PHOTOELASTIC ANALISYS IN THE LOWER REGION OF VERTEBRAL BODY L4

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ABSTRACT

Objective: To analyze the shear forces on the vertebral body L4 when submitted to a compression force by means of transmission photoelasticity. Methods: Twelve photoelastic models were divided into three groups, with four models per group, according to the positioning of the sagittal section vertebrae L4-L5 (sections A, B and C). The simulation was performed using a 15N compression force, and the fringe orders were evaluated in the vertebral body L4 by the Tardy compensation method. Results: Photoelastic analysis showed, in general, a homogeneous distribution in the vertebral bodies. The shear forces were higher in section C than B, and higher in B than A. Conclusion: The posterior area of L4, mainly in section C, showed higher shear concentrations, corresponding to a more susceptible area for bone fracture and spondylolisthesis. Economic and Decision Analyses – Development of an Economic or Decision Model. *Level I*

Keywords: Spine, Biomechanics, Tension.

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INTRODUCTION

The vertebral body is the largest and most important component of the spinal column. This study focuses on the lumbar region, as it bears a greater load and body weight against gravity. The integrity of the vertebral body refers to the non-impairment of its structure and function. On the other hand, loss of vertebral integrity results in impairment of bone resistance, predisposing to an increased risk of fracture. This etiology can be physiological and dependent on aging and hormonal changes, as in the case of menopause, or can be of traumatic origin with an increase of shear force and physical stress in the vertebral structure.[1]

The vertebrae are bone structures submitted to substantial biomechanical overload and it is believed that this stress is the determinant factor to define their bone microstructure. Changes in the vertebral microstructure in response to external overloads are adaptive, and in high-stress regions, the bone tissue becomes rigid and strong. However, there are medical conditions in which these adaptations fail, resulting in spontaneous vertebral fractures.[2] Corroborating the above statements, Yeni et al.[3] suggest that the application of stress on the vertebral bone structures plays an essential role in the determination of biomechanical properties, in the characteristics of bone remodeling and in the bone fracture pattern of the trabecular tissue. Osteoporosis is a disease that affects a large portion of the world population and causes bone fractures, particularly in the hip, vertebrae and wrist. As regards the vertebrae, it is estimated that 50% of elderly women will suffer a fracture of at least one vertebra during aging.[4] Lochmüller et al.[5] added that vertebral fractures considerably reduce the quality of life of individuals, due to pain, physical deformity and functional deficit, besides increasing mortality. Consequently, knowledge of the forces exerted on the vertebrae presents clinical importance, and studies should thus be conducted in this area.

Some experimental techniques are used in the study of forces exerted on bone structures. Photoelasticity is an experimental technique that uses light to study the physical effects resulting from the action of stresses or deformations in transparent elastic bodies, and is used in studies of structures with complicated forms, complex load distributions, or both.[6,7] This technique has been frequently used in qualitative and quantitative stress analyses in the engineering and medical areas.[8]

Yeni et al.[4] conducted a study of the microstructure and stress distribution in vertebrae and verified that T12-L1 presented the

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highest shear levels, thus justifying the greater incidence of fractures in this region of the spinal column. The authors analyzed and compared thoracic and lumbar vertebrae, yet did not emphasize the comparison between different regions of a single vertebra and did not verify the influence of the intervertebral disc in these shears.

Thus, the objective of this survey was to analyze the distribution of shear forces in the lower region of vertebra L4, through the photoelastic analysis method, taking into account the different vertebral regions and verifying the influence of the intervertebral disc geometry in this analysis.

MATERIAL AND METHODS

Images of three unilateral sagittal sections were obtained in vertebral body L4, with a distance between sections of 16.0 mm. The geometry of the intervertebral disc located in the lower region of the vertebra was obtained through these sections. This geometry was used as a basis to create models of photoelastic resin to study the influence of the geometry of intervertebral disc L4-L5 on the vertebral body of L4. (Figure 1)

Photoelastic model

Polytetrafluorethylene (Teflon®) molds were made for the three sections (section A, section B and section C). These molds were composed of a Teflon frame, and the profile of the upper region of intervertebral disc L4-L5 was positioned in the center, made of T-208 orthophthalic polyester resin (VI Fiberglass® - Brazil), dissolved in styrene monomer, with methyl ethyl ketone peroxide used as a catalyst. (Figure 2)

After preparation, the Teflon frame was filled with flexible photoelastic epoxy resin (Polipox®), whose modulus of elasticity is 4.51 MPa with a Poisson's coefficient of 0.4.

