INFLUENCE OF VERTEBRAL PEDICLE SIZE ON INSERTION TORQUE AND PULLOUT RESISTANCE OF PEDICLE SCREWS

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

André L. S. Grava
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
andgrava@uol.com.br

Célia Regina Galloro
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
celiagalloro@terra.com.br

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

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

Abstract. *An experimental study was carried out in order to assess the influence of vertebral pedicle size on the resistance to insertion and pullout strength of pedicle screws of vertebral bodies. Synthes® screws of the USS1 type, 5 mm in diameter, were used. The vertebral bodies were obtained from adult Landrace pigs aged 150 days and weighing on average 80 kgf. The following three experimental groups, of 10 test models each, were used: Group 1, 14-mm long pedicle; Group 2, 7-mm long pedicle; Group 3, no pedicle. The insertion and pullout tests were performed on the two pedicles. After standardization of vertebral pedicle length, orifices were drilled with a 3.8 mm burr, corresponding to the inner diameter of the screw. After this procedure, the insertion torque of the screws up to a depth of 25 mm was measured with a guide system coupled to a torque meter. The inserted pedicle screws were submitted to the pullout test using the EMIC® Universal Testing Machine. Data were analyzed by ANOVA and the Tukey-Kramer test at the 5% level of significance. The mean maximum pullout strength values were: Group 1 (1053 ± 179) N, Group 2 (962 ± 191) N and Group 3 (1002 ± 112) N. The mean maximum insertion torque values were: Group 1 (0.71 ± 0.11) Nm, Group 2 (0.69 ± 0.21) Nm and Group 3 (0.77 ± 0.30) Nm. No statistically significant differences were observed between the 3 groups for pullout strength or insertion torque. The results show that the presence and size of the pedicle were not important for the insertion torque or pullout resistance of the screw.*

Key Words: *pedicle, pedicle screw, insertion torque, pullout strength, pedicle fixation*

1. Introduction

The use of screws for spinal fixation is not a recent proposal. In 1944, King used screws to fix the facet articulation in the lumbosacral spine and, since then, new techniques and investigations have improved the results obtained with spine fixation using screws.

The introduction of intrapedicular fixation by Roy-Camille *et al.* in 1963 provided a strong impulse for the use of instrumentation by the posterior route with a pedicle screw, which has progressively become the most popular and efficient method of internal vertebral fixation for the treatment of various spinal pathologies such as vertebral fractures, scoliotic deformities, metastases, and degenerative disorders (Olsewski *et al.*, 1990). The advantage of this procedure is a more rigid spinal fixation that provides a rapid incorporation of the bone graft and subsequent segment fusion. This fixation is based on the behavior of screws fixed in the pedicle or in the vertebral body (Roy-Camille *et al.*, 1986; Louis, 1986; Hirabayashi *et al.*, 1991; Yuan *et al.*, 1994; Moore *et al.*, 1997). The first internal fixers for the treatment of vertebral fractures were then developed. The most recent advancement in the systems of vertebral fixation occurred with the use of pedicle screws, which have the property of withstanding loads in all directions, with the consequent observation of great biomechanical advantages (Shimano *et al.*, 1998).

Clinical aspects participate in and influence the clinical results obtained. The vertebral pedicles are osseous expansion connected to the vertebral body in its anterior portion and to the vertebral bone lamina in its posterior portion. They form the lateral surface of the vertebra and have the articular apophyses in their posterior portion. The pedicle limits the rachidian canal on both sides and is connected to the adjacent vertebrae through its articular apophysis (Knoplich, 1986).

