PHOTOELASTIC ANALISYS OF A HUMAN VERTEBRA MODEL WITH PEDICULAR SCREW

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ABSTRACT

Introduction: The vertebrae fixation system using pedicular screws is one of the most efficient methods to treat vertebral spine pathologies. When the screw is submitted to pullout strength, it causes internal tension near the medullar canal and this situation can be analyzed by using the photoelasticity technique. Objective: Were analyzed those internal tensions near the medullar canal of photoelastic vertebra models using different sizes of screws of the vertebral fixation system submitted to pullout strength. Methods: A lumbar vertebral model made of photoelastic material with three different USS1-type pedicular screw sizes (5, 6, and 7mm) was used. The internal tensions around the screw were tested in 12 predetermined points by a plain transmission polaroscope. Results: The areas of greater tension concentration were between the medullar canal and the curves of the transverse process. Comparing the maximum average pulling tension, statistical differences were observed between screws 5 and 7, and 6 and 7. On the other hand, for screws 5 and 6, there were no significant differences. Conclusion: The study evidenced that the internal tensions are greater in irregular areas, next to the medullar canal, showing that this is a critical region.

Keywords: *Spine. Lumbar vertebrae. Biomechanics.*

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INTRODUCTION

Photoelasticity is an experimental tension and deformation analysis technique, which is particularly useful for parts and structures with complex geometries. In these situations, the use of experimental analysis presents advantages, because strictly mathematical analytical methodologies are difficult to conduct and little feasible.[1]
Photoelastic analysis is a technique that changes existent tensions within bodies into visible light patterns, named fringes. The higher the number of visualized fringes, the higher the concentration of tension.[2] Those tensions may be similar to those found in the actual structure, since the material of the photoelastic model is homogenous and isotropic, and the model demands are similar to those seen in practice, not exceeding its elasticity limit.[1]
In order to analyze tensions using the photoelastic technique, the following is required: Models prepared with photoelastic material and a transmission polaroscope. This polaroscope is designed to polarize the light irradiated on the photoelastic model, as well as to analyze the light transmitted through that model.[3]
The introduction of intrapedicular fixation by Roy-Camille et al.[4] in 1963 strongly leveraged the use of instrumentation through posterior approach with a pedicular screw, and this has been one of the most efficient methods of internal vertebral fixation in the treatment of several spinal conditions, such as vertebral fractures, scoliotic deformities, metastasis, and degenerative disorders.[5] One advantage is that the technique does not enter the neural canal, as occurs with other kinds of implants (hooks and sub-laminar wiring)[6], but, in cases where the screw is submitted to pullout strengths, this causes tension around it, and may lead to a critical situation, especially when near medullar canal. In this case, this situation can be studied and analyzed by the photoelasticity technique.
Thus, the objective of this study was to assess internal tensions generated near the medullar canal of vertebral photoelastic models using different screw sizes of a vertebral fixation system submitted to pullout strength.

MATERIALS AND METHODS

In this study, photoelastic models simulating the fifth lumbar vertebra (L5) and pedicular screws with outer diameter of 5, 6 and 7 mm composing a 50 mm-long USS1-type vertebral fixation system have been used. (Figure 1)
The photoelastic models were made by using a flexible photoelastic epoxy resin (Polipox®) with catalyzer at a ratio of 2:1. The optical constant of the resin employed was 0.21 N/mm.
The models were built from silicone casts, reproducing the geo-

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metrical characteristic of the fifth human lumbar vertebra at a cross-sectional plane, 120 mm thick. The screws were positioned on the casts towards the pedicle with the whole threaded portion inserted within the photoelastic model. The screw direction within the pedicle was convergent to the mid-sagittal plane. (Figure 2)

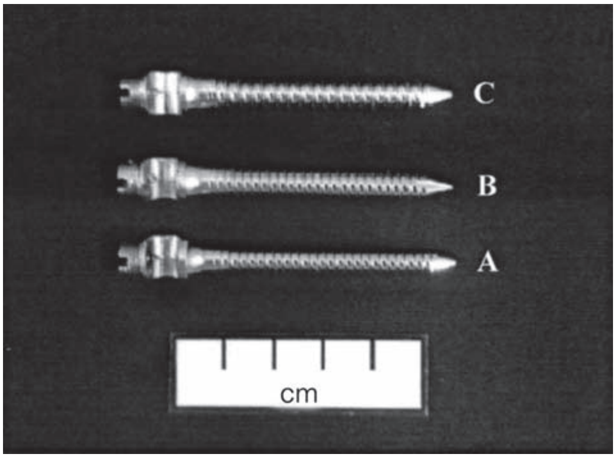

Figure 1 – *Image of USS1-type pedicular screws with outer diameters of 5 mm (A), 6 mm (B), and 7 mm (C).*

