Joint Diseases and Related Surgery

Jt Dis Relat Surg
2022;33(1):86-92

ORIGINAL ARTICLE

Traction therapy in lumbar disc hernias: A finite element analysis study

Erol Öten, MD[1], Osman Civan, MD[2], Levent Uğur, MD[3]

[1]Physical Medicine and Rehabilitation, Amasya University Faculty of Medicine, Amasya, Turkey
[2] Department of Orthopedics and Traumatology, Akdeniz University Faculty of Medicine, Antalya, Turkey
[3]Mechanical Engineering, Amasya University, Faculty of Engineering, Amasya, Turkey

ABSTRACT

Objectives: This study aims to evaluate the results of lumbar traction treatment at different traction angles and different traction forces using the finite element analysis (FEA).

Materials and methods: Computed tomography (CT) images of a healthy 35-year-old male patient who had no history of trauma or fracture were modeled in three-dimensional (3D) with Mimics® software for the lumbosacral spine model. Ligaments and discs were created on the 3D spine model in the SolidWorks® program. The obtained model was sent to the ANSYS version 18 software, and analyses were done non-linearly. All analyses were performed at different angles and forces from the center of the sacral surface to simulate traction therapy.

Results: Traction forces applied in the 0° axial direction decreased the intradiscal pressures by creating a similar tensile stress in the annulus fibrosus regions (anterior, posterior, and lateral) without any significant change in lordotic angle.

Conclusion: The method used in this study is promising to investigate the benefits of traction therapy. Moreover, individual traction force and direction can be determined to increase the effectiveness of the treatment by using magnetic resonance imaging or CT images in traction therapy.

Keywords: Biomechanics, finite element analysis, lower back pain, lumbar spine traction therapy.

Since the beginning of the 19th century, traction beds were used in the treatment of scoliosis, lumbar disc herniation (LDH), and spinal deformities. Traction therapy is a widely used conservative treatments for LDH. Traction therapy is a suggested method to relieve pain and enhance the joint functionality by diminishing pressure on discs or nerves.[1,2] Traction therapy was used to reduce lower back pain and recover joint functions by applying primary load along the lower-upper axis of the spine, reducing the pressure in the discs and nerves.[3]

A few studies have examined the biomechanical effects of traction therapy. Numerical simulation is one of the widely used methods to elucidate the impact of rehabilitation treatment in terms of biomechanics.[4,5] In the literature, the applied force was enforced in the axial direction from the center of the L1 vertebra to the superior for the studies on lumbar traction biomechanics.[5,6] However, lumbar traction devices used in clinical applications consist of two parts, the upper body with arm holders and the movable lower body, which provides positioning of the lower extremities.[7] As in our study, the direction of the force applied in clinical applications is toward the body inferior in the axial direction.[8]

We may use finite element analysis (FEA) to better understand biomechanics, make better choices, and make therapeutic decisions. It can be used as a non-invasive tool to assess the biomechanical qualities of existing and new treatments, as well as to replicate surgical operations in clinical cases. It

Received: December 11, 2021
Accepted: January 26, 2022
Published online: March 28, 2022

Correspondence: Osman Civan, MD. Akdeniz Üniversitesi Tıp Fakültesi Ortopedi ve Travmatoloji Anabilim Dalı, 07070 Kampüs, Antalya, Türkiye.

E-mail: civanosman@gmail.com

Doi: 10.52312/jdrs.2022.516

Citation: Öten E, Civan O, Uğur L. Traction therapy in lumbar disc hernias: A finite element analysis study. Jt Dis Relat Surg 2022;33(1):86-92.

©2022 All right reserved by the Turkish Joint Diseases Foundation

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes (http://creativecommons.org/licenses/by-nc/4.0/).

can also be used as an alternative to investigations that are costly, need specialist equipment for implementation, or involve animals or cadavers that are morally sensitive.[9,10]

In the present study, we aimed to examine the biomechanical results of lumbar traction therapy with FEA at different traction angles and different traction forces. Changes in lordotic angle, intradiscal pressure (IDP), and maximum stress values in the annulus fibrosus were compared in terms of different traction angles and different traction forces. In addition, the average stresses on the fibers of the annulus fibrosus were calculated.