The lumbar pedicle is the most resistant part of the vertebra. It is a cylindric cortical bone surrounded by a small cancellous bone. The medial side of the pedicle is close to the cauda equina and to the vertical segment of the roots. The roots are located very close, below the pedicle. When perforated, this is the most dangerous site. At other sites, laterally and above, a perforation is less dangerous (Roy-Camille *et al.*, 1986)

Zindrick *et al.* (1986) carried out biomechanical studies with transpedicular fixation using 29 human lumbosacral spines removed from cadavers. The pullout tests on the screws showed that failures occurred due to pedicle fracture in the vertebrae of younger specimens and due to osteoporosis in older specimens, without pedicle fracture. The screws inserted as far as the anterior vertebral cortex presented more strength than those inserted to a 50% depth into the vertebral body. Screws measuring 6.5 mm in diameter provided stronger anchorage than cortical screws measuring 4.5 mm in diameter. The use of methacrylate injected under pressure into the screw hole provided better anchorage strength in osteoporotic vertebrae. There was no difference in anchorage strength between the right and left side.

A biomechanical study using pedicle screws in thoracic vertebrae from cadavers was carried out to determine pullout strength, insertion torque and mineral bone density (Lehman *et al.*, 2003).

Previous studies have discussed the insertion torque regarding the properties of the bone materials and screw fatigue in bone. A screwdriver was adapted to measure torque during screw insertion. Based on a series of experiments, recommendations were schematically presented for optimum utilization of the screw in terms of inner diameter and for an insertion technique in terms of hole size. The properties of the bone into which a screw is inserted are determinant factors for the pullout strength of the screw. However, certain variables such as type of screw and method of hole preparation can also cause variation of the maximum pullout strength of the screw (Daftari *et al.*, 1994).

Öktenoglu (2001) investigated the effect of performing a guide hole before inserting the screw into the bone in pullout tests on the screws using or not an initial guide hole. He observed that such hole reduced the insertion torque and the pullout resistance of the screw. This guide hole is made before in order to guide and facilitate the insertion of the screw into the bone.

Other factors can also affect the pullout strength of the screw, such as bone mineral density and composition, insertion technique and screw model. All of these factors contribute to the need to make a clinical decision about the choice of the implant to be used (Pennal *et al,* 1964; Brantley *et al.*, 1994; Öktenoglu, 2001).

The choice of a screw for internal fixation in the bone is made by taking as reference the varieties of screws available, which differ not only in terms of material, geometry and dimensions, but also in terms of insertion technique. The choice of a good implant is difficult due to the almost total lack of information about implants, mainly regarding their mechanical properties determined in in vivo experiments (Cohen, 1961; Ansell *et al.*, 1968).

The resistance between the screw and the bone is the limiting factor of implant stabilization, at least during the first days or week. Metal fatigue or bone reabsorption may trigger a later problem. The pullout resistance of a pedicle screw is influenced by the profile, diameter and dimension of the screw thread (Krag *et al.*, 1986). The pedicle seems to be the strongest and most accessible site for the use of screws. The size of the screw may be a limiting factor in fixation into the vertebral body through the pedicle (Krag *et al.*, 1986). The most favorable vertebral segment for screw implantation is the lumbar region because of the larger diameter of the screws (Kim, 1944; Scoles *et al.*, 1988; Vaccaro *et al.*, 1995; Kothe *et al.*, 1997).

The interest in the use of pedicle screws has permitted the development of a large number of fixation systems which are currently available on the market. The vertebral fixation systems that utilize pedicle screws continue to be used for the treatment of various diseases of the spine such as fractures, deformities, tumors, and degenerative pathologies.

The present experimental study was carried out with the objective of assessing the influence of the size of the vertebral pedicle on the resistance to insertion and the pullout resistance of pedicle screws inserted into the lumbar vertebrae of swine.

2. Materials and Methods

2.1. Materials

Twenty vertebral bodies of four spines from male Landrace pigs (mean age: 150 days; mean weight: 80 kgf) were used. The spines were supplied by an abattoir in the municipality of Colina, SP. The selected spines were dissected and separated and the vertebral bodies from T9 to L6 were identified. The material was stored in a freezer at a mean temperature of -20º C.

The screws used in the experiments were of the USS1 type (Synthes®), 5.0 mm in outer diameter, 3.8 mm in inner diameter, with a 2.0 mm thread and 52.0 mm long.

