THE PHOTOELASTIC ANALISYS OF VERTEBRAL FIXATION SYSTEM SCREWS

Sarah Fakher Fakhouri[1], *Dayana Pousa Paiva de Siqueira*[1], *Cleudmar Amaral de Araújo*[2],
Helton Luiz Aparecido Defino[1], *Antônio Carlos Shimano*[1]

ABSTRACT

Introduction: The photoelasticity is used for assessing the tensions/deformations involved in photoelastic materials when submitted to a given load by the observation of optical effects. The screw performance and mechanical functions are directly associated to the quality of the screws fixation in the vertebrae. Photoelasticity is an important tool to perform comparative studies of this nature. Objective: The aim of this study was to compare, by using photoelasticity, internal stresses produced by the screw with an external diameter of 6 mm, when submitted to two different pullout strengths. Materials and Methods: For this, four photoelastic models were produced. The simulation was conducted by using two pullout strengths: 0.75 and 1.50 kgf. The maximum shear stresses were calculated on 19 points around the screws, using the Tardy compensation method. Results:The values of maximum shear stress were higher with the load of 1.50 kgf. Conclusion: Thus, the screw will be more susceptible to pullout when heavier loads are applied. According to our analysis, we also found that the site with the highest maximum shear stress was found to be at the peak of creast, particularly near the tips of the screws, regardless of the load employed.

Keywords: *Biomechanics. Screw. Resin*

Citation: *Fakhouri SF, Siqueira DPP, Araújo CA, Defino HLA, Shimano AC. The photoelastic analisys of vertebral fixation system screws. Acta Ortop Bras. [online]. 2009; 17(4):207-10. Available from URL: http://www.scielo.br/aob.*

INTRODUCTION

Photoelasticity is an experimental technique used for assessing tensions and its distribution on structural systems.[1] This technique allows for a swift qualitative and quantitative analysis of materials' internal tension status by observing optical effects of polarized light upon tension and deformation actions on photoelastic, elastic and clear models. The amount of deformation resulting from a force can be assessed by comparing reported tensions to a tension-free area.[2,3] By this technique, studies can be conducted using geometrically-shaped models and complex force distribution, or both.[4-6]

Vertebral fixation systems have been widely employed for treating traumatic, degenerative, tumoral diseases, and on vertebral spine deformities.[7-9] Screws are one of the anchoring elements of vertebral fixation systems, where the performance and the mechanical functions' properties of these systems are directly associated to the quality of screw fixation on vertebrae.[10-12]

Vertebral fixation systems' screws are usually submitted to flexion, shearing and pullout strengths. Pullout strength applied on screws produces tension around implants.[13,14]

A failure on vertebral fixation system's stability may be correlated to a mechanical failure of the implant or a failure on the interface between bone tissue and implant with pullout strength applied involving screws, causing system instability.[11] In this case, photoelasticity technique is an important tool for conducting comparative studies of this nature.

Therefore, the objective of this study was to observe, analyze and compare, by means of the photoelasticity technique, the internal tensions produced by a screw of 6 mm of outer diameter used on a vertebral fixation system, when submitted to two different levels of pullout strength.

MATERIALS AND METHODS

Four stainless steel screws measuring 6 mm of outer diameter and 50 mm in length used on the USS vertebral fixation system (Synthes®) have been employed in this study. (Figure 1)

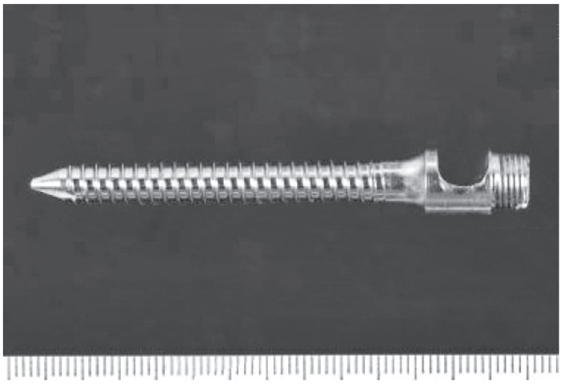

Figure 1 – *6-mm screw used in the study.*

All the authors state no potential conflict of interest concerning this article.