MATERIALS AND METHODS

Creation of the intact models

In this study a three-dimensional (3D) non-linear FEA of the lumbosacral spine was developed. In our study, computed tomography (CT) image of a 35-year-old healthy man in a supine position (height: 172 cm, weight: 71 kg) was examined. The CT images were obtained by scanning at 135 kV at a pixel size of 0.625 mm and resolution of 512×512 pixels. The patient without spine injury, osteoporosis, and radiographic fracture history were used to create the 3D geometry of the spine.

Images were captured in Digital Imaging and Communications in Medicine (DICOM) format. A software, Materialize Mimics® (Materialise Interactive Medical Image Control System, Materialize NV, Belgium) was used for the visualization and segmentation of the 3D dimension of CT images. The resulting 3D spine model was exported as stereolithography (STL) files from Mimics software. More detailed 3D solid models were obtained by sending STL files to the reverse engineering software Geomagic Studio 12.0 (Geomagic Inc., Cary, NC, USA). The resulting 3D lumbar spine (L1-L5) and sacrum model were transferred to SolidWorks® (Dassault Systèmes, Waltham, MA, USA) program to create discs and ligaments.

As shown in Figure 1, the resulting spine model included six vertebrae, five intervertebral discs, and seven principal ligaments. Vertebrae consist of cortical and cancellous bone. Each intervertebral disc consisted of an annulus ground substance, annulus fibers, and nucleus pulposus. According to previous studies, the stiffness of the annulus fibers was increased from the center toward the outer region.[11] Initially, the IDP was set to zero. The seven main ligaments in the lumbar spine: posterior longitudinal ligament (PLL), interspinous ligament (ISL), intertransverse ligament (ITL), anterior longitudinal ligament (ALL), capsular ligament (CL), supraspinous ligament (SSL), and ligament flavum (LF) were attached based on anatomical information using tension-only truss elements.

Mesh and material properties

The lumbosacral spine model was submitted to ANSYS Workbench version 19 (Ansys Inc., Technology Drive, Canonsburg., PA, USA) to run the FEA. Mesh structures were created as shown in Figure 1. The material properties of the lumbosacral spine are given in Table I. The models are assumed to be homogeneous, isotropic, and linear elastic.[12-15]

Mesh properties

For the FEA of the prepared 3D lumbosacral spine model, the mesh structure was created as shown in Figure 1. The mesh quality was selected based on literature data, angle, skewness, concerning element size and aspect ratio. Mesh convergence was tested by reducing element sizes. Element dimensions for vertebrae and discs were determined as 2 mm and 1 mm, respectively. Additional mesh improvements were applied in the contact zones to achieve convergence.[16] The final FEA model

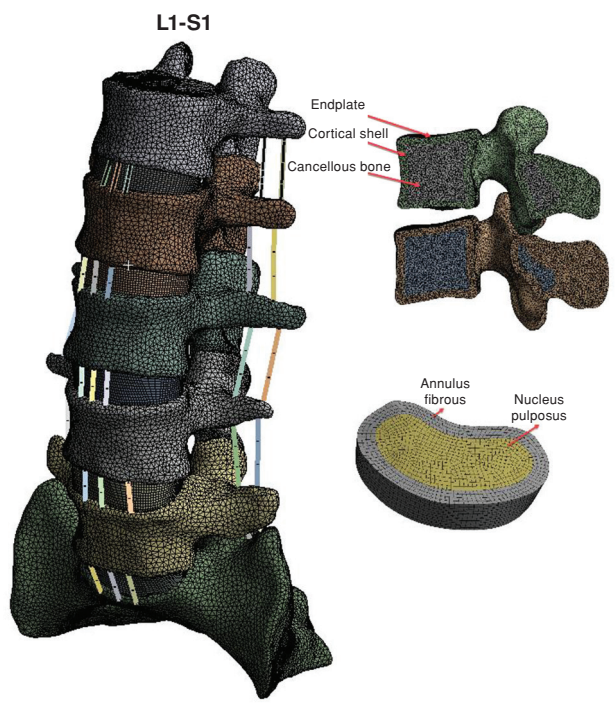


FIGURE 1. Three-dimensional nonlinear finite element analysis model of the human whole lumbosacral spine (L1-S1).