2.2. Experimental Groups

Before the formation of the experimental groups, the central region of each pedicle of each vertebra was measured. Three experimental groups were set up, each submitted to 10 tests. The size of the pedicle was standardized at a length of 14 mm for group 1 and of 7 mm for group 2. In group 3, the pedicle was completely removed.

2.3. Experimental Model

Each vertebra was fixed to a clamp and a hole was drilled through the pedicle using a manual drill with a burr 3.8 mm in diameter. Using a screwdriver stabilized with a magnetic support and guided by a system, the hole was positioned according to the anatomical angulation of the pedicle for placement of the screw. The entire system was fixed on a metal base. One end of the screwdriver was coupled to the screw and the other to a Mackenna® torque meter. After the screw, screwdriver and torque meter were placed in the initial reference position for the measurements, the insertion of the screw was started and its torque was measured at each turn until the entire thread was inserted into the pedicle (Figure 1). On average, 12 turns in the torque meter were necessary to tighten the screw to the end of the thread. The depth of penetration of the screws was standardized at 25 mm for all three experimental groups. Figures 2 and 3 show the screw fixed inside the pedicle of the vertebral body.

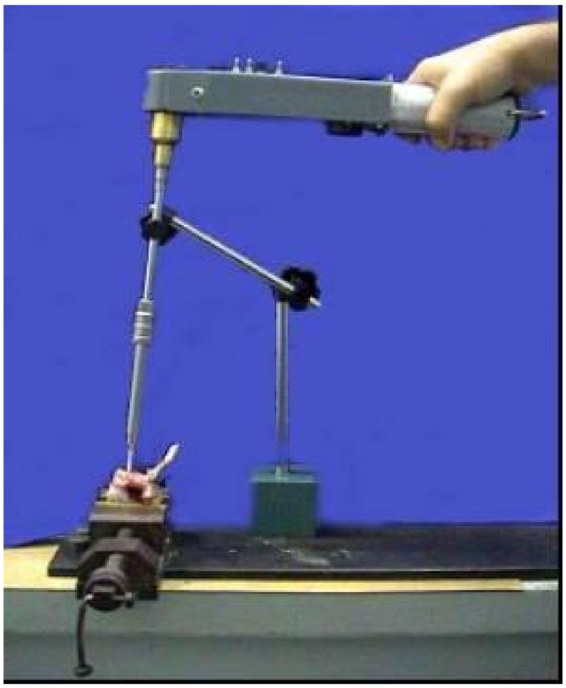
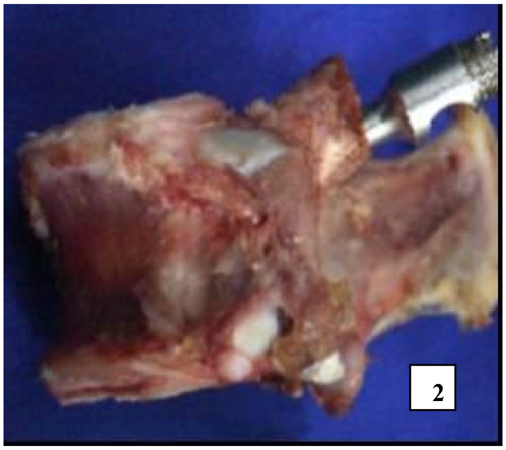
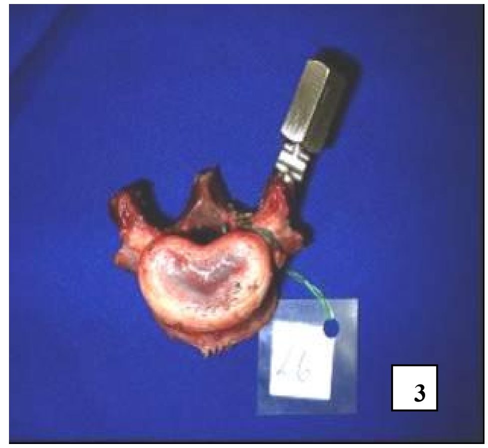


Figure 1. System used to measure the insertion torque.