---

1 – Department of Biomechanics, Medicine and Rehabilitation of the Locomotive Apparatus, Ribeirão Preto Medical School, University of São Paulo (USP)
2 – Department of Mechanical Projects, Mechanical Engineering School, Federal University of Uberlândia (UFU)

Correspondences to: ***Av. Bandeirantes, 3.800, Laboratório de Bioengenharia – Campus universitário, Monte Alegre, Ribeirão Preto, SP. Brasil. CEP: 14.049-900.***
Email: sarahfakhouri@yahoo.com.br; ashimano@fmrp.usp.br

Received in: 11/05/07; approved in: 01/09/08

The photoelastic models were made of flexible photoelastic epoxy resin (Polipox®), using a proportion of 2.2 ml resin and 1.0 ml catalyzer (amine-based). The final model has the appearance of a 12-mm thick, 58-mm large, 50-mm long tetrahedron. (Figure 2) Four photoelastic models were built for the study.

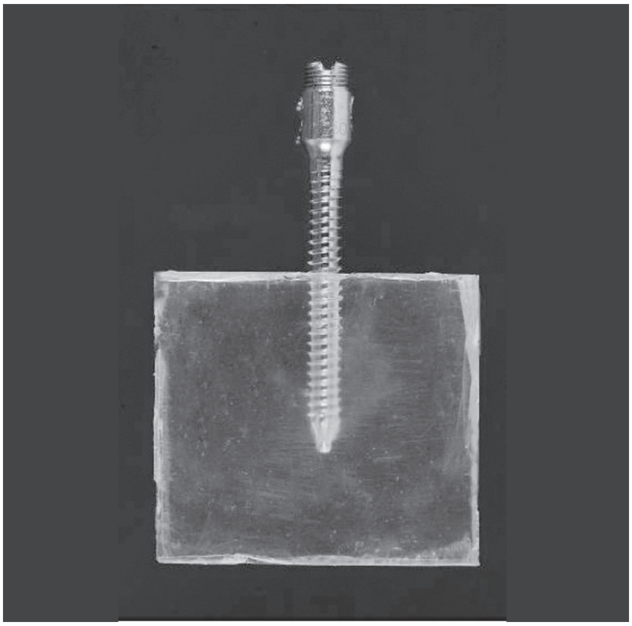

Figure 2 – *Front view of a photoelastic model with 6-mm screw.*

The screws were inserted on photoelastic models while resin was placed into the cast, with the insertion depth being standardized at 30 mm. For producing the models, a standard acrylic cast was used, enabling reproducibility of dimensions.

All photoelastic models employed in the study were submitted to evaluation for the presence of residual tension, named as edge effect, before the application of pullout strength on the screw. In the study, only photoelastic models not presenting residual tensions were used.

Photoelastic resin calibration was made with a circular disc under compressive load where the optical constant found was 0.21 N/mm fringe. This optical constant value was used for calculating shearing tensions.

Photoelastic Analysis

The photoelastic analysis was carried out on a transmission polaroscope (Figure 3) by applying pullout strength on the head of the screws inserted on photoelastic models. Tensions produced by screws were qualitatively and quantitatively assessed.

Qualitative Analysis

For making a qualitative analysis of tensions, the distribution of tensions around screws was assessed (starting point, kind of growth, and highest concentration point).

Quantitative Analysis

For making a quantitative analysis of the shearing tensions, a strength of 0.75 and 1.50 kgf, recorded by using a Kratos® load cell with 50 kgf capacity. In that analysis, internal tensions were checked by the fringe order of each photoelastic model, where shearing strengths were assessed in a standardized fashion along screw's body; Nineteen points were selected, the distribution of which is illustrated on Figure 4.

