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Investigation of postero-anterior mobilization in the lumbar spine: A finite element analysis study

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Ethics Committee Approval
Approval for the study was obtained from the Clinical Research Ethics Committee of Amasya University with the decision numbered 14.
All procedures in this study involving human participants were performed in accordance with the 1964 Helsinki Declaration and its later amendments.

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Abstract

Background/Aim: Postero-anterior (PA) mobilization is a non-invasive treatment method traditionally used to treat low back pain (LBP) in many countries. However, the effects of PA mobilization on lumbar spine biomechanics are still unknown. The aim of this study is to determine the maximum von Mises stresses on the lumbar vertebra (L5), with force applied at different angles during PA mobilization therapy using finite element analysis (FEA).
Methods: L5 vertebra CT images of a 34-year-old male patient were modeled in three dimensions (3D) with MIMICS software to examine the PA mobilization biomechanics. The resulting L5 spine model was submitted to the finite element software ANSYS (version 19) to evaluate the effects of PA mobilization. To simulate PA mobilization on the L5 vertebra, a static force of 100 N was applied over the spinal process in three different directions. The distribution of von Mises stresses occurring in the L5 spine was determined in the analyses.
Results: During PA mobilization, the stress distributions on the vertebra caused by the static force applied in three different directions in the L5 vertebra spinal process was determined. As a result of the analysis, higher stress values were found in the posterior elements of the vertebra in all directions compared to the vertebral corpus. However, when compared according to the direction of application, the lowest stress values were detected in the pedicles and laminas in PA mobilization applied toward the spine center.
Conclusion: Vertebral pedicles, laminae, and spinous process are critical areas prone to fracture. It was argued that the change in the direction of PA mobilization applied in the L5 vertebral spinal process affects the von Mises stress distributions occurring in the pedicles and laminae.

Keywords: Postero-anterior mobilization, Finite element analysis, Lumbar vertebra

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Introduction

Lower back pain (LBP) is one of the most prevalent health issues referred to doctors [1]. Approximately 40% - 70% of the global population experiences at least one LBP attack during their lifetime [2]. LBP can be caused by problems with any part of the spinal muscles, ligaments, bones, discs, and nerves in the lumbar spine that may be interrelated [3]. Conservative treatment of low back pain consists of medical therapy, electrotherapy, exercise therapy, and manual therapy.

Manual therapy is a widely used clinical technique for diagnosing and treating human joints and soft tissues [4, 5]. This involves massage, mobilization, and manipulation [6]. Postero-anterior (PA) mobilization is a low-speed passive movement technique used in physical therapy. One of the manual therapy procedures, PA vertebral mobilization, can be used to evaluate and treat patients with low back pain. This procedure involves posterior-to-front movements that occur with the application of manual force applied to a single vertebra above or lateral to the midline [7]. Pain relief, reduced spinal stiffness, and increased spine range of motion are all benefits of PA mobilization [8-10].

PA mobilization is performed on the vertebra in different directions and with different force, increasing the stress within the bone tissue. However, the processes underlying the effect of PA lumbar mobilization on the vertebra remain unclear. We can use finite element analysis (FEA), which has become popular in recent years, to better understand lumbar biomechanics, make better choices, and formulate therapeutic decisions. It can be used as a non-invasive method to evaluate the biomechanical efficacy and properties of new and existing treatments [11, 12]. In addition, there are a limited number of studies in the literature evaluating the biomechanical effects of PA mobilization [13]. The force applied in the PA mobilization studies was generally applied in one direction [13, 14]. However, since mobilization is a dynamic process, changes in the direction of application force may occur during treatment. For this reason, the aim of our study is to investigate the effect of static force applied at different angles during PA mobilization on L5 vertebra geometry using the FEA method.

Materials and methods

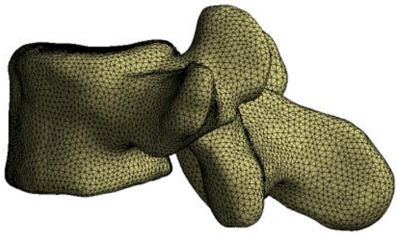
Creation of the 3D model

The anatomical geometry of the L5 vertebra was obtained from a computed tomography (CT) scan of a 34-year-old healthy male patient (height: 175 cm, weight: 74 kg) without osteoporosis or previous history. Approval for the study was obtained from the Clinical Research Ethics Committee of Amasya University with the decision numbered 14. The research was carried out in conformity with the principles of the Helsinki Declaration. CT images were recorded in the Digital Imaging Communication in Medicine (DICOM) format from a Toshiba Aquilion CT scanner at the Department of Radiology, Faculty of Medicine, Amasya University. Images were acquired at 135 kV with a pixel size of 0.625 mm and a resolution of 512×512 pixels. The resulting images were segmented using MIMICS 12 (Materialise, Leuven, Belgium) 3D image processing software and the L5 vertebra were modeled in 3D. The geometries were converted to stereolithography format with MIMICS software and sent to reverse engineering software Geomagic Studio 12.0 (Geomagic, Cary, North Carolina, USA) in order to edit the surface defects in the modeled vertebra and obtain the correct geometry. The resulting 3D model was transferred to ANSYS Workbench for FEA.