TABLE I
Material properties are used in the basic FEA model

Spinal site	Young's modulus (MPa)	Poisson's ratio	Density (g/cm^3)	Cross-sectional area, (mm^2)
Vertebrae				
Cortical bone	12,000	0.3	1.91	
Cancellous bone	100	0.2	1.87	
Cartilaginous endplate	23.80	0.4	1.0003	
Intervertebral disc				
Nucleus pulposus	0.2	0.49	1.0003	
Annulus ground	4.2	0.45	1.0003	
Annulus fibers	450	0.3	1.0003	0.15
Ligaments				
Anterior	20	0.3		63.7
Posterior	20	0.3		20
Flavum	19.5	0.3		40
Intertransverse	58.7	0.3		3.6
Interspinal	11.6	0.3		40
Supraspinal	15	0.3		30
Capsular	32.9	0.3		60

consisted of an average of 687514 element numbers and 1189462 nodes. Two nodes of each vertebra from the anterior-inferior and posterior-inferior corners in the sagittal plane were decided to measure the lordotic angles. The tilt angle of each vertebra was calculated from the coordinates of the two selected nodes. Next, the intersegment lordotic angle was calculated from the difference between the two inclination angles of the adjacent vertebrae (Figure 2a). The annulus fibers were partitioned into anterior, posterior, and lateral regions, and maximum von Mises stresses were recorded during traction (Figure 2b). All analyses were performed non-linear according to the Newton-Raphson method.[16]

Load and boundary conditions

The traditional device used in traction therapy consists of two main parts. With the help of the first piece, the upper part of the patient is fixed by using a thoracic belt and corset so that the body resistance does not oppose the applied force. Pulling is applied by moving the second part on the rail by applying force in the direction of the body inferior.[7] For the analysis of traction therapy, the upper surface of the

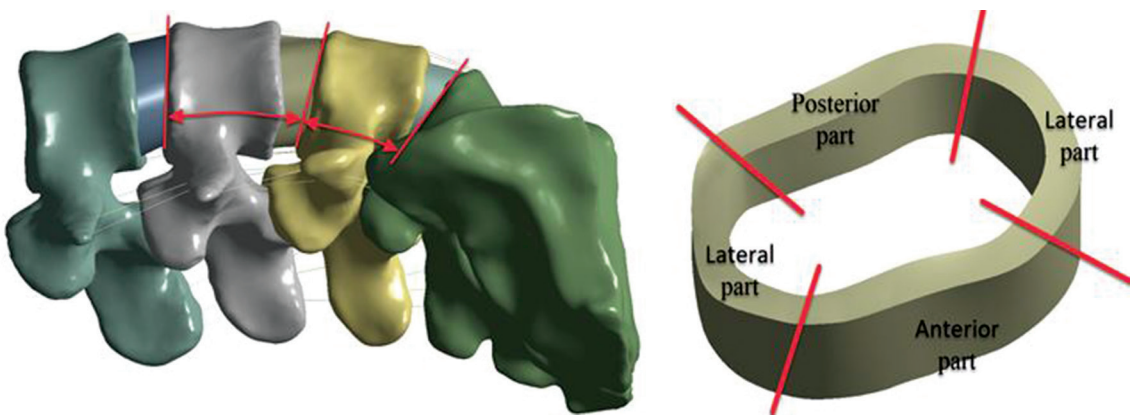


FIGURE 2. (a) Measurement of lordotic angle. **(b)** Partition of annulus fibers.

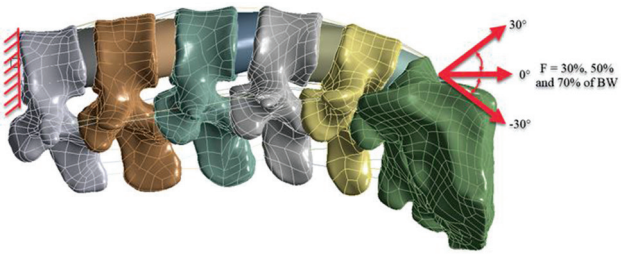


FIGURE 3. Boundary and load conditions of traction simulation.

L1 vertebra was fixed sport, since the upper part of the body was fixed. A force of 30%, 50%, and 70% of the body weight (BW) was applied from the center of the sacral surface to the lower side of the body. Loading angles were determined as 0° axial, 30° corpus, and -30° facet (Figure 3).

The study protocol was approved by the Amasya University Faculty of Medicine Clinical Trials Ethics Committee (No: 105). The study was conducted in accordance with the principles of the Declaration of Helsinki.

