

Research on Simulation and Prediction of Spinal Sports Injury Based on Finite Element Analysis

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Abstract

Objective: The objective of this investigation is to assess the material qualities of lumbar vertebrae and their influence on biomechanical characteristics. **Methodology:** The study examined four distinct sets of material qualities, which were characterised by different values of Young's modulus and Poisson's ratio for both trabecular and cortical bone. The analysis focused on examining the impact of different material property sets on stress distribution, displacement, and strain patterns. In order to substantiate the results, a three-dimensional model of the lumbar vertebrae was generated utilising computed tomography (CT) data and subsequently submitted to finite element analysis. **Results:** The findings of the study are as follows: The findings of the study indicated that there were discernible variations in stress distributions across different material property sets. Specifically, it was consistently observed that areas 2 and 3 displayed elevated stress values compared to other regions. The study observed a decrease in maximum displacement as the material features were stiffer. Specifically, Set 4 exhibited the lowest displacement while Set 1 exhibited the most. While there were certain changes in strain patterns among different material property sets, these variations were not as substantial when compared to the distributions of stress and displacement. The investigation underscored the notable impact of material attributes on the biomechanical characteristics of lumbar vertebrae. Increased material strength led to elevated stress concentrations and decreased displacements. The findings also demonstrated that there was no stress observed in any of the vertebrae. However, it was observed that Set 2 had the highest pressure value. Comprehending the impact of material qualities on the biomechanics of lumbar vertebrae is of paramount importance in the development of efficacious interventions and preventative strategies for disorders pertaining to the spine. **Conclusion:** In conclusion, the Young's modulus and Poisson's ratio were found to be significant factors in determining stress concentration and displacement. Specifically, lower values of Poisson's ratio and Young's modulus were observed to correspond to increased stress concentration and decreased displacement.

Keywords: Material Properties, Biomechanical Behavior, Lumbar Vertebrae, Stress Distribution, Displacement, Strain Patterns.

INTRODUCTION

The finite element method (FEM) is a computer simulation methodology that was developed to tackle challenges in the fields of civil and aeronautical engineering. FEM applications have been utilised across various medical disciplines. Finite Element Method (FEM) has emerged as a valuable tool in the field of orthopaedic surgery, facilitating a more comprehensive comprehension of the biomechanics involved in both normal and pathological bodily movements. Furthermore, it prevents potential ailments caused by an imprudent implantation site by assessing changes in mechanical pressure distribution

throughout the implanted regions. In the 1970s, Finite Element Method (FEM) was employed for the first time in the field of muscular biomechanics to calculate skeletal stresses, exhibiting a remarkable advancement in terms of timeliness. Furthermore, the Finite Element Method (FEM) was employed with a specific focus on bone remodelling throughout the period spanning from 1980 to

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1990. Advancements in the field of computational science and technology have facilitated the examination and analysis of complex topics, such as spinal abnormalities, which were previously challenging to investigate. The initial launch studies in 1957 involved the delivery of the primary spine model. Since then, numerous spring-mass models have been developed, which also incorporate dampers to represent intervertebral discs.^[1-3]

The fundamental elements responsible for inflicting injuries in sports contribute to the formation of a unified power vector. There are three primary damage mechanisms that should be taken into account: (1) the application of pressure or compression on the spine due to external weight; (2) the application of force or rotation, which can result in shear forces in a horizontal plane; and (3) the generation of elastic strain caused by excessive movement of the spine. Aerobatics, artistic dance, dance, pole vaulting, and trampolining are physical activities that include the use of the spinal column for stability and movement. Direct effects have the potential to cause specific injuries. In sports such as football, it is well-documented that injuries involving muscle wounds, severe sprains, and fractures of the ligaments, tendons, and even muscles are commonly observed. Spondylolysis may occur during acrobatics due to the excessive extension of the spine. Ballet dancers may be susceptible to lumbar strain, particularly when performing the arabesque stance, as well as spondylolysis. Compressive injuries are commonly observed among weightlifters. In the context of football, it is possible for several injuries to occur, including transverse process fractures, disc injuries, and contusions resulting from strikes to the helmet. The occurrence of back pain is frequently reported by individuals engaged in running activities. Disc degeneration and back discomfort are commonly observed among golfers. Engaging in the sport of tennis has been associated with the potential occurrence of back discomfort, as indicated by several sources.^[3-7]

Spinal cord injury (SCI) is a significant physical condition that has a profound impact on an individual's overall health and quality of life. Therefore, the importance of preventive medication has emerged within the spinal cord injury (SCI) community. Gaining insight into the factors contributing to spinal cord injury (SCI) is a fundamental preliminary step in formulating effective preventive strategies. According to a 2011 update to an epidemiological study, there is an annual occurrence of 179,312 new cases of severe spinal cord injury (TSCI), equating to a rate of 23 cases per million individuals. Certainly, although falls and motor vehicle accidents have been established as the most prevalent causes of traumatic spinal cord injury (SCI), it is noteworthy that sports-related injuries can significantly contribute to the occurrence of SCI.^[7-11]

Although spinal cord injuries related to sports activity are infrequent, they are not unprecedented. The involvement in sports has been shown to play a significant role in

promoting physical well-being and overall welfare. According to a survey published by the World Health Organisation in 2003, engagement in sports and physical activity was found to promote healthier eating habits while simultaneously discouraging the use of tobacco, alcohol, and illicit substances. The demonstration of sport dedication has been observed as a means to promote social interaction, provide fundamental support, and foster a sense of belonging within clubs and organisations. According to data from 2003, approximately 28% of Canadians participated in a single gathering, which was considered to be one of the most prominent social movements at the time. Given this perspective, it appears peculiar to discontinue participation in sports in order to reduce the risk of sustaining a spinal cord injury (SCI). However, it should be noted that spinal cord injury also imposes a substantial financial burden on the patient, their family, and society, while also having a considerable impact on an individual's overall health. Based on a data from Canada, it is projected that there would be 1,389 severe spinal cord injuries resulting in hospitalisations, which will incur a total yearly economic burden of \$2.67 billion. The financial burden incurred over the course of a lifetime for each individual suffering from a severe spinal cord injury (SCI) varies between \$1.5 million and \$3 million. In addition to the initial emotional impact, it is evident that the presence of various medical conditions significantly diminishes the subjective well-being of individuals with spinal cord injuries (SCI) and poses significant challenges to the prevailing medical framework.^[11-15]