Mesh and properties of material

The L5 vertebra model tetrahedral mesh structure was created using ANSYS Workbench (Version 19.0) software, as shown in Figure 1. For mesh convergence, the element size in the 3D model was increased by 0.2 from 0.2 mm spacing to 3 mm. For bone structures, Solid187 tetrahedron element types and mesh size of 1.2 mm were selected. Our models consisted of 46,2471 nodes and 327,788 elements. The material properties of L5 vertebra are defined as linear elastic and isotropic. Cortical and trabecular bones have Young's modulus values of 12.0 GPa and 100 MPa, respectively. The Poisson ratio was chosen as 0.3 for cortical bone and 0.45 for trabecular bone [15-18]. Nonlinear analyses were performed according to the Newton-Raphson method.

Figure 1: Mesh structure of the model



Boundary conditions

This study simulated static loading applied on L5 vertebra in different directions during PA mobilization. The lower endplate and upper endplate of the vertebra were considered fixed. To simulate PA mobilization, a force of 100 N was applied from the spinal process toward the lower endplate (Figure 2a), toward the center of the corpus (Figure 2b), and toward the upper endplate (Figure 2c).

Figure 2: The loading and boundary conditions a) toward the lower endplate b) toward the center of the corpus c) toward the upper endplate

a

b

c

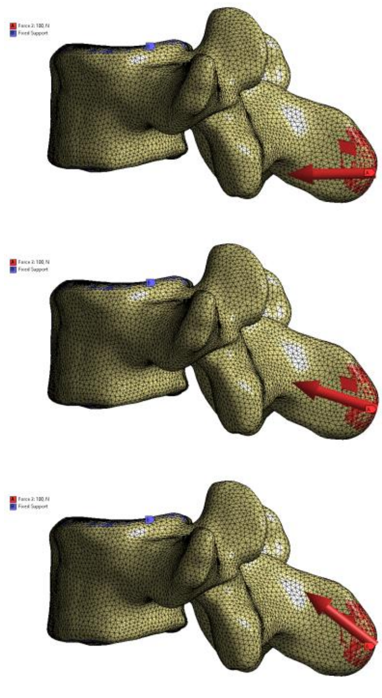
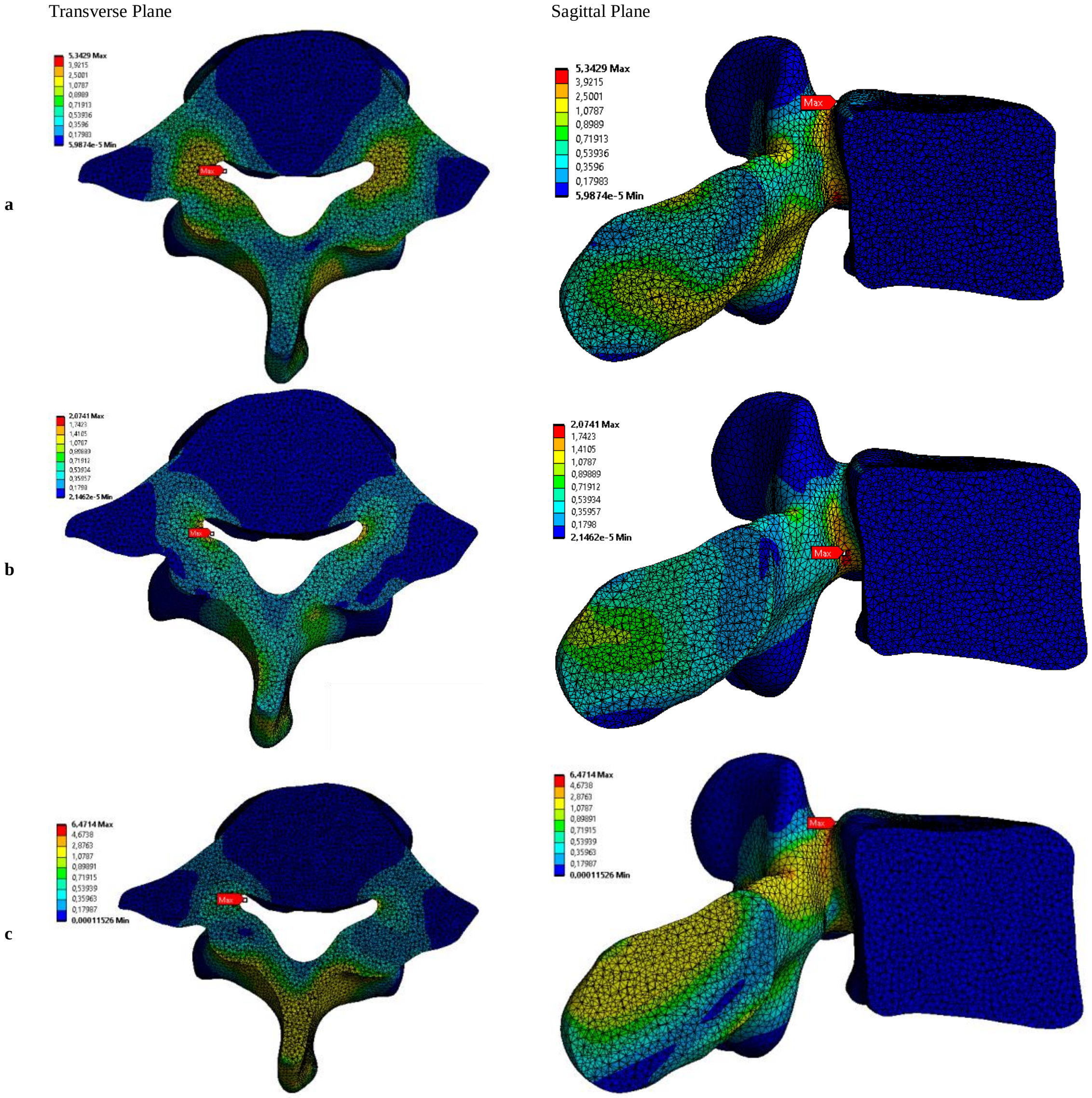