RESULTS

In this study, L4-L5 and L5-S1 segments were evaluated according to the following criteria: *(i)* lordotic angle, *(ii)* IDP, *(iii)* stress of annulus fibers.

Lordotic angle

In the initial model, the lordotic angle was measured as 16.81° in the L4-L5 segment and 21.82° in the L5-S1 segment. The changes in lordotic angles after loading with different angles and forces in the unloaded FEA model are shown in Figure 4. In the L4-L5 segment, non-significant change in the 0° axial direction and -30 facet direction were observed in lordotic angle at all traction forces applied. On the other hand, traction applied in 30° corpus showed a significant decrease in lordotic angle compared to 0° axial direction and -30 facet direction. When the L5-S1 segment was examined, no significant change was observed in the lordotic angle compared to the baseline in all traction applications.

Intradiscal pressure

The initial IDP at each model was assumed to be zero. Comparison of IDP at different traction angles and different traction forces is seen in L4-L5 and L5-S1 segments in the lumbar spine (Figure 5). The IDP values decreased in proportion to the applied force when traction was applied in the 0° axial direction and 30° corpus direction. However, no significant change in IDP was observed at the applied forces in the -30° facet direction.

Stress of annulus fibers

As seen in figure 6, the maximum stress in the annulus fibers increased in traction treatment applied in different directions and forces. As a result of the analyses, the maximum stress occurring in the posterior annulus fibers in the L4-L5 segment occurred at 30% BW and 50% BW traction forces in 0° axial direction, and 70% BW traction force in 30° corpus direction. In addition, the distribution

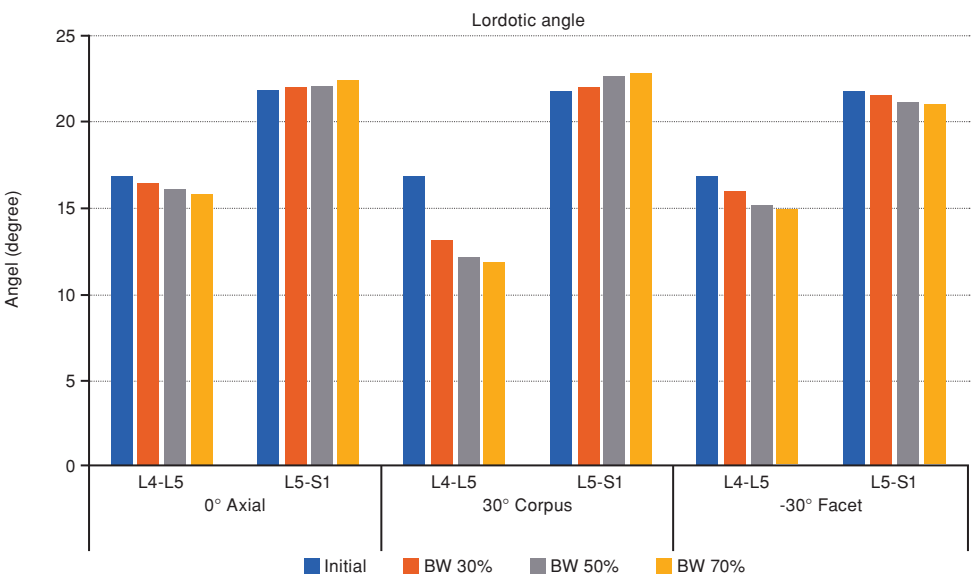


FIGURE 4. Changes in the lordotic angle.
BW: Body weight.