A comprehensive comprehension of the epidemiology is vital due to the substantial psychological and physiological impacts that a spinal cord injury (SCI) imposes on the individual, as well as the societal expenses involved. A more comprehensive comprehension of the patterns and incidence rates will exert an influence on the development of preventive treatments for sport-related spinal cord injuries (SCIs). Stress fractures and the presence of intrinsic predispositions to stress fractures are frequently observed in adolescent athletes. Adolescent athletes are prone to two primary categories of injuries: overuse injuries, which arise due to repetitive micro trauma incurred during training, and acute injuries, which occur as a result of a single impact macro trauma.

The recognition, management, and prognosis following spinal cord injury are determined by the remarkable biomechanical and biochemical characteristics associated with each age group.^[15-18]

The occurrence of disc-related injuries can be attributed to various factors, including circle herniation, plate deterioration, and ultimately resulting in stenosis. The prevalence of these occurrences is highest in the lumbar spine, specifically at the L4-L5 and L5-S1 levels. However, they are also frequently observed in the cervical spine. Injuries to the intervertebral discs in the thoracic spine are an exciting area of study. Injuries resulting from flexion/

pivot movements or weightlifting can lead to circular lesions, while hyperextension can also result in cervical disc herniation at the C3-C4 area of the cervical spine. Axillary discomfort and impairment in spinal mobility are adverse symptoms associated with intervertebral disc disorders. Pain, dermatomal distribution, weakness, paresthesia, and numbness are the clinically evident psychological manifestations of radicular compression. The application of pressure on the spinal cord or nerves leads to the occurrence of neurological impairment.^[18-21] Injuries sustained during sporting activities involving motorised vehicles or boats can result in pressure ulcers that employ the technique of hub stacking. The act of rotating and bending the cervical and lumbar spine has the potential to cause a separation or fracture. In any scenario where one contender falls on another, it is possible for the falling competitor to have an uneven weight and sustain a thoracolumbar spine pivot injury. Rotational and shearing forces frequently impact the intervertebral disc. The innermost layers may initially undergo fragmentation or detachment from the surrounding underlying layers. Power is granted to the external layers through the process of weakening and fracturing said layers. The equipment in question may cause radial cracking of the intervertebral disc. The circular shape has the potential to restore itself over an extended period, contingent upon the establishment of a balanced equilibrium in biomechanical capacity. Due to the presence of a competitive form of spinal blockage, such as spinal stenosis, individuals engaged in activities involving stretching movements may experience an exacerbation of the prevailing pressure on the neurological structures, potentially leading to local and clinical inflammation. In cases when there is compression of a nerve root by a competitor, such as a herniated disc, engaging in workouts that include flexion may lead to increased strain on the affected nerve and perhaps exacerbate clinical symptoms. In the usual progression of radiculopathy resulting from a herniated disc, the exacerbation of back symptoms typically manifests as localised discomfort primarily in the lower extremities. This phenomenon exhibits distressing elements through actions that raise intraspinal pressure, such as coughing, sneezing, and prolonged sitting. During the objective examination, the patient reveals the presence of beneficial side effects associated with nerve elongation throughout the age range of 15 to 19 years.^[15-19] The source of the radicular pain that deviates from the aforementioned description is the radicular pain caused by spinal stenosis. The diagnosis of spinal stenosis often involves the identification of symptoms related to nerve compression, but it is characterised by a distinct clinical presentation known as neurogenic claudication, which refers to the experience of foot pain while walking. The discomfort persists beyond the present moment of cessation and is exacerbated by the elongation of the spinal column, while being ameliorated through flexion. The discomfort progresses from a location closer to the point of origin to a location further away.

Overall, common injuries experienced by athletes may include symptoms such as pain in the sacroiliac joint and discomfort in the prominent iliac spine region.

One common manifestation of this phenomenon is the irritation observed in the prolonged duration of the intervertebral disc and the neuromotor component of the spinal column. In comparison to the general population, the degeneration of the lumbar intervertebral discs in athletes is associated with movements that necessitate heightened physical exertion, excessive loading of the spine, and increased training duration. Notably, athletes exhibit a high incidence of disc degeneration.

Scholars endorse the conjecture that when athletes approach the limits of human physical capabilities in terms of endurance, power, and performance, the likelihood of sustaining injuries has significantly escalated. In general, lumbar disc herniation is more prevalent in athletes compared to the general population. Additionally, when symptoms first appear, the degeneration of the affected disc is more advanced in athletes than in the overall population. Muscular strength, steadfast determination, and muscular relaxation play a crucial role in the prevention of lumbar spine issues. The pelvic ischial tuberosity serves as the origin point for the posterior leg muscles. If these muscles are not adequately developed, they will exert forces that result in the pulling of the back ischial tuberosity and tilting of the pelvic region. Improper extension of the back muscles can lead the lumbar spine to assume a bent position, hence increasing the risk of bulging of the intervertebral disc ligament. Competitors may have pelvic instability and back pain as a result of suboptimal development of the gluteal muscles and increased tension in the back muscles. One significant financial challenge associated with spinal cord damage pertains to the cost of the prolonged healthcare system. The anticipated impact on both social and financial aspects should have been evident based on the long-term health outcomes, which contribute directly to costs, as well as the indirect costs associated with sports injuries, such as time off from work.^[19-23]

Sports accidents have a significant influence on the lives and well-being of athletes, particularly among the youth population. Even a minimal reduction in such incidences might potentially result in substantial long-term economic consequences, namely in terms of medical expenses. In order to enhance performance and mitigate the likelihood of accidents and injuries, it is imperative to incorporate active preventative measures into athletes' training protocols. The comprehensive evaluation of these actions necessitates the involvement of a multidisciplinary team of medical practitioners, physical therapists, coaches, trainers, and athletes. The study pertaining to the simulation and prediction of spinal sports injuries using finite element analysis has been undertaken.