Figures 2 and 3. Screw inserted into the vertebral pedicle

2.4. Pullout test

For the screw pullout tests a coupling accessory was constructed and screwed onto the head of the screw externally with a washer and internally with another smaller screw, providing stable fixation. In the upper end of this accessory there is a transverse hole which is transfixed with a pin for the coupling of the steel handle for the execution of the test.

The pullout step is performed with the vertebral body positioned and fixed in a clamp at the base of the Universal Testing Machine (EMIC®) (Figure 4). The upper end of the screw was fixed to the mobile piston of the machine through the steel handle. Figure 5 illustrates a detail of the experimental model being tested.

Figure 4. Universal testing machine

Figure 5. Experimental model being tested

The Universal Testing Machine used was from the Bioengineering Laboratory of the Faculty of Medicine of Ribeirão Preto, USP. A load cell with the capacity to measure up to 200 kgf was used. A TESC ® program permitted the control of the measurements through a computer coupled to the testing machine. The rate of load application used was 1 mm/min. The tests were carried out at an ambient temperature of 25° C.

The tests were performed until rupture or until the total loss of pullout resistance of the screw.

2.5. Statistical Analysis

The mean insertion torque and pullout resistance values for the screws of the three experimental groups were analyzed statistically by ANOVA to determine the normality of the data, followed by the Tukey-Kramer test. The level of significance was set at 5%.

3. Results

The mean maximum insertion torque values are first presented, followed by the mean maximum pullout loads of the screws.

3.1. Mean maximum insertion torque

The torque value increased up to a certain number of turns of the screw and then remained constant until the end. To determine the mean maximum insertion torque we always determined the maximum value for each screw inserted, as measured by the torque meter.

Mean maximum insertion torque was (0.71 ± 0.11) N.m for group I (pedicle length of 15 mm), (0.69 ± 0.21) N.m for group II (pedicle length of 7 mm), and (0.77 ± 0.30) N.m for group III (no pedicle). No significant difference was observed between groups ($p \geq 0.05$) (Figure 5).

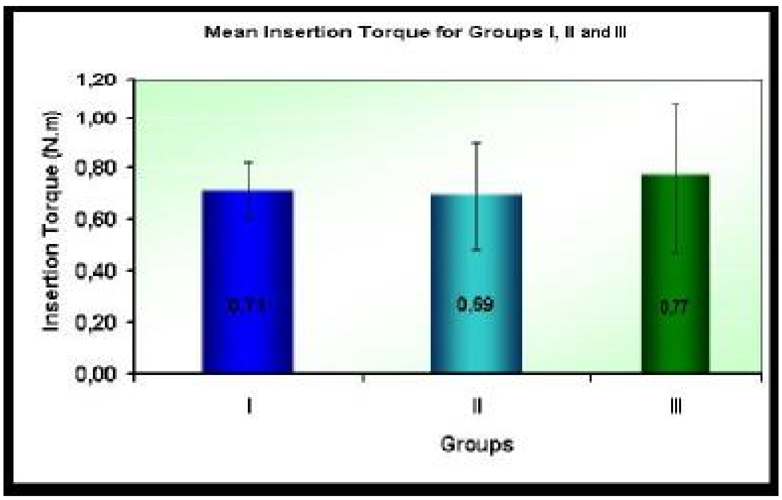


Figure 6. Graphic Presentation of Mean Insertion Torque for Groups I, II and III.

3.2. Mean maximum loads

The mean maximum load was (1053 ± 179) N for group I, (962 ± 191) N for group II and (1002 ± 112) N for group III. No significant differences were observed between groups ($p \geq 0.05$).

