10101116
[28] Goel VK, Kong W, Han JS, Weinstein JN and Gilbertson LG (1993) A combined finite element and optimization investigation of lumbar spine mechanics with and without muscles. Spine (Phila Pa 1976) 18:1531-41.
[29] Zheng J, Yang Y, Lou S, Zhang D and Liao S (2015) Construction and validation of a three-dimensional finite element model of degenerative scoliosis. J Orthop Surg Res 10:189. doi: 10.1186/s13018-015-0334-1
[30] Rinella A, Lenke L, Whitaker C, Kim Y, Park SS, Peelle M, Edwards C, 2nd and Bridwell K (2005) Perioperative halo-gravity traction in the treatment of severe scoliosis and kyphosis. Spine (Phila Pa 1976) 30:475-82. doi: 10.1097/01.brs.0000153707.80497.a2
[31] Mac-Thiong JM, Petit Y, Aubin CE, Delorme S, Dansereau J and Labelle H (2004) Biomechanical evaluation of the Boston brace system for the treatment of adolescent idiopathic scoliosis: relationship between strap tension and brace interface forces. Spine (Phila Pa 1976) 29:26-32. doi: 10.1097/01.Brs.0000103943.25412.E9
[32] Shirazi-Adl A, Ahmed AM and Shrivastava SC (1986) Mechanical response of a lumbar motion segment in axial torque alone and combined with compression. Spine (Phila Pa 1976) 11:914-27. doi: 10.1097/00007632-198611000-00012
[33] Yamamoto I, Panjabi MM, Crisco T and Oxland T (1989) Three-dimensional movements of the whole lumbar spine and lumbosacral joint. Spine (Phila Pa 1976) 14:1256-60. doi: 10.1097/00007632-198911000-00020
[34] Xiao Z, Wang L, Gong H and Zhu D (2012) Biomechanical evaluation of three surgical scenarios of posterior lumbar interbody fusion by finite element analysis. Biomed Eng Online 11:31. doi: 10.1186/1475-925x-11-31
[35] Heth JA, Hitchon PW, Goel VK, Rogge TN, Drake JS and Torner JC (2001) A biomechanical comparison between anterior and transverse interbody fusion cages. Spine (Phila Pa 1976) 26:E261-7. doi: 10.1097/00007632-200106150-00012
[36] Adams MA, McNally DS, Wagstaff J and Goodship AE (1993) Abnormal stress concentrations in lumbar intervertebral discs following damage to the vertebral bodies: a cause of disc failure? Eur Spine J 1:214-21. doi: 10.1007/bf00298362
[37] Acar N (2017) Behavior of Injured Lamina in Lumbar Burst Fractures during Reduction Maneuvers: A Biomechanical Study. Asian Spine J 11:507-512. doi: 10.4184/asj.2017.11.4.507
[38] Nepple JJ and Lenke LG (2009) Severe idiopathic scoliosis with respiratory insufficiency treated with preoperative traction and staged anteroposterior spinal fusion with a 2-level apical vertebrectomy. Spine J 9:e9-e13. doi: 10.1016/j.spinee.2009.01.009

DOI: https://doi.org/10.14232/analecta.2024.3.88-100

Analecta Technica Szegedinensia
Vol. 18, No. 3 ISSN 2064-7964 2024

[39] Ge T, Hu B, Zhang Q, Xiao J, Wu X and Xia D (2023) Biomechanical Evaluation of Two-Level Oblique Lumbar Interbody Fusion Combined With Posterior Four-Screw Fixation: A Finite Element Analysis. Clinical Neurology and Neurosurgery:107597.

[40] Zhang Q, Zhang Y, Huang J, Teo EC and Gu Y (2022) Effect of Displacement Degree of Distal Chevron Osteotomy on Metatarsal Stress: A Finite Element Method. Biology (Basel) 11. doi: 10.3390/biology11010127

DOI: https://doi.org/10.14232/analecta.2024.3.88-100