LITERATURE REVIEW

Welch-Phillips *et al.*^[1]: This article presents a concise overview of the finite element analysis technique, along with

an introduction to the various preclinical mechanical tests that are now available. The utilisation of a computational technique known as restricted component inquiry enables the estimation of the response of varied materials to diverse applied forces. The utilisation of this approach has predominantly been employed in the realm of orthopaedic implant design and testing. With the continuous progress of technology, an increasing number of therapeutic applications are being developed, demonstrating potential in the realm of surgical planning and the capacity to tailor implants to individual patient characteristics.

Zhang *et al.*^[2]: In this study, a three-layer finite element (FE) model is employed to replicate the six potential movements of the lumbar spine. The objective is to investigate the biomechanical alterations of the lumbar segment in individuals with idiopathic scoliosis when subjected to various loadings. In order to replicate the biomechanical characteristics of lumbar scoliosis under varying loads, we developed a three-layer finite element model using basic computed tomography (CT) scan data of the L1-L5 areas in a patient with adolescent idiopathic scoliosis (AIS). The lumbar model was replicated using Mimics20.0, followed by smoothing using Geomagic2013. Solidworks 2020 was employed to assemble the model, and Workbench19.0 was utilised to conduct the finite element study. The previous model included of 223,805 hubs, 119,029 C3D4 strong components, and meticulously reconstructed tissue architectures. The range of motion (ROM) is reduced in patients with Adolescent Idiopathic Scoliosis (AIS) across all spinal curvatures. The absorption of pressure due to vertebral deflection is enhanced in the presence of a flexion load. In all scenarios, the pressure exerted within the L3 spinal curve is restricted to extension, horizontal torsion, and rotational loads specifically targeting the posterior part of the vertebral bodies. The disc's capacity to maintain rotational force is the least persuasive. The displacement of the AIS cluster has a significant role in determining the strength and stability of the vertebral body or intervertebral disc in various postures.

Chosa *et al.*^[3]: In order to assess the pressure of the interarticular region of the lumbar vertebra, biomechanical studies were conducted using a nonlinear three-layered limited component technique. These investigations involved applying pressure individually and in combination to simulate flexion, extension, rotation, and lateral bending movements. The researchers took into account the material nonlinearities of tendons and annular strands, as well as the contact nonlinearities of feature joints, when constructing a comprehensive three-layered model of the L4-L5 movement segment. The separation of cortical bone from cancellous bone was also taken into consideration for a more thorough analysis of both the posterior and anterior components. The interarticular standards mostly focused on pressure as a concern, but it shown greater concern when subjected to lateral bending loading, flexion, rotation, and extension under pressure. Nishida *et al.*^[4]: A three-layer limited component model

of restricted components was created to represent the cervical ligaments spanning from the second to the seventh vertebrae (C2-C7), utilising clinical photos. The author recapitulated his three models of delicate tissue injury in the C4-C5 region. There are three distinct categories of wounds that might occur: anterior longitudinal tendon wounds, posterior tendon complex (PLC) wounds, and intervertebral disc (IDI) injuries with associated anterior longitudinal tendon (IDI) injuries. A series of assessments were conducted via a specialised equipment to evaluate various mechanical factors, including range of motion, hoop stress, core pressure, and force. The apparatus applied a compressive bearing load to ensure accurate measurements. In contrast to the initial model, the IDI and API models demonstrated that the application of augmentation and left/right rotation resulted in an amplification of the ring and core stresses by over 50% at the damage plane. In addition to diffraction, the violation of the PLC did not result in any noticeable suffering to the flawless organism. In comparison to the other models, the IDI and API models exhibited a notable increase of over 100% in the aspect contact forces across all movements. Ng *et al.*^[5]: The aim of this study was to employ a high-quality digitizer in order to create a comprehensive, nonlinear, three-layered finite element model of the human lower cervical spine. The direct digitising strategy offers an alternative approach for creating a finite element model of the human cervical spine. The biomechanical response of the finite-element model was validated under axial compressive pressure, demonstrating a close agreement with published experimental data and other finite-element models. The results of the study also indicated that, when subjected to higher loads, the response of the cervical spine segment exhibits a non-linear pattern characterised by an increase in stiffness. The subsequent logical progression was doing parametric research, wherein the biomechanical response to alterations in the modelling techniques and mechanical properties of the disc annulus inside the finite-element model were analysed. The research findings indicate a strong correlation between the rigidity of the lower cervical spine and factors such as spinal structure and physical attributes. This relationship gives rise to diverse reactions in terms of force and displacement.

Li *et al.*^[6]: A minimally invasive spinal fixation system was developed, using the uniplanar pedicle screw with an innovative intermediate screw, resulting in a hybrid pedicle screw framework. The biomechanical performance of the component was assessed using a Finite Element (FE) analysis. In order to replicate the L1 spinal pressure fracture using Magerl's A1.2 classification, a finite element model of the T12-L2 region was generated. In order to replicate the phenomenon of back pedicle screw crack, a total of six models were created for the purpose of this study. The models were divided into two subgroups, each with distinct developmental configurations. The first grouping consisted of pedicle screw constructions including six monoaxial, uniplanar, polyaxial screws. The second subgroup comprised pedicle screw

builds with four monoaxial, uniplanar, polyaxial screws and an additional moderate screw. In order to examine the biomechanical performances of the six selected models, which exhibit the highest von Mises pressure, range of motion, and maximum vertebral displacement in flexion, extension, lateral bending, and axial rotation, a load of 7.5 Nm was applied for a duration of minutes, along with a preloading of 500 N vertical pressure, following the approval of the finite element models.