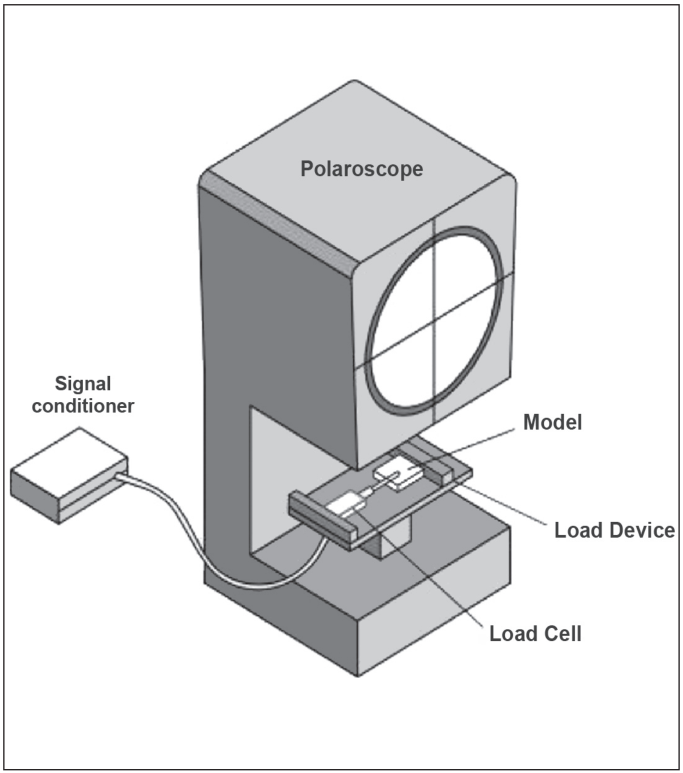

Figure 3 – *Schematic illustration of a transmission polaroscope.*

The maximum shearing strength (τ_{max}) around the screw was calculated using the Tardy[15] compensation method, represented by the formula below:

$$\tau_{max} = \frac{f \cdot N}{2 \cdot h}$$

Where: (f) corresponds to the optical constant of the model, (N) fringe order, and (h) model thickness.

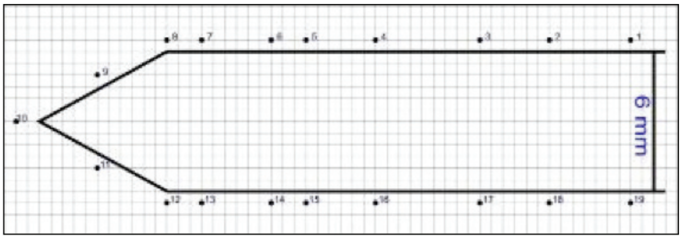

Figure 4 – *Illustration of the 19 selected points along screw body.*

For the analysis of results, the Multifactorial Variance Analysis method (ANOVA) was employed, with the following variables: Screw (with 2 levels) and the assessed Points (with 19 levels) in order to assess the behavior of data. For a comparative analysis between experimental groups, the Bonferroni's *post hoc* method was used. In all analyses, a significance level of 5 % ($p \leq 0.05$) was adopted.

RESULTS

Qualitative Analysis

On the qualitative analysis, the fringe order was assessed along the screws' crests on all photoelastic models. In all models, the starting point and the highest concentration point were found to be located on screws' tips, increasing in a helicoidal fashion.

Quantitative Analysis

In this analysis, shearing tensions were calculated on the 19 points on all photoelastic models. The mean values of screws' shearing tension are presented on Table 1. For a pullout strength of 0.75 kgf, the overall mean value and the standard deviation for shearing tension was (9.20 ± 3.12) KPa and, for a pullout strength of 1.50 kgf, the mean value and the standard deviation of the screws' shearing tension was (15.67 ± 4.52) KPa. (Figure 5) In the comparison between the mean shearing tensions values for both loads, a statistically significant difference was found ($p < 0.001$).

Table 1 – *Mean shearing tension values on the 19 points*

Points	Pullout Strength	
	0.75 kgf	1.50 kgf
1	5.46 ± 0.81	10.10 ± 0.17
2	6.54 ± 1.00	11.07 ± 0.13
3	6.96 ± 1.23	12.19 ± 0.69
4	7.68 ± 1.08	14.46 ± 0.73
5	10.18 ± 2.81	16.27 ± 1.07
6	10.06 ± 1.54	20.39 ± 3.29
7	11.78 ± 1.40	20.21 ± 0.78
8	11.30 ± 1.27	19.83 ± 1.97
9	13.12 ± 1.34	22.99 ± 1.07
10	14.43 ± 2.34	20.88 ± 2.30
11	12.54 ± 1.90	21.15 ± 2.23
12	10.56 ± 1.58	17.51 ± 0.44
13	10.19 ± 1.25	17.85 ± 1.00
14	11.46 ± 3.18	16.37 ± 0.12
15	8.60 ± 1.59	13.78 ± 2.56
16	7.33 ± 1.02	12.54 ± 0.64
17	5.95 ± 0.84	10.94 ± 0.57
18	5.66 ± 0.31	10.04 ± 0.69
19	5.07 ± 0.74	9.18 ± 0.58
Mean	9.20 ± 3.12	15.67 ± 4.52

