

# RESISTANCE OF OSTEOSYNTHESSES WITH PLATES AND SCREWS IN ANTERIOR CERVICAL SPINE FIXATION: AN EXPERIMENTAL STUDY

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## SUMMARY

In order to evaluate the stability of the anterior fixation with plate and screws, the author conducted an experimental study in segments of the cervical spine (C3-C7) in fresh human cadavers, comparing 3 different types of plates. He used a H-type Orozco's plate (4 specimens); a conventional plate of 1/3 tubular (4 specimens); plates described by Mendonça (5 specimens); and the control group without fixation (5 specimens). In all specimens a Corpectomy was used and the lateral walls of the vertebral bodies were left intact. The specimens were tested in axial compression machine, with slow and progressive loading, using mechanical graphic recorder. Results have shown that, concerning initial failure,

stabilization of the fixations is similar among groups but inferior to the control group. Statistically, the difference was significant between the control group and the 1/3 tubular and Mendonça plates, but it was similar to the H plate. Concerning maximum resistance, no significant differences were observed in comparing fixations to the control group. Based on the results, the author concludes that fixation with the H plate offers better stability when compared to other fixations and that the plates and screws used in the study decreased resistance when compared to the control group.

**Keywords:** Spinal injuries; Fracture fixation, internal; Bone plates; Bone screws; Cadaver

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## INTRODUCTION

Overall, traumatic injuries of the cervical spine result in serious socioeconomic problems to society. For example: the incidence of spinal cord injuries in the United States is as high as 50 cases in each million people a year, which means about 10,000 new cases each year. The approximated cost for society for each new cervical injury with neurological deficit has been estimated by the American Spinal Injury Association into US\$ 400,000. Medical treatment costs for these patients, in the short term, reached amounts of approximately US\$ 1.5 billion in 1980 in the United States, while for society and for all spinal cord injured patients, it reached to US\$ 4 billion<sup>(1)</sup>. Although these values point out to a relevant problem, the tragedy of spinal cord injuries is only fully understood when its consequences on patients' lives are considered, particularly those resulting in paraplegia or quadriplegia, most of them in their third decade of life.

Cervical cord injuries are disabling, most of times permanently, since modern treatment techniques still can get much in restoring neurological functions.

Anatomical and biomechanical factors make cervical spine a critical region for vertebral trauma, and failures in primary healthcare, difficulties on diagnosing and providing early treatment are also included here, as well as the potential of associated injuries.

Literature shows an evident progression of vertebral spine trauma observation, such as the study of vertebral unit, meaning the segment formed by two intact vertebrae, intervertebral disc and ligaments; functional units representing spine are also studied, simulating cervical injuries in cadavers<sup>(2,3)</sup>. Cervical spine biomechanics is not yet fully understood due to peculiarities of the various structures composing it, and also because of its physiological and anatomical complexity<sup>(4)</sup>. Biomechanics gathers accrued and available knowledge on various technology fields, using them in conjunction in the different medicine and biology areas. A major contribution is provided by the development of experimental models simulating movements and cervical traumas. The insufficient interpretation of experimental results is sometimes due to the absence of muscles' stabilizing activity, and those influences cannot be fully reproduced and assessed. Because it involves combined variable magnitude, direction and speed strengths also can make its reproduction in an experimental environment difficult. Despite these and other limitations, it is believed that those studies allow for reproducing comparisons of several kinds of internal fixation and potential interactions between a studied specimen's vertebral spine and the implant.

In 1955, cervical anterior fusion became a universally accepted procedure in arthrodesis, in a single level, in cervical

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degenerative diseases<sup>(5)</sup>. Unfortunately, the same results are not achieved in fractures, tumoral resections and kyphosis deformities, where unacceptable rates of progressive deformities, instability and graft extrusion are seen<sup>(5)</sup>.

Since 1964, fixation systems - conventional plates<sup>(6,7)</sup> and Orozco's H type<sup>(8)</sup> - have been used, although not fully accepted due to the risks of spinal cord, radicular and vascular injuries during its insertion. Injuries to the esophagus and other surrounding structures secondary to the late migration of screws, plate or bone graft, have also been described<sup>(9)</sup>. In the traditional system unblocked plate-screw, the screws will be better fixated in the bone if they trespass the posterior wall of the vertebral body and are placed in an oblique position, towards intervertebral disc.

In the blocked plate-screw system, described in 1986<sup>(10)</sup>, screws do not trespass the posterior wall of vertebral body, the thread step is lower and they are placed in a convergent position, providing better fixation into the bone.

Several kinds of instruments have also been developed for fixing cervical spine through posterior port<sup>(7,11-16)</sup> and these would be indicated, especially, in dislocations that cannot be reduced by using conservative methods.

In cervical spinal cord trauma due to fracture by vertebral body explosion with bone fragments within spinal cord channel, anterior decompression is indicated, while the discussion of whether to perform an anterior, posterior or combined surgical access for stabilizing other traumatic injuries of the cervical spine still persists.

In kyphotic fractures, tumors or deformities, occasionally, a second procedure is indicated (posterior) for providing better stabilization. In order to avoid a second surgical access after "corpectomy" the concept of anterior bone grafting associated to fixation with plates and screws has emerged<sup>(6-8,10,17-19)</sup>. That fixation using the same anterior access as used in the corpectomy may be performed with plates and screws, such as: H-type plate<sup>(8)</sup>, trapezoidal-type<sup>(18)</sup>, conventional 1/3 tube straight<sup>(6,7)</sup> and straight with proximal and distal hooks<sup>(20)</sup>.