Figure 3: Stress distributions in the transverse and sagittal planes as a result of the analyses a) toward the lower endplate b) toward the center of the corpus c) toward the upper endplate



Results

Stress distributions occurring in the L5 vertebra during PA mobilization therapy, which is widely used in the treatment of LBP, were determined using the FEA method. Stress distributions occurring on the L5 vertebra under loads applied at different angles were performed on the transverse and sagittal planes as seen in Figure 3.

When the analyses were examined, the maximum stress values according to the force directions were obtained as 5.3429 MPa when applied toward the lower endplate, 2.0741 MPa when applied toward the center of the corpus, and 6.4714 MPa when applied toward the upper endplate. In addition, it was observed that the maximum stress was on the pedicles in all models. However, it was noted that the force applied in the direction of the upper and lower endplate of the maximum stress was in the upper part of the pedicles, and the force applied in the direction of the corpus was in the central part of the pedicles.

Discussion

There are a limited number of studies examining the effects of PA mobilization on the vertebra, and the biomechanical results remain unclear. In our study, the effect of PA mobilization applied in different directions on the geometry of the L5 vertebra on the maximum stresses occurring in the anatomical parts of the vertebra was investigated using finite element analysis.

Mobilization is a complementary and alternative medical practice that is widely used mainly for spine and soft tissue treatment [19]. Mobilization consists of low-speed, variable-intensity, repetitive passive movements within the range of normal joint motion [20]. There are many specific mobilization techniques that vary according to patients' needs. However, the forces and directions applied during these spinal techniques may vary among clinicians depending on the treatment area and patient characteristics [21]. In addition, it is not fully known whether clinicians adhere to mobilization techniques in daily practice [22]. Various complications may develop during treatment sessions for low back and neck pain. Reported complications have included disc herniation, vertebral fracture, and cervical arterial strokes [23-25]. It is important to determine the intensity and direction of the force to be applied in order to prevent possible complications.

In our study, with the application of static 100 N force in three different directions, it was observed that there were more stress distributions in the posterior elements of the L5 vertebra, consisting of the spinal process, laminas and pedicles, compared to the corpus. Boonyoung et al. [14] found that the lumbar vertebral pedicle and lamina regions of an elderly male patient were susceptible to fracture. They also showed that in severe osteoporosis, not only the pedicles, but also the spinal process is a high-risk fracture site. Another in vivo study has shown that the spinous process is displaced anteriorly during PA mobilization [26]. As a result, more loading occurs on the pedicles during the anterior movement of the spinous process. In our study, the highest maximum stress values were observed especially in the pedicles, which act as a bridge in connecting the posterior bone components and the corpus. Therefore, pedicles are critical structures during mobilization.

One of the most important results of our study is that after force was applied from the spinal process to the center of the corpus, the maximum tension in the pedicles was found to be significantly lower than the forces applied in the upper and lower endplate directions. This information can be helpful in preventing complications that may develop during vertebral mobilization applications, especially in high-risk patients. In addition, changes in the direction of the force applied during PA mobilization significantly affect the stress distributions created by the vertebra on the bone elements. Thus, effective and appropriate use of power can be ensured and the success of the treatment can be achieved.

Limitations

Our study has several limitations. First, the material properties of bone are defined linearly. Secondly, real environment experiments were not carried out. Disc and vertebral ligaments were not included in our model. Therefore, it may not clearly reflect the complex structure of this region. In addition, only static loading was applied in our study. However, both static and dynamic loads occur during PA mobilization. Due to the limitations of FEA, outputs may not accurately reflect real-life situations; however, even approximate results can provide useful information.

Conclusion

In this study, we investigated the stress distributions that occur after force is applied at different angles over the L5 spinal process. It was observed that loading applied at different angles can increase the maximum tension, especially in the pedicles. It was found that as a result of the force applied toward the center of the corpus, less stress was created than in other directions. These results are important in terms of predicting and preventing damages that may occur in the vertebra during mobilization. They can also be used to increase the effectiveness of treatment.

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