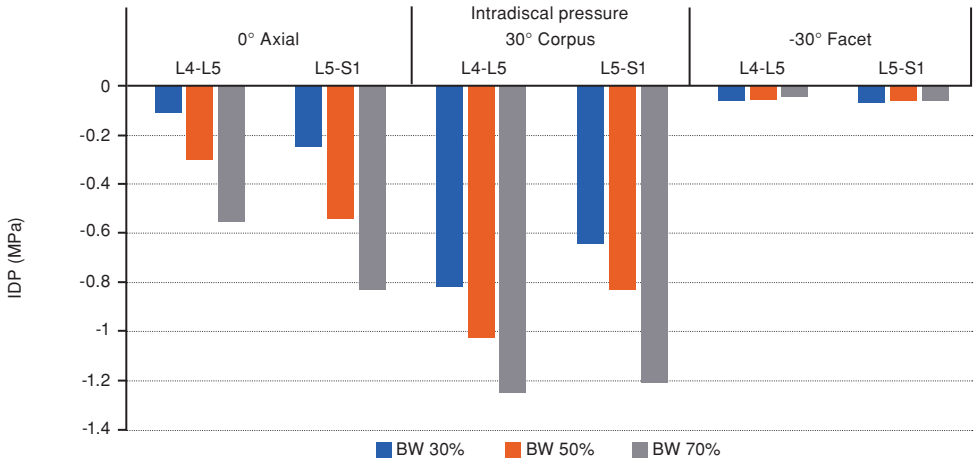


FIGURE 5. Changes in intradiscal pressures.
BW: Body weight.

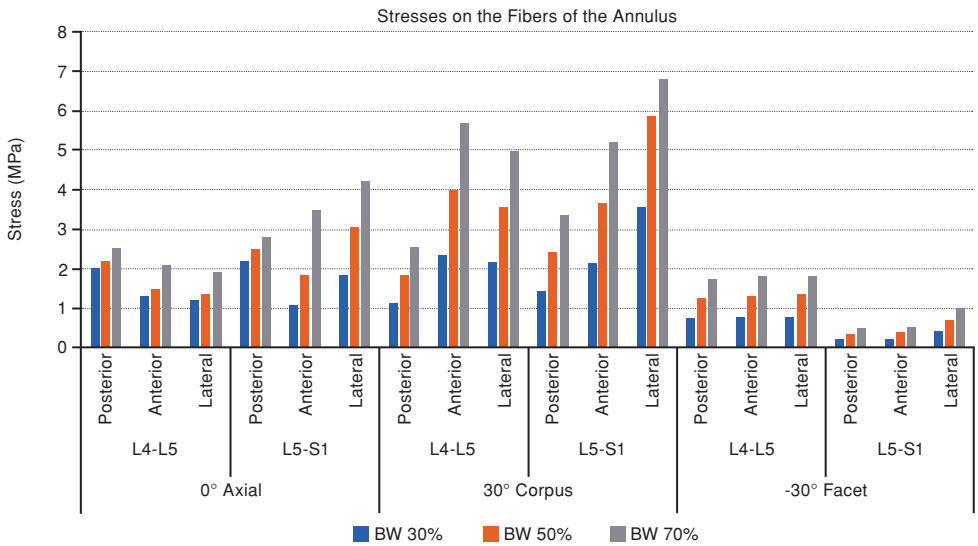


FIGURE 6. Maximum stresses on the fibers of the annulus fibrosus.
BW: Body weight.

of stress occurring in the 0° axial traction and the annulus regions (anterior, posterior, and lateral) in this segment was close to each other. In the L5-S1 segment, at 30% BW and 50% BW traction forces, the maximum stress on the posterior annulus fibers was in the traction applied in the 0° axial direction. Also, 30° corpus traction force was observed to have higher tensions in posterior annulus fibers than in 0° axial and -30° facet directions at 70% BW conditions. Notwithstanding, the maximum stress on the anterior and lateral annulus fibers was significantly higher in the traction forces applied to the L4-L5 and L5-S1 segments in the direction of the 30° corpus.

DISCUSSION

Traction is widely used in the treatment of disc herniations in the clinic. Lumbar disc herniation is most commonly seen in the L4-L5 and L5-S1 segments.[17] There are many clinical and biomechanical studies examining traction therapy.[5,6] However, there is no other study evaluating the changes in stresses on annulus fibers, lordotic angle and IDP during traction

treatment at different angles and strengths applied from the lower part of the body to the distal.[18] Therefore, this study biomechanically examined the effectiveness of lumbar traction therapy in L4-L5 and L5-S1 segments in different directions and forces using the FEA.

According to the results of the current study, while lordotic angle changed in L4-L5 and L5-S1 segments, IDP decreased in all traction treatments. Annulus fibers were under tensile stress during traction. Since the stress increase in posterior fibers is undesired due to the risk for annular tear or extension of the present tear, the traction force direction and magnitude must be selected according to the effect of stress rise at posterior fibers. The FEA results obtained as a result of the analyses can provide an understanding of the effectiveness of traction therapy. In addition, it can help to prevent soft tissue injuries that may be caused by the direction and severity of force to be applied during the treatment.