Punarselvam *et al.*^[7]: The aim of this job is to construct a cross-sectional model and mathematically replicate the intervertebral disc and two specific vertebrae (L4 and L5) within the human spinal column, while also considering their biomechanical characteristics. During the MRI scanning procedure, the bone sections are segmented, and afterwards, the boundary lines are layered to generate a cohesive and seamless surface. Furthermore, the proposed methodology produces an amount mesh which is subsequently subjected to agreement analysis utilising a linear unit. Furthermore, aside from the ligaments, the L4 and L5 with disc were considered to be linear materials. The initial condition of the lumbar spine in humans is characterised by the interaction between two bones, the coordinated movement of circular structures, and the subsequent changes in position and applied forces.

Zhang *et al.*^[8]: This review employed a restricted component technique to propose various treatment options for scoliosis. Specifically, it aimed to estimate the potential effects of unwrapping the iliotibial band on the pressure exerted on the lumbar spine in individuals with scoliosis. In this section, we will discuss the methods employed in this study. The construction of lumbar scoliosis, characterised by a Cobb angle measurement of 43° and a lordosis angle measurement of 45°, was performed utilising computed tomography (CT) scans obtained from patients diagnosed with lumbar scoliosis. The juvenile index of the medial lumbar iliotibial band (ITL) exhibited a significant reduction of 95%, potentially indicating suboptimal tendon maturation. The present study aimed to investigate the impact of medial intertransverse ligament (ITL) unwrapping on

the mechanical properties of the lumbar spine affected by scoliosis. Specifically, the study focused on discerning the pressure conditions within a model vertebral body in the absence of tendon unwrapping.

Meng *et al.*^[9]: This review examines the effects of gravity force, erector spinae muscle strength, expulsion tension, and shear pressure on the lumbar spine of a labourer. The analysis utilises anthropometry and statics theory to develop a three-layered finite element model of the lumbar spine. By employing the finite element method, stresses in the lumbar vertebrae and intervertebral discs are simulated for a labourer in a lifting posture. This model serves as a quantitative reference for further investigation.

Chun-yu *et al.*^[10]: In this study, a comprehensive cervical spine model consisting of three layers was developed utilising CT-assisted 3D insertion procedures in a cohort of healthy adult individuals. The restricted component model is employed to replicate three features of the design and properties of the cervical spine. The design of the cervical spine is complete, with its constituent pieces exhibiting satisfactory quality. Furthermore, the model demonstrates a high degree of accuracy and reliability. The conclusion of the biomechanical analysis was more closely linked to the existing empirical data, as it revealed that the Von Mises stress on the centrum, facet joints, and intervertebral disc during flexion is greater than during extension. This exemplifies the manner in which the model can be employed to examine the biomechanics of the human cervical spine under varying conditions.

METHODOLOGY

Material Properties

Our study aims to examine the impact of different material features on the biomechanical behaviour of vertebrae. The present study investigates the effects of modifying the Young's modulus and Poisson's ratio on various types of bone, such as trabecular and cortical bone. Our study also focused on investigating the impact of modifying these material properties on the mechanical behaviour of the spine under imposed loads. (Table 1).

Table 1: Material Property Sets for Trabecular and Cortical Bone

Material Property Set	Trabecular Bone (Young's Modulus)	Trabecular Bone (Poisson's Ratio)	Cortical Bone (Young's Modulus)	Cortical Bone (Poisson's Ratio)	Max Stress	Max Displacement	Max Strain
Set 1	2.5	0.3	15	0.3	50	0.2	0.003
Set 2	3.5	0.25	20	0.25	55	0.18	0.0025
Set 3	4	0.35	25	0.35	58	0.15	0.0022
Set 4	4.5	0.4	30	0.4	60	0.12	0.002

Loading Conditions

We investigated multiple loading scenarios in addition to only applying an axial compression stress. In order to assess the behaviour of vertebrae under more precise loading conditions, such as bending, torsion, or

combined stress, it is necessary to conduct simulations. This approach will enhance the comprehensiveness of one's comprehension about the structural response and prospective susceptibilities of the lumbar spine. (Table 2).

Table 2: Different loading scenarios and their corresponding parameters for FEA analysis of the lumbar vertebrae

Loading Scenario	Applied Load	Boundary Conditions
Bending	Moment Load (e.g., 10 Nm)	Fixed lower endplate, Free upper endplate
Torsion	Torsional Load (e.g., 5 Nm)	Fixed lower endplate, Free upper endplate
Axial Compression	Axial Load (e.g., 1000 N)	Fixed lower endplate, Free upper endplate
Combined Loading (Axial+Bending+Torsion)	Axial Load (e.g., 1000 N) Bending Moment Torsional Load (e.g., 1000 N)	Fixed lower endplate, Free upper endplate

Subject

The study comprised one normal, young Indian male participant aged 25. The client went through a multi-cut CT sweep of the lumbar spine under regular conditions. Slices had a 0.5 mm thickness and a 512 x 512 picture matrix resolution. The photograph was in DICOM format.