DISCUSSION

Photoelasticity is used in the field of Orthopaedics and Traumatology, with several published articles, but we didn't find scientific reports using this technique in analysis of vertebral fixation system's components.

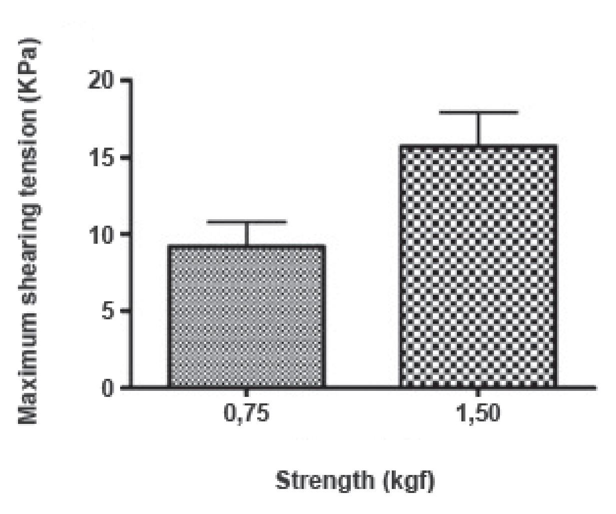

Figure 5 – *Comparison of the mean shearing tension values for 0.75 and 1.50 kgf strengths.*

The photoelasticity technique employed in this study was able to qualitatively and quantitatively[16] assess internal tensions produced by screws. The goal of the quantitative analysis of fringe orders was to determine the numeric values of shearing tensions, especially on the most critical points of the model.[5,17,18]

Screws directly melted on photoelastic models suggest a simulation of a screw submitted for a chronic postoperative period as seen in clinical practice.

Screw insertion into the model was limited to 30 mm, and this was performed in order to avoid screw head influence, making the models further standardized for photoelastic analysis. This limitation on screw's insertion into the model was also intended to simulate the models used by Defino et al.[19] as well, in which mechanical pullout assays of screws fixated on the lateral surface of lumbar vertebral bodies of pigs. For these models, the authors limited screw insertion to 30 mm in order to prevent opposite vertebral body cortical from being exceeded.

The qualitative analysis, in the photoelasticity technique, is a brief analysis of tension status by means of the assessment of optical effects on photoelastic models[5,18]. In this study, we could also visualize, in a fast and effective way, the sites with stronger shearing tensions around the screws. In a general analysis, we see that the fringe order started to grow at screws' tips, and the distribution of fringes followed the helicoidal formats of the screws' threads, especially at the crest. The site with the higher fringe order was always found on the first thread steps from the screw tip.

In the quantitative analysis, when using two different pullout strengths, we found that, on screw body, regardless of the strength applied, the highest shearing tension values were seen on the region close to the tips and on threads' crest peaks. We also noticed that, with increased pullout strength, the fringe orders also increased, and, consequently, shearing tension has also increased. This increased maximum shearing tension probably turns the region around the screw more critical, being more likely to get loose.

The results found in our study showed that the higher concentration of tensions generated on screws with the application of pullout strengths occurred on its end. However, in pullout assay studies, which represent another study modality, but also study this phenomenon, the pilot hole diameter close to screw head was reported to be the most important anchorage point[20]. With these studies, the authors suggest that the screw insertion point should be the most accurate and tight as possible. The comparison and the analysis of our results with the report by Daftari et al.[20] contribute for designing further studies to elucidate if the screw tip is the portion generating initial stronger tensions only or if this would be also the most resistant portion to strength application, provided the pilot hole diameter was homogenous throughout its length.