The IDP measurement is one of the most appropriate methods to evaluate spinal loading.[19] Mechanical loads change the IDP. Therefore, it directly affects the stresses experienced by the annulus fibrosus.[20] As a result, the annulus fibers are damaged and cause herniation. In order for the hernia to be retracted, the IDP must decrease. In addition, IDP decompression assists the retraction of the hernial disc. It also improves the nutrition of the disc and regulates the chemical environment of pain receptors in the annulus.[21,22] Park et al.[5] performed assisted and unassisted axial traction analyses in their biomechanical study. In the aforementioned study, IDP values decreased in all segments as a result of unassisted traction. Non-significant IDP changes were observed in traction forces in the -30° facet direction in segments L4-L5 and L5-S1 in our study. In addition, IDP decreased significantly at all forces when traction was applied in the 30° corpus and 0° axial directions. However, more significant IDP reduction was observed in the 30° corpus direction.

The lordotic angle decrease is not the desired result while applying traction for LDH. The more lordosis occurs with the traction the more nucleus pulposus material shifts anteriorly which would release the lumbar spinal roots of the herniated nucleus material. When the L4-L5 segment was examined, the alterations in the lordotic angle in the traction forces in 0° axial direction were non-significant. In the traction applied in the 30° corpus and -30° facet direction, a magnificent decrease in lordotic angle compared to the 0° axial direction was observed. No decrease in lordotic angle was observed in the forces applied in 0° axial direction and 30° corpus direction in L5-S1. However, the lordotic angle was decreased in -30° facet direction.

This study was divided into regions to better evaluate the stress distribution occurring in the annulus fibers. The annulus fibers were divided into anterior, posterior, and lateral, respectively. There was less angle change in traction applied in the 0° axial direction in the lordotic angle in the L4-L5 segment. Therefore, the stress distribution occurring in the annulus regions (anterior, posterior, and lateral) in the traction applied in the 0° axial direction in the L4-L5 segment was similar to each other. In addition, a significant reduction in IDP was obtained. Similarly, the stress distribution in the annulus regions was observed close to each other in the traction applied in the -30° facet direction while a non-significant change occurred in IDP. Although a significant decrease was observed in IDP in traction applied in the 30° corpus direction, it was noticed that the change in lordotic angle was high. Therefore, the stress distribution occurring in the anterior and lateral regions of the annulus fibers was high. For L5-S1 segment the lordotic angle was similar to the initial value in all traction directions and forces, but the tension in the lateral and anterior annulus fibers was greater in the traction applied in the direction of the 30° corpus. The stress of posterior annulus fibers increased most with 30° corpus direction; however, it seemed to be in between acceptable limits with 30% and 50% BW traction amount. In addition, there was no significant change in IDP in the traction applied in the -30° facet direction.

There are some limitations to this study. Although FEA is a useful tool for understanding the mechanical behavior of biological materials, it is susceptible to a variety of errors that may occur throughout the computerized analysis process.[23] The simplified modeling used in this study may not accurately portray the lumbar region's complicated structure. Material attributes and boundary conditions have also been described using various assumptions. Due to the limitations of FEA, outputs may not accurately reflect real-life situations; nonetheless, even approximate results can provide useful information.

In conclusion, FEA was used to evaluate the biomechanical effects of different traction forces applied in the 0° axial, -30° facet and 30° corpus directions on L4-L5 and L5-S1 segments in this study. Traction forces applied in the 0° axial direction decreased the IDP pressures by creating similar tensile stress in the annulus regions

(anterior, posterior and lateral) without a significant change in the lordotic angle. However, as it does not reduce the lordotic angle in the L4-L5 segment, a 70% BW force can be applied in the -30° facet direction. Also, traction therapy can be applied for the L5-S1 segment at 30° corpus direction and 30% BW traction force. The method we used in our study may be useful in examining the effectiveness of traction therapy. In addition, the effectiveness of the treatment can be increased by determining the traction force and direction specific to the individual by using magnetic resonance imaging or CT images in traction therapy.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