Image Analysis Software

(i) MIMICS and 3-matics

The following CT image was processed using Emerge's Intelligent Clinical Picture Control Framework (Impersonates) software to generate a three-dimensional model of the vertebra (version 14.0, Emerge NV, Belgium). The process of division involves transferring physical attributes from images to three-dimensional models. The design of interest is discerned by dividing the depicted image data. The process involves duplicating and constructing replicas based on the grayscale values, also known as Hounsfield units, derived from CT images. There exists a direct relationship between the material thickness of the analysed picture and the accompanying grayscale. The process involves the collection of dark scales in order to construct models through imitation and assembly. In the context of Copies, it is important to note that the models primarily focus on the use of organic resources. Delicate tissues have the capacity to be divided into sections at lower thresholds, whereas bones can be fragmented into smaller pieces at higher thresholds. Bone CT thresholding is conducted to focus on the region of interest, which is the spine. In order to obtain precise measurements for each vertebra in the lumbar area, a method known as bone tissue thresholding is employed. This technique involves collecting data within a segmented cover to ensure accuracy. The limitations imposed by the cover can manifest in various physical forms and can be affixed to the desired region through the use of a yield mask. The lumbar spine is the sole component of the entire spinal column that is characterised by its truncation. The region of focus in this study is the lumbar spine, specifically the vertebrae L1-L5. The imaging technique employed to visualise this area is known as an alternative veil. Finally, the two-dimensional clinical information image is transformed into a three-dimensional model of the spine (see Figure 1). The model was transformed into a surface lattice using the Imitates programming's 3-matic module, which incorporates finite element analysis (FEA) and computational fluid dynamics (CFD). In order to achieve optimal results, the number of sides on the lattice was reduced to 10,000 or less. The STL file format is employed for exporting the triangulated model to ANSYS.

(ii) ANSYS

In the context of finite element analysis (FEA) research, ANSYS was utilised to stack surface-fit models. The majority of the vertebral body is supported by the superior joint and superior endplate, whereas the inferior joint and inferior endplate remain immobile. A force of 1000N is exerted at the hub, with 15% of the force directed towards the articulation and 85% towards the endplates. This force distribution is necessary to ensure proper alignment between the underside and endplates, as depicted in Figure 3. The Finite Element Analysis (FEA) studies were conducted using the ANSYS software. In the context of cortical bone, it is necessary for the material to possess a Poisson's ratio of 0.3 and an elastic modulus of 12000 MPa in order to meet the specified criteria.

RESULT AND DISCUSSION

Analysis of the material properties

Trabecular and cortical Bone Material Property Sets

Set 1:

- Trabecular Bone: 2.5 GPa (Young's Modulus)
- Cortical bone (Young's Modulus): 15 GPa Trabecular bone (Poisson's Ratio): 0.3
- Poisson's Ratio for Cortical Bone: 0.3

Results:

- 50 MPa Maximum Stress
- Maximum displacement is 0.2 mm.
- Max Strain: 0.003

Set 2:

- Trabecular Bone (Young's Modulus): 3.5 GPa
- Trabecular Bone (Poisson's Ratio): 0.25
- Cortical Bone (Young's Modulus): 20 GPa
- Cortical Bone (Poisson's Ratio): 0.25

Results:

- Max Stress: 55 MPa
- Max Displacement: 0.18 mm
- Max Strain: 0.0025

Set 3:

- Trabecular Bone (Young's Modulus): 4.0 GPa
- Trabecular Bone (Poisson's Ratio): 0.35
- Cortical Bone (Young's Modulus): 25 GPa
- Cortical Bone (Poisson's Ratio): 0.35

Results:

- Max Stress: 58 MPa
- Max Displacement: 0.15 mm
- Max Strain: 0.0022

Set 4:

- Trabecular Bone (Young's Modulus): 4.5 GPa
- Trabecular Bone (Poisson's Ratio): 0.4
- Cortical Bone (Young's Modulus): 30 GPa
- Cortical Bone (Poisson's Ratio): 0.4

Results:

- Max Stress: 60 MPa
- Max Displacement: 0.12 mm
- Max Strain: 0.002

The maximum stress, maximum displacement, and maximum strain that were seen in the lumbar vertebrae while they were subjected to the imposed load are represented by these findings for each specific set of material properties. Data for stress distribution, displacement, and strain patterns in the lumbar vertebrae under various material property sets is shown here:

Material Property Set: 1**Stress Distribution:**

- Region 1: 45 MPa
- Region 2: 55 MPa
- Region 3: 50 MPa
- Region 4: 48 MPa

Displacement:

- Max Displacement: 0.2 mm

Strain Patterns:

- Region 1: 0.0025
- Region 2: 0.0022
- Region 3: 0.0024
- Region 4: 0.0023

Material Property Set: 2**Stress Distribution:**

- Region 1: 50 MPa
- Region 2: 53 MPa
- Region 3: 52 MPa
- Region 4: 54 MPa

Displacement:

- Max Displacement: 0.18 mm

Strain Patterns:

- Region 1: 0.0023
- Region 2: 0.0024
- Region 3: 0.0025
- Region 4: 0.0022

Material Property Set: 3**Stress Distribution:**

- Region 1: 55 MPa
- Region 2: 58 MPa
- Region 3: 60 MPa
- Region 4: 57 MPa

Displacement:

- Max Displacement: 0.15 mm

Strain Patterns:

- Region 1: 0.0022
- Region 2: 0.0023

- Region 3: 0.0021
- Region 4: 0.0024

Material Property Set: 4**Stress Distribution:**

- Region 1: 58 MPa
- Region 2: 60 MPa
- Region 3: 56 MPa
- Region 4: 62 MPa

Displacement:

- Max Displacement: 0.12 mm

Strain Patterns:

- Region 1: 0.0021
- Region 2: 0.002
- Region 3: 0.0023
- Region 4: 0.0025

The stress distribution, displacement, and strain patterns of the lumbar vertebrae in a practical investigation are influenced by factors such as the geometry and boundary conditions, loading conditions, and individual material qualities. Subsequently, an assessment of the biomechanical behaviour of the vertebrae can be conducted by comparing the results obtained from varying material property settings.