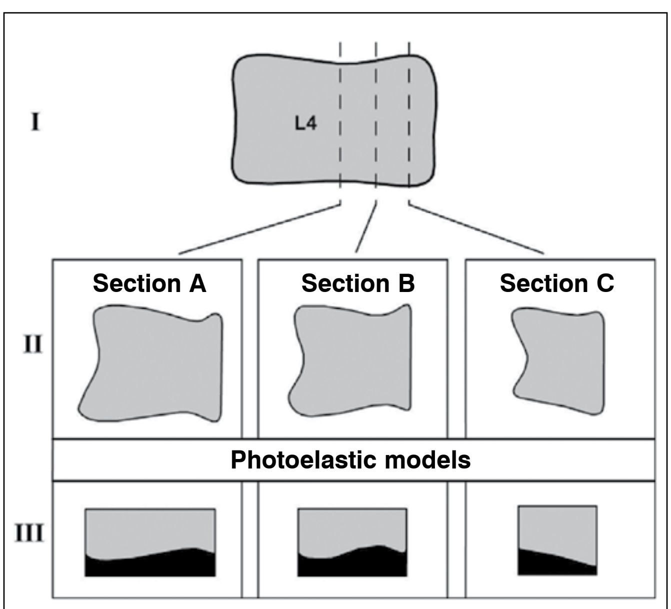

Figure 1. *Diagram of the three unilateral sagittal sections (A, B and C) created in vertebral body L4 to obtain the geometries of the photoelastic models. I- Location of the sagittal sections (A, B and C) in vertebral body L4. II– Geometry of sections A, B and C. III– Photoelastic models of sections A, B and C.*

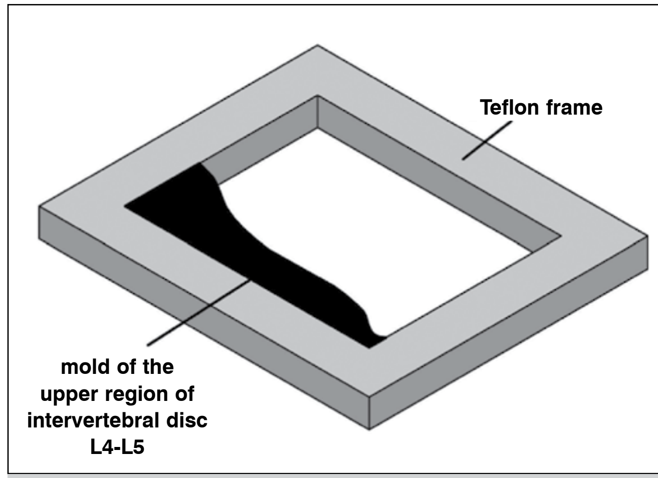

Figure 2. *Diagram of a polytetrafluorethylene (Teflon®) mold with the disc made of T-208 resin, positioned in the center of the mold.*

Four identical photoelastic models (total of 12 models) were created for each section. The width of the model was different for each section, whereas that of section A was 40.0 mm, section B was 35.0 mm and section C was 27.0 mm. For all the models the height was 60.0 mm and the thickness 8.0 mm.

These models were previously evaluated with regards to the presence of residual stress, called “edge effect”, before the application of the compression force on the vertebral body. The photoelastic resin used was calibrated and presented an optical constant of 0.375 N/mm fringe.

The photoelastic analysis was conducted using a Transmission Polariscope through the application of a compression force in the center of the vertebral body of the photoelastic model.

The internal shears produced in the vertebral body in the three sagittal sections were evaluated qualitatively and quantitatively. By means of the qualitative analysis the participants observed the distribution of fringe orders and the point of highest shear concentration in each section. A load of 15 N was applied in the quantitative analysis, recorded in aKratos® Load Cell, with a capacity of 100 N. The shear forces were calculated in a standardized manner, according to the geometry of each section. A total of 23 points were selected for section A, 27 points for section B and 22 points for section C. (Figure 3)

Tardy’s method of compensation was used to calculate the shear force (τ).[9]

RESULTS

Qualitative analysis

In the qualitative analysis it was observed that sections B and C had a more homogeneous distribution of shear than in section A. This section (A) presented low shear concentration in the central region and higher concentrations in the anterior and posterior regions. Section B presented a region of low shear concentration located in the anterior and central region, close to intervertebral disc L4-L5, while section C presented lower shear forces in the anterior, central and posterior region, located close to intervertebral disc L4-L5. It was also observed that the posterior region of vertebral body L4 has higher shear force, regardless of the section analyzed. (Figure 4).

