MECHANICAL PROPERTIES OF VERTEBRAL FIXATION USING AN INTERNAL FIXATOR WITH THE PARTICIPATION OF THE GRAFT AND OF A LATERAL STABILIZER

Rodrigo Okubo
Department of Biomechanics, Medicine and Rehabilitation of the Locomotor Apparatus, Faculty of Medicine of Ribeirão Preto, University of São Paulo, Av. Bandeirantes, 3900. 14049-900 Ribeirão Preto, SP, Brazil
miyagiokubo@yahoo.com.br

Gisele Kristina Reis Ale
Department of Biomechanics, Medicine and Rehabilitation of the Locomotor Apparatus, Faculty of Medicine of Ribeirão Preto, University of São Paulo, Av. Bandeirantes, 3900. 14049-900 Ribeirão Preto, SP, Brazil
gkraile@bol.com.br

Prof. Dr. Helton L. A. Defino
Department of Biomechanics, Medicine and Rehabilitation of the Locomotor Apparatus, Faculty of Medicine of Ribeirão Preto, University of São Paulo, Av. Bandeirantes, 3900. 14049-900 Ribeirão Preto, SP, Brazil
hladefino@fmrp.usp.br

Prof. Dr. Antônio Carlos Shimano
Department of Biomechanics, Medicine and Rehabilitation of the Locomotor Apparatus, Faculty of Medicine of Ribeirão Preto, University of São Paulo, Av. Bandeirantes, 3900. 14049-900 Ribeirão Preto, SP, Brazil
ashimano@fmrp.usp.br

Abstract. *The fixation system has been extensively used in modern spine surgery in order to provide stability of the vertebral segment and/or to correct deformities.The objective of the present study was to evaluate the participation of the graft and of the lateral stabilizer in the mechanical stability of vertebral fixations with an internal fixator. The experimental model consisted of two blocks of mahogany wood which simulated the vertebral segment fixed with an internal fixator. Three experimental groups of 10 models each were used. Group 1: an assembly with an internal fixator only; Group 2: an assembly with a graft; Group 3: an assembly with a graft and a lateral stabilizer. Mechanical tests of the flexion-compression, lateral flexion and torsion types were performed only up to the elastic phase of resistance of the assemblies using deflexions of 1.5 and 2.0 mm and an angular deformation of 9.5^{o}, respectively. The mechanical tests were performed with a Universal Testing Machine using specific accessories for each type of test. Data were analyzed statistically by ANOVA and by the Tukey-Kramer test, with the level of significance set at 5%.. Comparison of groups 2 and 3 for the flexion-compression tests did not show a significant difference, whereas all other comparisons showed significant differences. For the lateral flexion tests, there was a significant difference between groups 1 and 3, but not between any other groups. In the torsion tests, again, there was a significant difference between groups 1 and 3, but not between any other groups. The use of a graft and/or a lateral stabilizer improved the stability of the assembly in the flexion-compression, lateral flexion and torsion tests regarding the property analyzed.*

Keywords*: Vertebral fixation, internal fixator, spine, mechanical tests.*

1. Introduction

The spine is a segmented cuirasse whose segments are arranged in such a way as to prevent aggressive forces, moving in any direction. It consists, on average, of 7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccigeal vertebrae. These 33 vertebral bodies represent the main pillars of the spine, all of them having their own characteristics (An, 2001)

The spine has flexibility which is provided by the mobility between the vertebral bodies. Stability is provided by its ligament and osteomuscular structure. In addition to these characteristics, the spine has other important functions such as protection of the spinal cord, aiding movement and gait, maintenance of an erect position, support of body weight and linkage of all its regions from the occipital bone to the sacrum (Ashman *et al.*, 1989).

Arthrodesis is the surgical procedure most frequently employed in the treatment of orthopedic and traumatic diseases of the spine because of the anatomical and physiological characteristics of this segment of the locomotor apparatus. The oldest reports of internal fixation of the spine date back to 1891, with Berthold Hadra in Galveston and to 1909, with Fritz Lange in Munich. The next great advance in spinal surgery occurred with the development of the Harrington rods in 1962 (Dick, 1987; Ebraheim *et al*, 1994).

The searches for surgical solutions for situations of mechanical instability of the spine have guided the development of systems of vertebral fixation. Pedicle fixation represented a great advance in modern spinal surgery due to its ability to achieve rigid segmental fixation (Fraccaroli, 1981) with high rates of bone consolidation (Greve e Amatuzzi, 1999).