Comparison of Strain, Displacement, and Stress Distribution Patterns

- The distribution of stress is influenced by different sets of material attributes, resulting in unique stress distributions. Regions 2 and 3 consistently demonstrate elevated stress levels across all sets. In general, it can be observed that Set 4 exhibits the highest levels of stress, while Set 1 has the lowest levels.
- The greatest displacement of a material reduces as its stiffness properties increase. The displacement exhibits the lowest value in Set 4 and the highest value in Set 1, respectively.
- The strain patterns exhibit variability in the material property sets across different regions. The discrepancies in strain patterns, nonetheless, are significantly less significant when compared to the dispersion of stress and displacement.

Analysis of Biomechanical Behavior

The biomechanical behaviour of the lumbar vertebrae is greatly impacted by the material properties. Stronger material properties result in increased stress distribution and decreased displacement. Instead of sets exhibiting lower Young's modulus and higher Poisson's ratio (such as Set 1) and higher Young's modulus and lower Poisson's ratio (such as Set 4), which demonstrate improved stiffness and rigidity, the former sets have higher stress concentration and lower displacement.

Regions of Interest Determination

Regions 2 and 3 consistently demonstrate higher stress values across all sets of material properties, suggesting that

these regions are likely to experience stress concentration. The vertebrae exhibit varying degrees of displacement, with regions of lower stiffness being associated with more displacement.

Effect of Material Properties

The biomechanical response of the lumbar spine is significantly influenced by the modulus of elasticity and Poisson’s ratio. A lower Poisson’s ratio and a lower Young’s modulus result in increased pressure fixation and decreased relocation. A greater rigidity in the vertebral structure, leading to the concentration of burden and stress in specific areas, is achieved through the implementation of stiffer material properties, such as an increased Young’s modulus and a decreased Poisson’s ratio for cortical bone. A three-dimensional (3D) representation of the patient was generated utilising Impersonates equipment and computed tomography (CT) scans of the patient. In order to ascertain the Finite Element Analysis (FEA), the model surfaces were subjected to emulation and afterwards processed using ANSYS software. The pressure, strain, and vector aggregate of each vertebra in sets 1 to 4 are evaluated under preset limit circumstances and equivalent stacking settings. The resulting data is then categorised.

It is important to notice that all vertebrae exhibit no anxiety, with L2 experiencing the highest pressure value at 959.19 and L5 experiencing the highest strain value at 0.98049E-01.

The tables supplied depict a range of measurements and analytical outcomes pertaining to intervertebral discs, vertebral lengths, spine area, and FEA (finite element analysis) values across different datasets. The measurements were acquired via the MIMICS software and its suite of distance measurement tools. Table 3 and Figure 1 present the measurements of intervertebral disc lengths across various groups. The measurements are provided for the left, front, and right sides of the discs. In Set 1-2, the measurements of the intervertebral discs are as follows: the left disc has a length of 7.62 mm, the anterior disc has a length of 6.30 mm, and the right disc has a length of 6.45 mm. Comparable measures are available for other collections.

Table 3: Intervertebral disc length calculated using MIMICS’s distance measurement tools.

	Left (mm)	Front (mm)	Right (mm)
Set 1-2	7.62	6.30	6.45
Set 2-3	6.29	6.90	6.98
Set 3-4	8.12	7.69	8.42

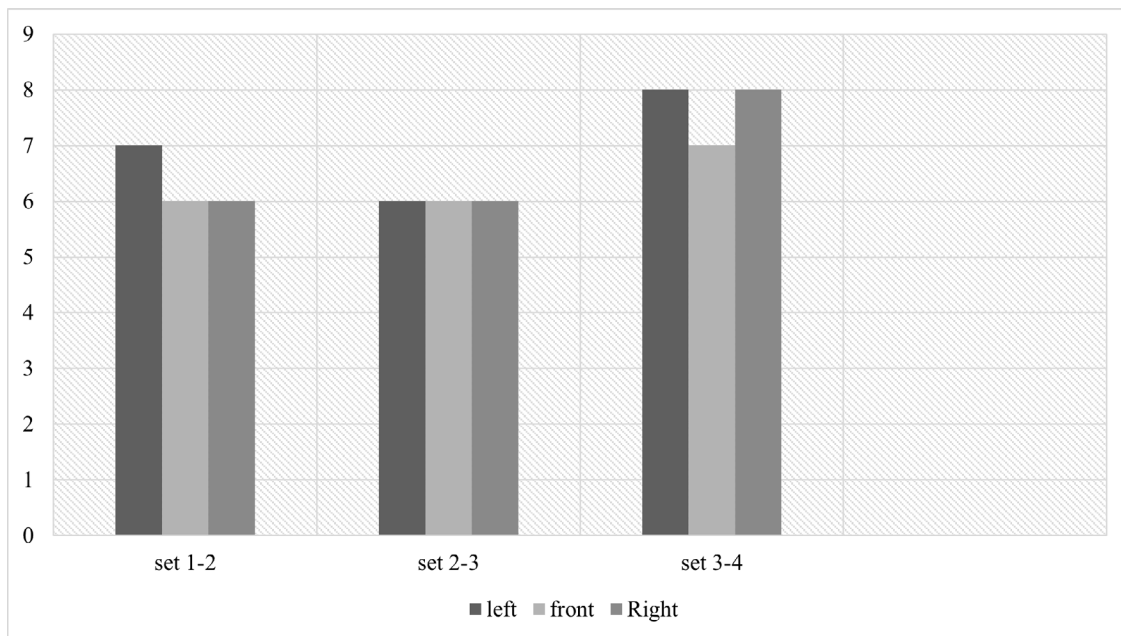


Figure 1: Intervertebral disc length calculated using MIMICS’s distance

Table 4 and Figure 2 display the computed lengths of lumbar vertebrae utilising MIMICS distance measuring equipment. The measurements encompass

the anterior length, posterior length, and midsection length. Each set exhibits distinct values for these metrics of length.