CONCLUSIONS

We noticed that, in all models, the starting point for fringe orders and the point of highest concentration of tension were located at screws' tips, helicoidally increasing, according to screw format. With increased pullout strengths, shearing tensions become more critical, thus making screw more likely to get loose.

ACKNOWLEDGEMENT

Study conducted with support by FAPESP and CAPES.

REFERENCES

1. Mahler DB, Peyton FA. Photoelasticity as a research technique for analyzing stresses in dental structures. J Dental Res. 1955;34:831-8.
2. Hirokawa S, Yamamoto K, Kawada T. A photoelastic study of ligament strain. IEEE Trans Rehabil Eng.1998;6:300-8.
3. Rubo JH, Souza EAC. Métodos computacionais aplicados à bioengenharia: solução de problemas de carregamento em próteses sobre implantes. Rev FOB. 2001;9:97-103.
4. Abdu AT. Estudo da distribuição de tensões na mandíbula humana usando fotoelasticidade tridimensional [dissertação]. Uberlândia: Departamento de Engenharia Mecânica da Universidade Federal de Uberlândia; 1994.
5. Doyle JF, Phillips JW. Manual on experimental stress analysis. 5th ed. Bethal: Society for Experimental Mechanics; 1978.
6. Wang W, Tsai Y. Digital dynamic photoelastic and numerical stress analyses of a strip. J Vibrat Control. 2006;12:927-38.
7. Boos N, Webb JK. Pedicle screw fixation in spinal disorders: a European view. Eur Spine J. 1997;6:2-18.
8. Hailong Y, Wie L, Zhensheng M, Hongxun M. Computer analysis of the safety of using three different pedicular screw insertion points in the lumbar spine in the Chinese population. Eur Spine J. 2007;16:619-23.
9. Vaccaro AR, Rizzolo SJ, Allardyce TJ, Ramsey M, Salvo J, Balderston RA et al. Placement of pedicle screws in the thoracic spine. Part 1: Morphometric analysis of the thoracic vertebrae. J Bone Joint Surg Am.1995;77:1200-6.
10. Benzel EC. Biomechanics of spine stabilization. In: Implant-Bone Interfaces. Nova York: Thieme; 2001. p.55-170.
11. Lastra J, Benzel CE. Biomechanics of internal fixation. In: Vaccaro AR, Betz RR. Zeidman SM, editors. Principles and practice of spine surgery.1st.ed. Mosby: St. Louis; 2003. p.43-65..
12. Law M, Tencer AF, Anderson PA. Caudo-cephalad loading of pedicle screw: mechanisms of loosening and methods of augmentation. Spine. 1993;18:2438-43.
13. Browner BD, Jupiter JB, Levine AM, Trafton PG. Skeletal trauma. 2a ed. Philadelphia: Saunders; 1998.
14. Coe JD. Influence of bone material density on the fixation of thoracolumbar implants: a comparative study of transpedicular screws, laminar hooks, and spinous process wires. Spine.1990;15:85-90.
15. Dally JW, Riley WF. Experimental stress analysis. 2ª ed. Nova York: Mcgraw-Hill; 1978.
16. Kinomoto Y, Torri M. Photoelastic analysis of polymerization contraction stresses in resin composite restorations. J Dent. 1998;26:165-71.
17. Araújo CA, Neves FD, Bernardes SR. Stress analysis in dental implants using the photoelasticity technique. Proceedings of the 3th National Congress of Mechanical Engineering, Belém. CD ROM; 2004.
18. Oliveira LCA. Análise comparativa da distribuição de tensões em incisivo central superior restaurado com diferentes sistemas de pinos intra-radiculares.[Dissertação]. Araraquara: Faculdade de Odontologia de Araraquara da Universidade Estadual Paulista; 2002.
19. Defino HLA, Wichr CRG, Shimano AC, Kandziora F. Influência do diâmetro do orifício piloto na resistência ao arrancamento dos parafusos do corpo vertebral. Acta Ortop Bras. 2007;15:76-9.
20. Daftari TK, Horton WC, Hutton WC. Correlation between screw hole preparation, torque of insertion, and pullout strength for spinal screws. J Spinal Dis. 1994; 7:139-45.