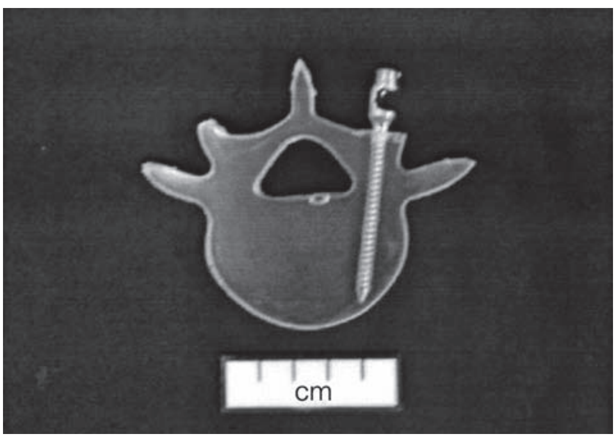

Figure 2 – *Screw position into the vertebra.*

Three experimental groups were built according to the size of the screw employed. In each experimental group, 4 photoelastic models were used, totaling 12 models in the study. An 8N pull-out strength was applied on screws' head; for this, a Kratos® 50 Kgf load cell was used. The photoelastic analysis was made in a transmission polaroscope. The applied strength produced fringes of up to order 3.

The analyses in this study were conducted both qualitatively and quantitatively.

The qualitative analysis was made by checking the tensions produced by the screw on the photoelastic model at a region near medullar canal by means of the behavior of the fringe images produced on the photoelastic model.

The quantitative analysis was made by calculating the shearing tensions around the screw in 12 selected points. These points had the same location in all screw sizes, and these were marked at 1 mm from the outer diameter of each screw. Figure 3 shows the distribution map for 6-mm screw points.

The fringe order and the shearing tension were calculated at the selected points using Tardy's offset method.[7]

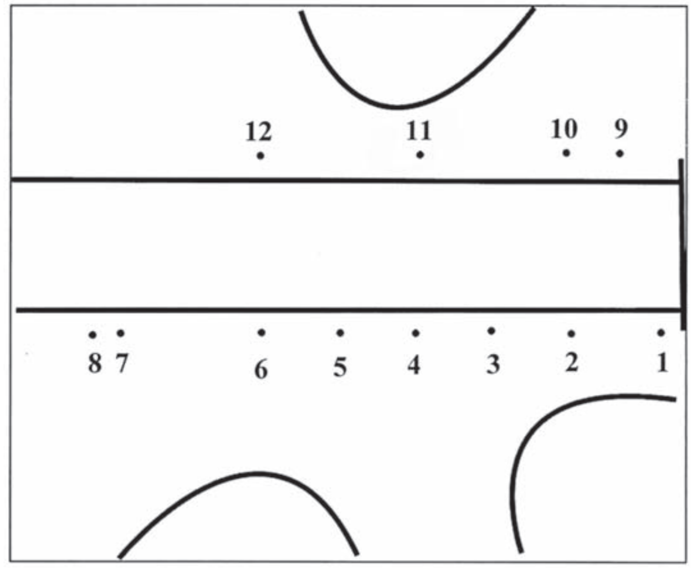

Figure 3 – *Schematic illustration of the points assessed around the screw at the pedicle region.*

The comparison of values of the tensions produced by the different screws employed on the models was provided by using the multifactorial variance analysis (ANOVA) method. For post-hoc comparisons, the Bonferroni method was employed. In all analyzes, a significance level of 5% ($p<0.05$) was adopted.

RESULTS

Qualitative Results

The regions with the highest tension concentrations were found between medullar canal and the transverse process curves, and on the medial surface of the distal portion of the screw. Figure 4 illustrates the distributions produced by the screw on the vertebral model. The distribution of tensions on the three kinds of screws showed similar characteristics.

Quantitative results

The values of tensions produced on each selected point were compared to each other. The comparison of each point between screws did not show statistically significant differences.

The overall average of maximum shearing tensions of the 5, 6, and 7-mm screws were, respectively, 12.45 ± 2.02 KPa, 12.48 ± 3.10 KPa, and 14.31 ± 1.85 KPa. In the comparison of maximum shearing tensions between 5 and 6-mm screws, no statistically significant difference was found ($p=1.000$). But, when comparing 5 and 7-mm screws ($p=0.002$), and 6 and 7-mm screws ($p=0.002$) we found statistically significant differences. (Figure 5)

Figure 6 shows the mean values of shearing tensions of the 12 points assessed on each screw.

By comparing the points, we found that point 11 (located between medullar canal and the inner surface of the screw), was the one with the highest tension level among all analyzed screws.