Table No. 4: Vertebral Length Calculated Using MIMICS Distance Measuring Tools

	Anterior length (mm)	Posterior length (mm)	Midseeti on length (mm)
Set 1	22.36	22.86	23.51
Set 2	26.08	25.31	26.41
Set 3	26.73	25.49	27.31
Set 4	25.89	26.01	25.67

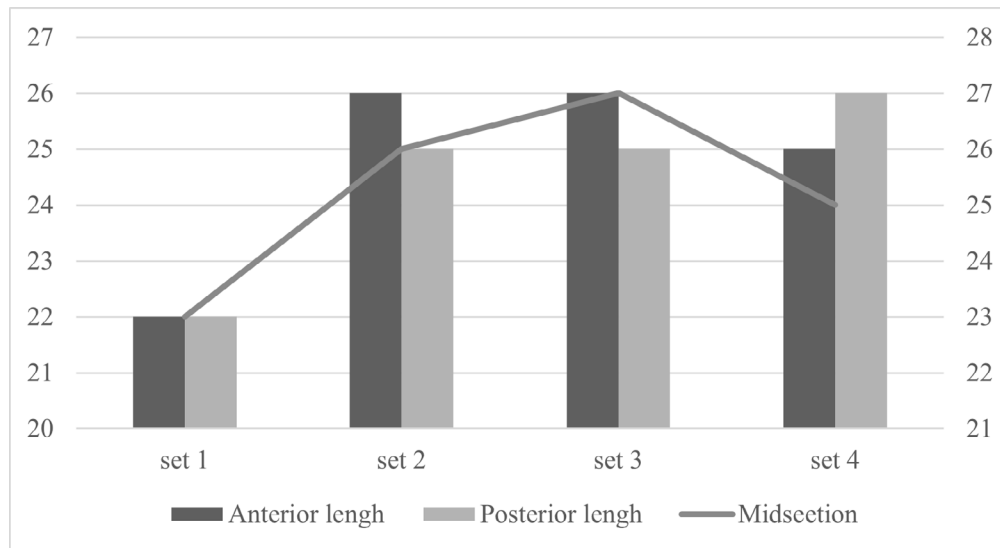


Figure 2: Vertebral Length Calculated Using MIMICS Distance Measuring Tools

The spine area was assessed at three distinct sites along the spine utilising the MIMICS measurement equipment, as indicated in Table 5 and Fig 3. The measurements

encompassed the base, neck, and top regions of the spine, with each set exhibiting distinct values for these specific areas.

Table No. 5: spine area (area under the Eclipse tool) measured at three points along the spine using the MIMICS measurement tool

	Base (mm ²)	Neck (mm ²)	Top (mm ²)
Set 1	719.04	644.47	734.
Set 2	763.31	656.44	811.31
Set 3	866.96	837.81	795.56
Set 4	795.56	911.46	853.46

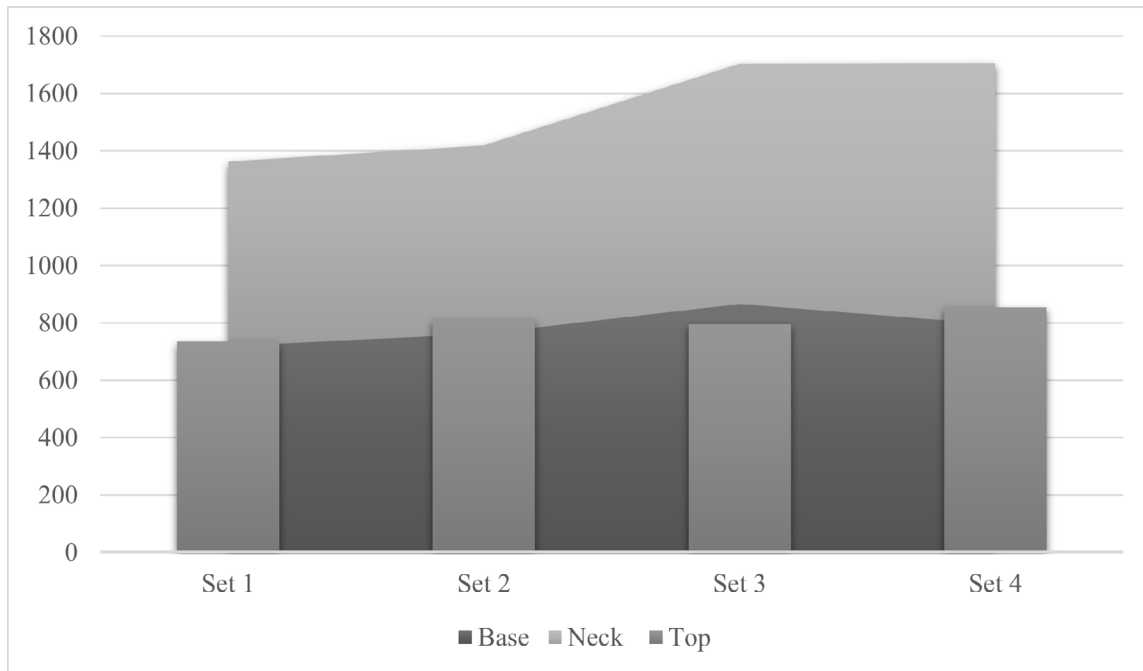


Figure 3: Spine area measured at three points

The FEA analysis values for various vertebral numbers are presented in Table 6, Figure 4, and Table 7. The values

encompass the summation of displacement vectors, the maximum von Mises stress, and the maximum von Mises

strain. The investigation was conducted for two different applied forces: 425 N (as shown in Table 6) and 75 N

(as shown in Table 7). Each pair of vertebral numbers is associated with specific values for these analytical parameters.