The thoracolumbar region is one of the sites of higher incidence of spinal injury, with various diseases potentially leading to spinal instability. Among the main causes are traumatic injuries, tumors (primary and metastatic) and degenerative diseases (Harrington, 1962). The vertebral region most suitable for screw implantation is the lumbar one because of the wider diameter of the pedicles. Pedicle implants can also be used in the thoracic region, but with caution, due to the smaller dimensions of the pedicles and the proximity of neural structures (Kim *et al.*, 1994; Knoplich, 1985).

The biomechanical advantages of the technique of transpedicle fixation are as follows: the pedicle, being the most resistant site of the vertebra, provides adequate fixation of the pedicle screws; posterior surgical access is easier; the patient can start walking earlier after the operation; there is no need for external postoperative support. The disadvantages are: difficult stabilization of the screw in vertebrae with osteoporosis, the limited use in certain regions of the spine, the need for in-depth knowledge of local anatomy, and the skill needed for screw implantation in the pedicles (Krag *et al.*, 1986).

Although this procedure is applied in order to increase the mechanical stability of systems of pedicle fixation, resulting in better rates of bone consolidation, its participation in the stability of these systems of vertebral fixation has not been fully clarified (Luque, 1986).

In view of the controversy about pedicle fixation, the present study was carried out with the main objective of determining the participation of the graft and of lateral stabilization in the mechanical stability of different assemblies with an internal fixator in a situation of vertebral corpectomy in which the variable under study were related to the type of assembly.

2. Materials and Methods

2.1. Materials

The present experiment was based on the use of test bodies made of wood, with the parameter of analysis being the mechanical resistance of internal spine fixators, with the assembly of the groups proposed varying to simulate a corpectomy (lack of a vertebral body), and with screws fixed to the vertebral pedicles using a graft with or without lateral stabilization (Shimano, A.C.; Defino, H.L.A. e Souza, R.C.B., 1998).

For each experimental model (assembly**)** two wood bodies were used, simulating the vertebrae. The bodies were cylindrical in shape, 55 mm in diameter and 95 mm long. In one of the bodies, one of the ends was reduced in diameter to 1 inch. This side was used to fix the model to the accessory part of the system.

The system of pedicle fixation used in the tests was a stainless steel Synthes® internal fixator system consisting of 4 Schantz type pins, and 4 mechanisms of fixation joining 2 pins to the rods. The pins measured 5 mm in diameter and the longitudinal rods were 6 mm in diameter by 100 mm in length.

The structures simulating the bone grafts were made of mahogany and were 46 mm long and 22 mm in diameter.

Lateral stabilization was performed using 3 pedicle screws 5 mm in diameter and 30 mm in length, a joining mechanism of the longitudinal rod and the screw fixed in the graft. The longitudinal rod was 6 mm in diameter by 150 mm in length.

2.2. Mounting of the experimental models

In order to maintain the standardization of the measurements and the angulation established by the norms *International Standardization for Organization (ISO/TC 150/SC 5/WG 2. Document n 107, Pt 2a)*, a guide was used during the mounting of the test bodies to perforate the wood models and to introduce the metal implants, with the aim of reducing the experimental errors. The main measurements recommended by the norm are a 46 mm space between the bodies and an angulation of 30^{o} between the screws, simulating the angles of the pedicles.

To mount the models, the two wood bodies were fixed in a clamp with the guide already positioned for the execution of the perforations with the burs. The wood bodies were perforated with a manual drill using a burr 3.8 mm in diameter. With the holes ready, the guide was removed and the four Schantz pins were put in place and later fixed with two longitudinal rods, thus joining the two wood bodies. The entire assembly was standardized, with a 10 mm distance being always left between the mechanisms of fixation and the wood.

2.3. Experimental Groups

Three experimental groups were set up, with the following three types of tests being performed for each group: flexion-compression, lateral flexion, and torsion. Ten experimental models were used for each type of test, for a total of 90 tests. For group 1, a simple assembly was used employing only the internal fixator system (Fig. 1); for group 2, an assembly of the fixator system combined with the wood graft was used (Fig. 2) and for group 3 an assembly combining the fixator, graft and lateral stabilizer was used (Fig. 3).