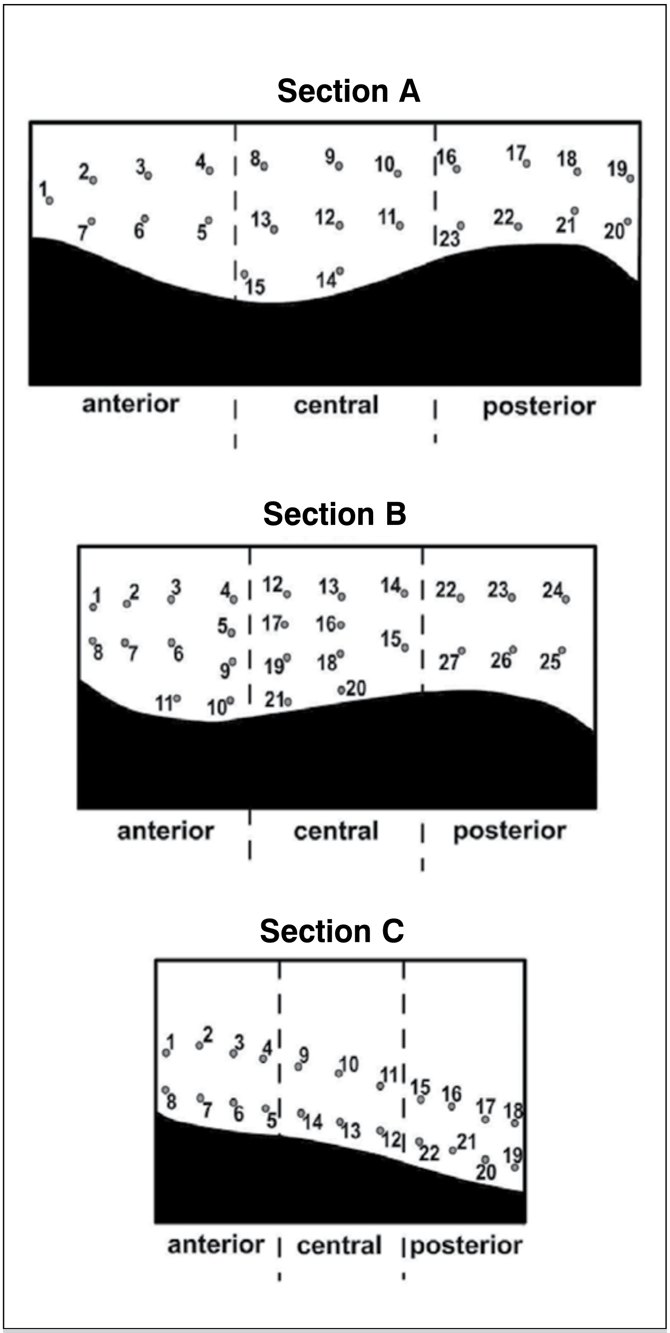

Figure 3. *Diagram of the points selected for analysis of the shear forces in the three vertebral sections.*

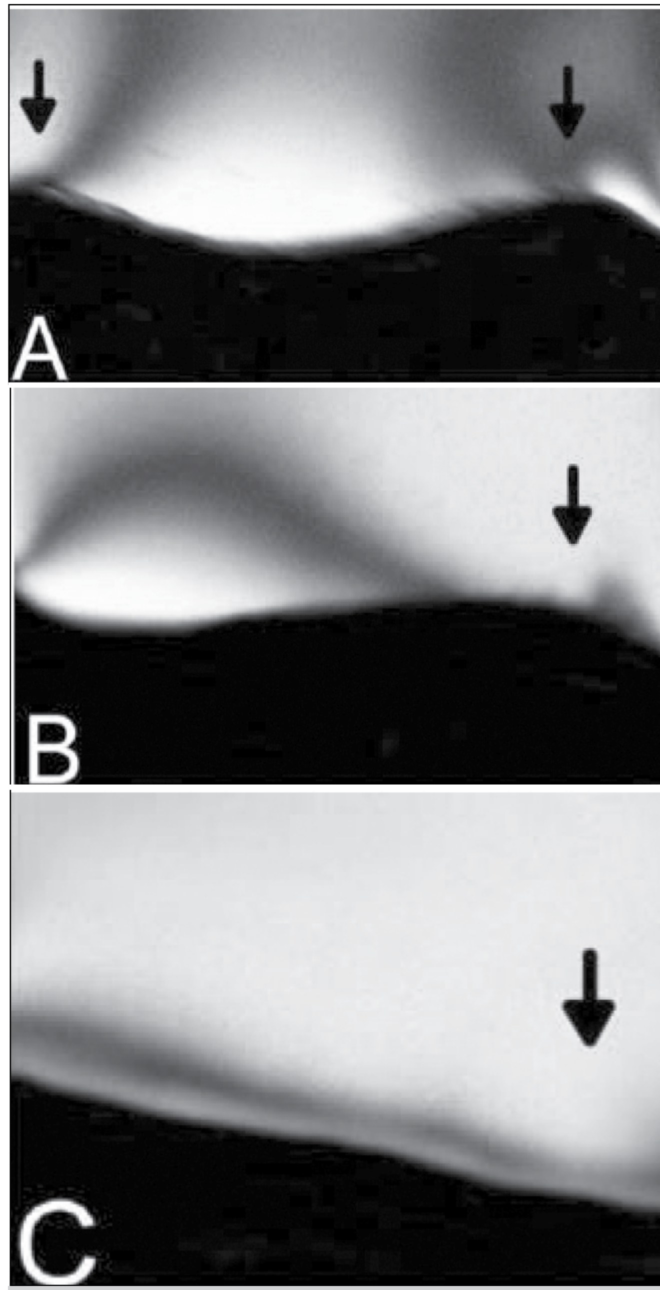

Figure 4. *Distribution of shears in sections A, B and C. In section A, the shear concentration was higher in the anterior and posterior regions of the vertebra (arrows). In sections B and C, the shear concentration was higher in the posterior region (arrows).*