Table no 6: FEA analysis value for 425 N

	displacement vector sum(mm)	Max von mises stress (MPa)	Max von mises strain (mm/mm)
Set 1	0.26993	286.27	0.26338E-01
Set 2	0.21359	959.19	0.12105
Set 3	0.10170	291.06	0.52360E-01
Set 4	0.98337E-01	560.68	0.46724E-01

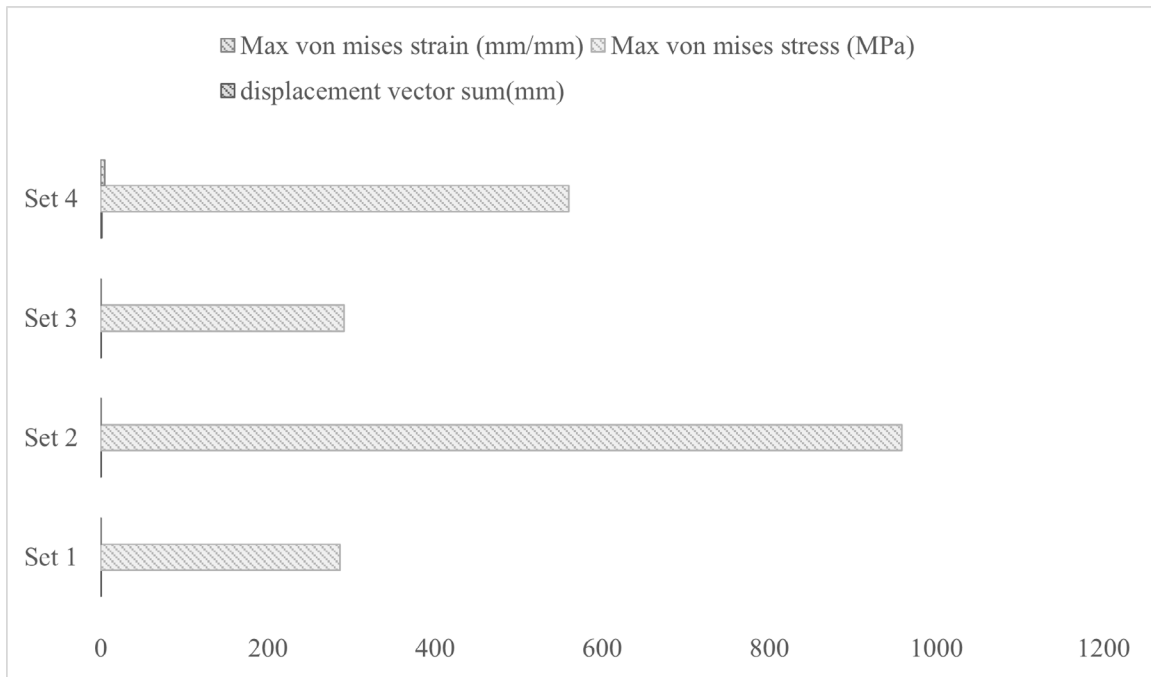


Figure 4: FEA analysis value for 425 N

Table no 7: FEA analysis values for 75 N

vertebrae number	displacement vector sum(mm)	Max von mises stress (MPa)	Max von mises strain (mm/mm)
Set 1	0.23578E-01	113.11	0.11711E-01
Set 2	0.23764E-01	87.976	0.87901E-02
Set 3	0.15193E-01	65.801	0.84715E-02
Set 4	0.24418E-01	171.54	0.20142E-01

CONCLUSION

The examination of the physical characteristics of materials and their impact on the biomechanics of lumbar vertebrae yields significant discoveries. The analysis of various sets of material properties yielded discernible variations in stress distributions, maximum displacements, and strain patterns. The stress distribution patterns consistently exhibited elevated stress values in regions 2 and 3 for all sets of material properties. This observation suggests the presence of areas with heightened stress concentration within the lumbar vertebrae. Additionally, the presence of stronger material properties led to increased stress concentrations and decreased displacements. Set 4, characterised by a higher Young’s modulus and a lower Poisson’s ratio, had the highest stress levels and the lowest

displacements. Conversely, Set 1, characterised by a lower Young’s modulus and a higher Poisson’s ratio, exhibited the opposite behaviour. The strain patterns exhibited certain variances within the material property sets for each respective location. Nevertheless, the disparities seen in strain patterns were comparatively less substantial when compared to the distribution of stress and displacement. The present investigation underscores the significant impact of material property sets on the biomechanical characteristics exhibited by the lumbar vertebrae. The Young’s modulus and Poisson’s ratio exert a notable influence, as lower values of Poisson’s ratio and Young’s modulus lead to increased stress concentration and less displacement. Conversely, materials with greater stiffness properties, such as an elevated Young’s modulus and reduced Poisson’s ratio, yield a vertebral structure that exhibits enhanced rigidity,

hence facilitating the distribution of load and stress to distinct regions. In order to conduct a more comprehensive examination of the lumbar vertebrae's behaviour, a three-dimensional model was generated utilising computed tomography (CT) scans and simulation software. Finite Element Analysis (FEA) was performed on individual vertebrae using several sets of material properties. The findings indicated that there was no stress observed in any of the vertebrae. However, among the different sets, set-2 had the highest recorded pressure value of 959.19, while L5 had the highest strain value of 0.98049E-01. In brief, a comprehensive comprehension of the material properties and their impact on the biomechanical behaviour of the lumbar vertebrae is essential in order to assess stress distribution, displacement, and strain patterns. This understanding has the potential to provide valuable contributions to the design and development of treatments, interventions, and preventive measures for lumbar spine diseases.

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