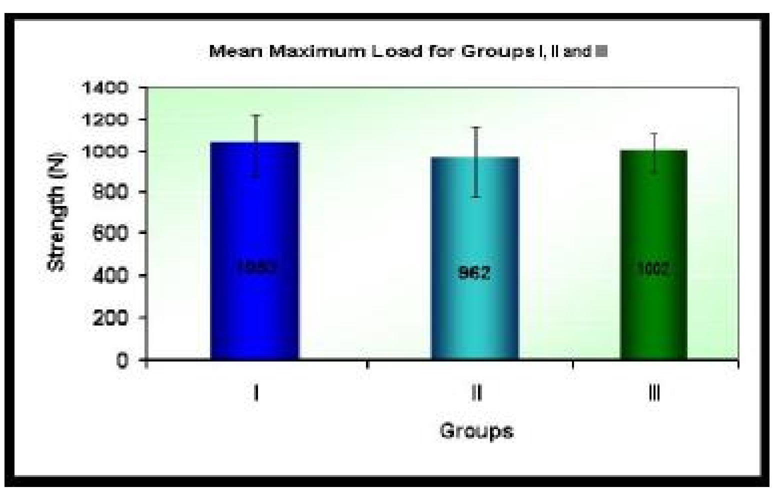


Figure 7. Graphic Presentation of the Mean Maximum Loads for Groups I, II and III.

4. Discussion

In general, bones are not homogeneous, especially regarding the posterior surface of vertebral bodies and their pedicles. Their geometrical shape with its important angulations makes it difficult to mount a stable system for the placement of pedicle screws. Even when the age and weight of the animals are standardized, the dimensions of the vertebrae vary, even in the same animal. In the present tests, care was taken to respect the anatomical shape of each pedicle.

In the mechanical pullout tests, the positioning of the experimental model was always respected, with the screw being always kept in a vertical position together with the steel handle, so that no other type of effort might affect the results.

A problem observed in some tests was the loosening of the vertebral body from the clamp, which probably occurred due to the great pullout resistance of the screw or to the non-homogeneity of the vertebra, which impairs fixation in the clamp.

Pedicle screws come in different sizes. In the present study we opted for screws with an outer diameter of 5 mm, which was better adapted to the anatomy of the vertebral pedicles of swine, and also because these screws were easily available in our service.

The results obtained for mean maximum insertion torque showed that pedicle length did not significantly affect its value. An important detail is that, since we standardized the depth of penetration of the screws and varied the size of the pedicle, in group III, vertebrae without pedicle, the screw was fixed directly into the vertebral body and, on the basis of the depth and size of the body, the screw reached the opposite cortical bone. This probably caused an increase in the absolute value of the insertion torque and of pullout resistance in this group compared to group I, in which the pedicle was left in place almost in its entirety.

Among the characteristics that qualify the pedicle as the anchoring point for vertebral implants, particularly important is its considerable resistance, which causes it to be the site of greatest rigidity and biomechanical compatibility of the vertebra, appropriate to receive the implant. Its easy access by a posterior surgical approach provides good anchorage for the implant in each instrumented vertebra and control of the instrumented segment (Kabins, 1996).

The vertebral pedicle is classically considered to be a cylindric structure of cortical bone filled with a small amount of cancellous bone on whose medial and inferior borders the roots of the spinal nerves are lodged (Saillant, 1976).

When we analyzed the torque and load values for group II we noted that, in absolute numbers, they were lower than those for groups I and III. Between groups I and III, the values showed an increasing order. This was probably due to the lack of the pedicle and to the distance from the opposite cortical bone.

This experiment showed the importance of cortical bone for screw fixation. The strength of screw fixation depends on the combined strength of cortical and cancellous bone. If cortical bone is removed, even from just some areas, the strength of fixation will decrease since the resistance of cortical bone is more reliable than that of cancellous bone, which is relatively weaker.

Analysis of these parameters shows that the fixation of the pedicle screw is not affected solely by pedicle preparation. The depth of screw insertion and screw anchorage to the anterior cortical bone of the vertebral bodies were important factors affecting the results obtained. It is necessary to establish additional criteria and to study other properties that might interfere with the fixation of these pedicle screws.

5. Conclusion

The importance of the presence of pedicles for the resistance of pedicle screws to rotational and lateral movements is clinically recognized. However, the results obtained in the present study show that the presence and size of the pedicle were not important for the increase or lack of increase of the insertion torque and of resistance to longitudinal pullout of the screw.

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