Quantitative analysis

In this analysis, the shear forces were calculated at the points corresponding to the three vertebral sections, in all the photoelastic models. The mean values of the shear forces in sections A, B and C are presented in Table 1.

In section A, vertebra L4 presented a general average of 21.26 KPa, while section B presented 25.06 KPa and section C, 35.15 KPa. (Table 1) It can be noted that section C presented a higher general average shear force than section B, which presented a higher general average than section A. The posterior region was the most critical, as it presented higher shear concentrations, mainly in section C.

Table 1. *Values of the means and standard deviation of the shear forces (KPa).*

	Section A	Section B	Section C
Anterior	23.50±6.56	20.96±7.47	32.78±2.44
Central	13.74±2.83	24.77±5.40	34.22±1.07
Posterior	26.83±2.84	33.04±0.68	38.23±4.13
General average	21.26	25.06	35.15

DISCUSSION

Due to the mechanical overload to which they are submitted, the vertebrae are susceptible to bone fractures. Most vertebral fractures occur in the thoracic spine,[4] yet deformities in the lumbar vertebrae cause greater pain intensity than deformities in the thoracic vertebrae.[5] Thus arose the idea of performing photoelastic analysis of vertebral body L4 to understand the transmission of shear forces to the vertebrae.

Photoelasticity is used in the area of Orthopedics and Traumatology, with various articles published, yet no scientific reports using this technique were found in analyses of the influence of the geometry of intervertebral disc L4-L5 on vertebral body L4. The photoelasticy technique used in this trial was able to qualitatively and quantitatively[10] evaluate the internal stresses generated by the intervertebral disc geometry. The goal of the quantitative analysis of the fringe orders was to determine the numerical values of the maximum shear forces, especially at the most critical points of the model.[6,11,12]

The photoelastic molds were made from Teflon as this is an easy machinable material, does not adhere to the resins used (T-208 and flexible photoelastic epoxy resin) and presents good dimensional resistance. T-208 resin was chosen as it is easy to handle, has a low cost and does not possess photoelastic characteristics. Moreover, this resin has a much higher modulus of elasticity than flexible photoelastic resin, which was an important characteristic as with the applied load (15N) it did not suffer significant deformations.

In this study, the intervertebral disc was considered rigid, since the objective was to observe the geometry of intervertebral disc L4-L5 in the vertebral body of L4.

The analysis was only carried out in vertebral body L4 to better detail the shear forces in each region and, as the vertebrae have bilateral symmetry,[13] the sections in the vertebral bodies were created unilaterally.

Through the quantitative analysis it was possible to observe that in all the sections (A, B, and C) the shear forces were higher in the posterior region of the vertebral body. Section C (more peripheral region of the vertebra) presented higher shear forces concentrations than section B, which in turn presented higher values than section A. These results are consistent with the qualitative analysis. Thus it was noted that the posterolateral region was the most critical site when applying perpendicular compression force on the vertebra. These regions are probably more susceptible to bone fractures and spondylolisthesis, whereas these results corroborate the study by Etsuo et al.[14]

The area of least shear force was the region that corresponds to the central part of the vertebral body of section A. Coincidentally it is the site of the nucleus pulposus, which is located in the center of the intervertebral disc.

It was possible to obtain significant results with the technique used in this study, which can be performed to analyze the behavior of the distribution of shear forces in other situations such as in different vertebrae, and to apply non-perpendicular compressive forces to simulate the flexion movements of the spinal column.

With the results obtained from the photoelastic analysis of the lower region of vertebra L4, we were able to conclude that the posterior region of the vertebra has the highest concentrations of stress when we apply a perpendicular compression force on the vertebra, and the geometry of the vertebral disc has a significant influence on the distribution of stresses in the vertebrae.

CONCLUSIONS

It was observed in all the photoelastic models that the point of highest concentration of shear forces was located in the posterior region of vertebral body L4. However, section C (more peripheral region of the vertebra) presented the highest shear force values. Therefore, the posterolateral region was the most critical location, by means of the application of a perpendicular compression force on the vertebra. These regions are probably more susceptible to bone fractures and spondylolisthesis.

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