Figure 1: Group 1 model, a fixator only

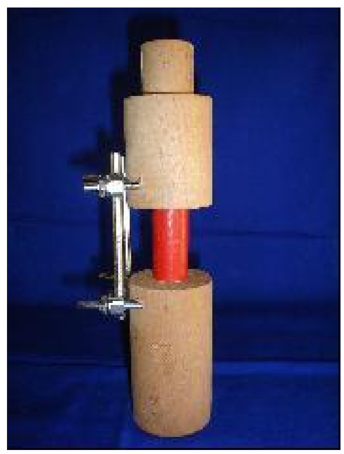

Figure 2: Group 2 model, an internal fixator combined with a wood graft

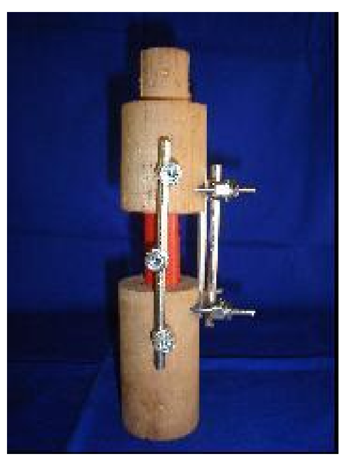

Figure 3: Group 3 model, an internal fixator combined with a graft and a lateral stabilizer

2.4. Mechanical Tests

The mechanical tests of flexion-compression, lateral flexion and torsion were performed on the Universal Testing Machine of the Bioengineering Laboratory of the Faculty of Medicine of Ribeirão Preto, USP. The applied loads and deflexions were controlled and measured with the Tesc® software in a microcomputer. A load cell with the capacity to measure up to 200 kgf was used for the 3 types of test.

2.4.1. Flexion-compression test

In this test, a preload of 15 N was used, with a time of accommodation of 30 seconds. The rate of load application was 1 mm/min. A maximum deflexion of 1.5 mm was standardized.

For the tests, the models were positioned vertically, resting on the base of the testing machine. The load was always applied by forming a 40 mm lever arm between the fixator and the site of load application (Fig. 4).

Figure 4: model positioned for the flexion-compression tests.

2.4.2. Lateral flexion test

In this test, a preload of 15 N was used, with an accommodation time of 30 seconds. The rate of load application used was 1 mm/min. A maximum deflexion of 2 mm was standardized.

For the lateral flexion tests, the models were positioned horizontally and were fixed by their finest portion to an accessory fixed on the base of the testing machine. Load application was always performed at a site located at a distance of 180 mm from the fixed point of the model (Fig. 5).

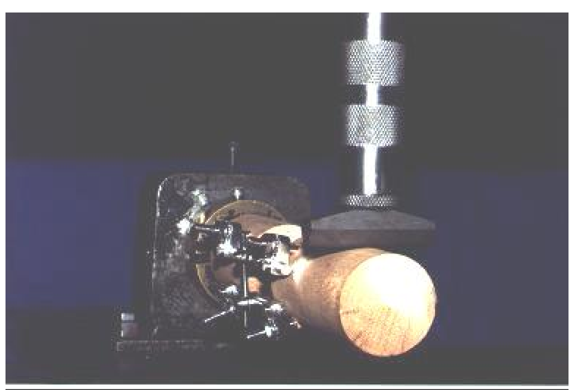

Figure 5: Model positioned for the lateral flexion test

2.4.3. Torsion test

In this test, a preload of 20 N was used, with an accommodation time of 30 seconds. The rate of load application was 1 mm/min. A maximum angular deformation of 9.5% was standardized.

For the torsion tests, the model was fixed in the horizontal position to an accessory part to which one side was fixed rigidly while on the other side a ball bearing system caused the model to turn freely. On this side, a steel wire around this accessory part causes torsion of the model when the machine starts to stretch the wire (Fig. 6).

Figure 6: Model positioned for the torsion test.

In each mechanical test performed, a load x deflexion line resulted on the diagram for the flexion-compression and lateral flexion tests. In the torsion tests, a load x angular deformation line resulted on the diagram. Only mean maximum torque was analyzed for all tests.

2.5. Statistical analysis

The mean maximum torque values were calculated for each experimental group in each test and were then analyzed by ANOVA to determine normality of the data, followed by the Kolmogorov-Smirnov test. The level of significance was set at 5%.

3. Results

3.1. Flexion-compression test

The mean maximum torque values for the flexion-compression tests were: Group 1 (7.4 ± 0.7) N.m, Group 2 (55.7 ± 20.0) N.m and Group 3 (60.2 ± 16.3) N.m (Fig. 7). Only the comparison between groups 2 and 3 did not show statistical significance, whereas all other comparisons showed significant differences ($p < 0.05$).