REFERENCES

1. Diab AA, Moustafa IM. Lumbar lordosis rehabilitation for pain and lumbar segmental motion in chronic mechanical low back pain: A randomized trial. J Manipulative Physiol Ther 2012;35:246-53.
2. Gagne AR, Hasson SM. Lumbar extension exercises in conjunction with mechanical traction for the management of a patient with a lumbar herniated disc. Physiother Theory Pract 2010;26:256-66.
3. Gay RE, Brault JS. Evidence-informed management of chronic low back pain with traction therapy. Spine J 2008;8:234-42.
4. Kurutz M, Oroszváry L. Finite element analysis of weightbath hydrotraction treatment of degenerated lumbar spine segments in elastic phase. J Biomech 2010;43:433-41.
5. Park WM, Kim K, Kim YH. Biomechanical analysis of two-step traction therapy in the lumbar spine. Man Ther 2014;19:527-33.
6. Farajpour H, Jamshidi N. Effects of different angles of the traction table on lumbar spine ligaments: A finite element study. Clin Orthop Surg 2017;9:480-8.
7. Tadano S, Tanabe H, Arai S, Fujino K, Doi T, Akai M. Lumbar mechanical traction: A biomechanical assessment of change at the lumbar spine. BMC Musculoskelet Disord 2019;20:155.
8. Tanabe H, Akai M, Doi T, Arai S, Fujino K, Hayashi K; for Low back-pain Traction Therapy (LTT) Study. Immediate effect of mechanical lumbar traction in patients with chronic low back pain: A crossover, repeated measures, randomized controlled trial. J Orthop Sci 2021;26:953-61.
9. Kılıçaslan ÖF, Levent A, Çelik HK, Tokgöz MA, Köse Ö, Rennie AEW. Effect of cartilage thickness mismatch in osteochondral grafting from knee to talus on articular contact pressures: A finite element analysis. Jt Dis Relat Surg 2021;32:355-62.
10. Ye Y, You W, Zhu W, Cui J, Chen K, Wang D. The applications of finite element analysis in proximal humeral fractures. Comput Math Methods Med 2017;2017:4879836.
11. Schmidt H, Heuer F, Simon U, Kettler A, Rohlmann A, Claes L, et al. Application of a new calibration method for a three-dimensional finite element model of a human lumbar annulus fibrosus. Clin Biomech (Bristol, Avon) 2006;21:337-44.
12. Natarajan RN, Watanabe K, Hasegawa K. Biomechanical analysis of a long-segment fusion in a lumbar spine-a finite element model study. J Biomech Eng 2018;140.
13. Xu G, Fu X, Du C, Ma J, Li Z, Tian P, et al. Biomechanical comparison of mono-segment transpedicular fixation with short-segment fixation for treatment of thoracolumbar fractures: A finite element analysis. Proc Inst Mech Eng H 2014;228:1005-13.
14. Park WM, Park YS, Kim K, Kim YH. Biomechanical comparison of instrumentation techniques in treatment of thoracolumbar burst fractures: A finite element analysis. J Orthop Sci 2009;14:443-9.
15. Su Y, Wang X, Ren D, Liu Y, Liu S, Wang P. A finite element study on posterior short segment fixation combined with unilateral fixation using pedicle screws for stable thoracolumbar fracture. Medicine (Baltimore) 2018;97:e12046.
16. Workbench A. ANSYS Viewer 18.2 User's Guide. Canonsburg, PA: Ansys Inc; 2017.
17. Xu DR, Song YD, Wang H, Li SG. Meta-analysis of lumbar disc herniation in Chinese adolescents. Zhonghua Yi Xue Za Zhi 2013;93:3606-9.
18. Atik OŞ. What are the expectations of an editor from a scientific article? Jt Dis Relat Surg 2020;31:597-8.
19. Guehring T, Unglaub F, Lorenz H, Omlor G, Wilke HJ, Kroeber MW. Intradiscal pressure measurements in normal discs, compressed discs and compressed discs treated with axial posterior disc distraction: An experimental study on the rabbit lumbar spine model. Eur Spine J 2006;15:597-604.
20. Noguchi M. Examining changes in intradiscal pressure during intervertebral disc herniation. [Master Thesis] Ontario, Canada: University of Waterloo; 2013.
21. Cox JM. Low back pain: mechanism, diagnosis and treatment. Philadelphia: Lippincott Williams & Wilkins; 2012.
22. Kuo YW, Hsu YC, Chuang IT, Chao PH, Wang JL. Spinal traction promotes molecular transportation in a simulated degenerative intervertebral disc model. Spine (Phila Pa 1976) 2014;39:E550-6.
23. Cheung JT, Zhang M. A 3-dimensional finite element model of the human foot and ankle for insole design. Arch Phys Med Rehabil 2005;86:353-8.