DISCUSSION

The photoelasticity technique was able to identify the points with the highest level of inner tension on the suggested photoelastic vertebral model. The points were located near medullar canal, on the medial pedicle portion. These points were the same as

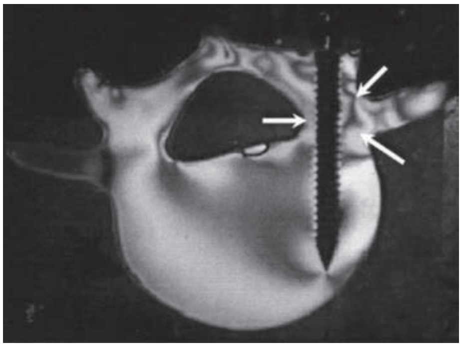

Figure 4 – *Image of the distribution of internal tensions along a pedicular screw in a vertebral model. Arrows: highest tension concentrations.*

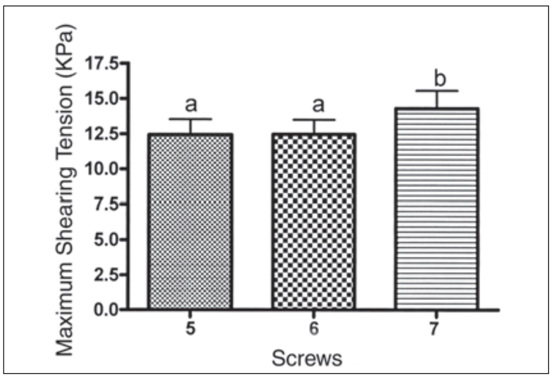

Figure 5 – *Graph showing the mean values of shearing tensions for 5, 6, and 7-mm screws.*

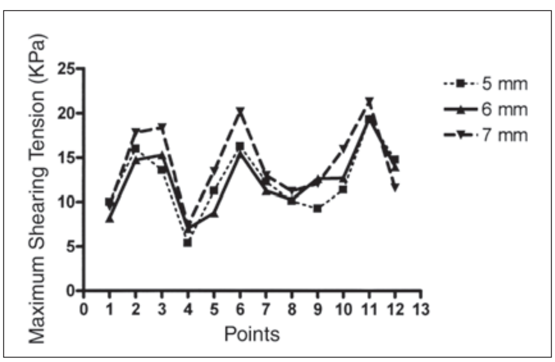

Figure 6 – *Mean values of shearing tensions in each point of each screw.*

the ones identified by Gayet et al.[8] who conducted a study using a finite elements method in vertebral models, simulating pullout strength. The authors carried out mechanical pullout assays in order to validate the method employed on the finite element; in these assays, they found that pedicle fractures occurred on sites showing the highest concentration of tension.

Photoelastic models made with epoxy resin, with fixated screws, suggest that we are simulating a chronic situation, as we usually find in clinical practice.

By analyzing the model as a whole, we found that the highest tension concentrations occurred at regions where stronger outlines could be seen around the screw, such as near medullar canal and on transverse processes' curves. These concentrations of tension probably occurred as a result of the shape of the vertebra.

Our findings showed a trend for 5 and 6-mm screws to behave similarly when the mean maximum shearing tensions were assessed. The 7-mm screw showed higher shearing tension values than the other screws, with smaller inner diameters. This result proved that the outer diameter of a pedicular screw may influence the positioning and stability of a vertebral fixation system. In this case, for a same vertebral size as adopted for the photoelastic model, a screw with a bigger outer diameter will also take a larger space, particularly on the pedicle region, being closer to medullar canal, thus producing inner tensions, making the site critical. Therefore, the selection of a screw for internal fixation on the bone must be made by considering the variety of screws available, which not only differ by material, geometry and size, but also by insertion technique.[9,10]

The outer diameter of the screw must be selected considering the size of each pedicle. Thus, tension transmission will occur in a more appropriate manner from the screw to the pedicle.[8]

Qualitatively speaking, we found that in addition to the region near medullar canal, at the medial surface of screw's end as compared to the lateral surface, a higher concentration of tensions was seen. This is probably due to the fact that when we apply pullout strength to the screw, the photoelastic model tends to spin over its own axis, counter-clockwise, because the screw is not centered on the model.

Several factors may affect a screw's pullout strength, such as: bone mineral density and composition, the insertion technique, and the screw model. All these factors contribute to a clinical decision when choosing the implant to be used[11-13], but an analysis to check the influence of a given implant on vertebral fixation may provide important benefits, in order to improve its use, especially suggesting which the best screw size should be used in order to avoid damages to medullar canal.

CONCLUSION

The highest inner tensions were found at the regions rear medullar canal, which has proven to be a critical region when larger screws are employed. The distribution of tension on the model behaved similarly between the different screw sizes, progressively increasing according to outer diameters.

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