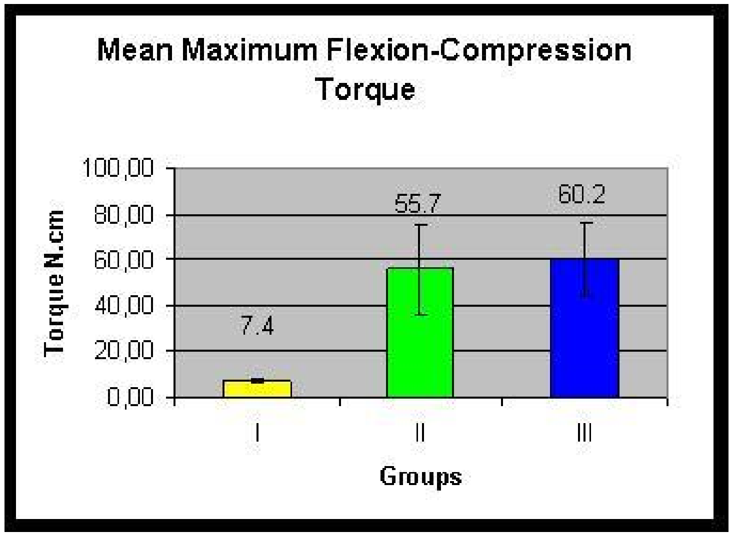

Figure 7: Means and standard deviations for mean maximum torque in the flexion-compression tests

3.2. Lateral flexion test

The mean maximum torque values obtained for the lateral flexion tests were: Group 1 (5.2 ± 0.9) N.m; Group 2 (6.7 ± 1.9) N.m and Group 3 (8.7 ± 3.1) N.m (Fig. 8). A statistically significant difference was observed only between groups 1 and 3 ($p< 0.05$), whereas no significant difference was observed in the other comparisons.

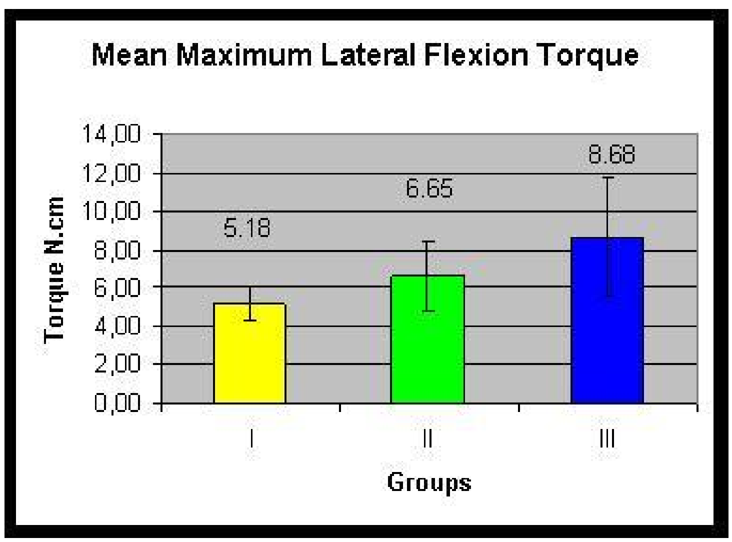

Figure 8: Mean and standard deviation values for mean maximum torque obtained in the lateral flexion tests

3.3. Torsion test

The following mean maximum torque values were obtained for the torsion tests: Group 1 (1.6 ± 0.4) N.m; Group 2 (2.1 ± 0.3) N.m and Group 3 (2.1 ± 0.7) N.m (Fig. 9). A statistically significant difference was observed only between groups 1 and 3 ($p< 0.05$), whereas no significant difference was observed in the other comparisons.

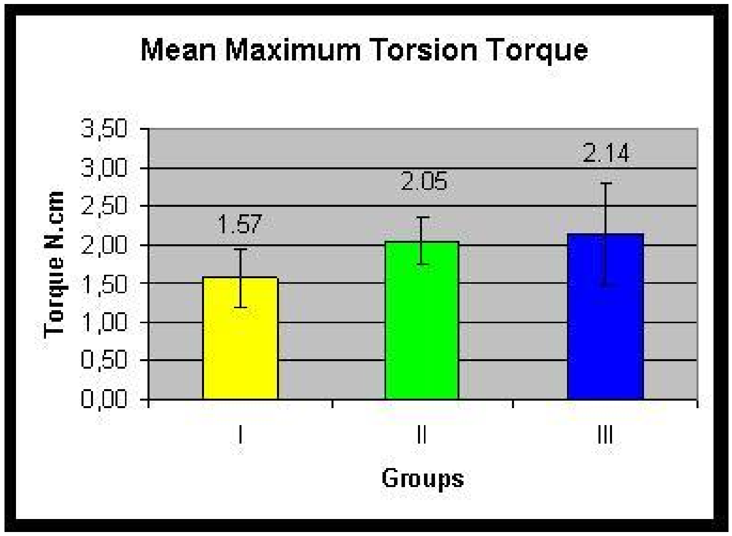

Figure 9: Mean and standard deviation values for mean maximum torque in the torsion tests

4. Discussion

According to Ashman (1989), pedicle fixation represented a great advance in modern spine surgery because of its ability to achieve a rigid segmental fixation. However, according to Roy-Camille (1986), the use of a graft alone, which is of fundamental importance for vertebral arthrodesis, does not correct the vertebral deformities because it does not block the movements until bone integration occurs, with consequent unacceptable rates of pseudoarthrosis.

In order to show the influence of the central graft associated or nor with bilateral stabilization when using an assembly with a spine fixator, we submitted the assemblies to different mechanical tests (flexion-compression, lateral flexion and torsion) according to ISO norms. We observed that the graft proved to be important in the flexion-compression tests, but did not cause a significant improvement for maximum torque when combined with lateral stabilization. In the lateral flexion tests, when we used only the graft without the lateral stabilizer (group 2), there was no significant improvement for the assembly compared to group 1. In contrast, when the graft was combined with the lateral stabilizer (group 3), a perceptible improvement of the results was observed and in the torsion tests again it was observed that the graft alone without the lateral stabilizer did not improve the results. When the graft was combined with the stabilizer, the improvement was significant.

5. Conclusion

According to results, the use of a graft proved to be important for the flexion-compression test, increasing the stability of the assembly. The lateral stabilizer with a graft increased the stability of the assembly in the lateral flexion and torsion tests.

6. Acknowledgements

This work was supported by CAPES (Fundação Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), and FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo).

7. References

An, H.S., 2001, “Cirurgia da coluna vertebral”. Manual prático. 1ª ed., Rio de Janeiro, Ed. Revinter LTDA.
Ashman, R.B. et al., 1989, Biomechanical analysis of pedicle screw instrumetation systems in a corpectomy model. “Spine”, Vol. 14, n. 12, pp. 1398-1405.
Dick, W. 1987. The ‘fixeteur interne’ as versatile implant for spine surgery. “Spine”, Vol. 12, n. 9, pp. 882-900.
Ebraheim, N.A. et al., 1994, Use of titanium implants in pedicular screw fixation. “Journal of Spinal Disorders”, Vol. 7, n. 6, pp. 478-486.
Fraccaroli, J.L., 1981, “Biomecânica – análise dos movimentos”. 2ª ed., São Paulo, Ed. Cultura Médica.
Greve, J.M.D.A. e Amatuzzi, M.M., 1999, “Medicina de reabilitação aplicada à ortopedia e traumatologia”. 1ª ed., São Paulo, Ed. Roca LTDA.

Harrington, P.R., 1962, Treatment of scoliosis. Correction and internal fixation by spine fixation. “The Journal of Bone and Joint Surgery”, Vol. 44A, pp. 591-610.

Kim, N.H. et al., 1994, Morphometric study of the pedicles of thoracic and lumbar vertebrae in Koreans. “Spine”, Vol. 19,n. 12 pp. 1390-1394.

Knoplich, J., 1985, “A coluna vertebral da criança e do adolescente”. Ed. Paramend.

Krag, M.H. et al., 1986, An internal fixator for posterior application to short segments of the thoracic, lumbar, or lumbosacral spine desing and testing. “Clinical Orthopaedics and Related Research”, n. 203, pp. 75-93.

Luque, E.R., 1986, Interpeduncular segmental fixation. “Clinical Orthopaedics and Related Research”, n. 203, pp. 54-57.

Roy-Camille, R.; Saillant, G. and Mazel, C., 1986, Internal fixation of the lumbar spine with pedicle screw plating. “Clinical Orthopaedics”, Vol. 203, pp. 7-17.

Shimano, A.C.; Defino, H.L.A; Souza, R.C.B., 1998, “Avaliação biomecânica na estabilidade do sistema de fixação vertebral”. Anais do Fórum Nacional de Ciência e Tecnologia em Saúde. pp. 25-26.