Due to the existence of uncountable questionings regarding the use of plates and screws on cervical spine, such as support, stabilization and absorption of strengths applied on vertebral set, we compared different types of plates, using a given experimental model that has been previously used by other authors<sup>(21-23)</sup>. Cervical vertebral sets were submitted to axial compression tests after corpectomy of the intermediate vertebra (C5) and fixation of the screws on adjacent cervical vertebrae (C4-C6). Early failure and maximum resistance of these fixated vertebral sets and of the control group were then identified.

## MATERIALS AND METHODS

Nineteen human cervical spines were used, which were removed from male cadavers, ages ranging from 25 to 40 years, with anatomicopathological diagnosis not related to any disease involving bones, and death confirmed within less than 24 hours before spine removal.

The studied material, during the years of 1990 and 1991, belonged to the Death Examination Service of the Medical College, University of São Paulo.

The material was prepared with the cadavers positioned at ventral decubitus, head placed beyond the edge of the anatomical table, so that the neck remained hyperflexed by gravity action. Then, by means of posterior longitudinal cervical incision, the piece was removed as a single block, from

the first cervical vertebra to the first thoracic vertebra, with capsules, discs and ligaments preserved. In this spinal segment, the detachment of the set constituted of C3, C4, C5, C6 and C7 (from the third to the seventh cervical vertebra) was provided, being identified from the axis (C2).

Each of the vertebral sets was stored into polyethylene bags, removing as much as possible the air inside it, and hermetically closed and kept into freezer at a temperature of 20 degrees Celsius. For preparing simulations, each spine was removed from freezer and allowed to reach room temperature and humidity on a plastic tray filled with 0.9% saline solution, where the pieces remained in isotonic bath for at least two hours. Then, the pieces were dissected, removing soft parts of C3, C4, C5, C6 and C7, except for joint capsule, ligaments and intervertebral discs.

The pieces to be tested were divided into four groups, aiming to study three different kinds of osteosynthesis, plus Control Group. All pieces were submitted to central corpectomy, which means a resection of approximately 1/3 of the cross-sectional diameter of the vertebral body, including anterior and posterior walls of the fifth cervical vertebra (C5) (Figure 1), associated to the removal of intervertebral discs and anterior and posterior longitudinal ligaments of C4-C5 and C5-C6. That procedure mimics, as much as possible, the surgical procedure itself. The central portion of the vertebral body and the adjacent soft parts were removed, by blocks, with the aid of surgical tweezers. The empty space corresponding to the corpectomy is upper limited by the lower surface of C4 body, lower limited by the upper surface of C6 body and laterally by the lateral walls of C5 vertebral body. After that procedure, internal fixation was performed by using three different kinds of plates and fixation with 3.5-mm wide and 16-mm long cortical screws on the anterior surface of C4 and C6 vertebral body.

The H-type plate - described by Orozco and Llovetpapes<sup>(8)</sup>, as a unique concept, because it is fixated by two proximal and two distal cortical screws, also 3.5-mm wide and 16-mm long, causing an anti-rotational effect (Figure 2). The 3.5 mm 1/3 tube plate - AO<sup>(6,7)</sup> is a conventional narrow and straight plate that is fixated by a proximal and a distal cortical screw - 3.5-mm wide and 16-mm long. The Mendonça plate<sup>(20)</sup>, developed at the Medical College, University of São Paulo, also shows a different concept compared to both previous plates, because it has two proximal and two distal jaws, as well as fixation with two 16-mm long and 3.5-mm wide cortical screws - one proximal and the other distal (Figure 3).

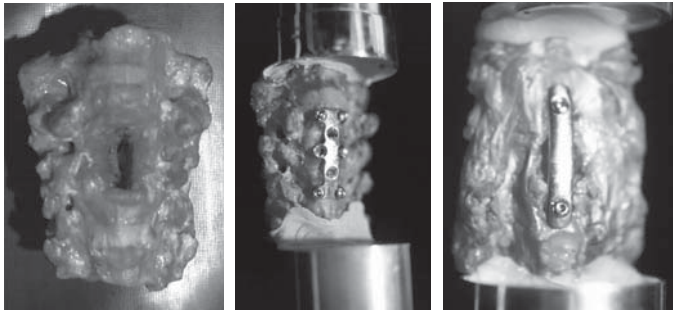
No bone graft or acrylic cement was used for filling the space corresponding to the corpectomy, so that the plate and lateral walls of the vertebral body as well as the disc-ligament structures could support the effect of axial compression of the experimental model.

Additionally to the three osteosynthesis groups, another group with five pieces was used as control, in which only the central corpectomy was performed at C5, without internal fixation.

For comparison purposes, an additional piece was testes, in which the lateral walls of C5 vertebral body were sectioned after central corpectomy, with no osteosynthesis, serving as a Pilot Test.

The four tests groups and their respective kinds of osteosyntheses and the number of cases are depicted on Table 1.

For conducting the tests, for each piece, an axial compression assay was performed with slowly progressive loads,



**Figure 1** – Cervical set (C3 – C7) showing corpectomy at C5. In this study, three different types of plates for cervical spine anterior fixation have been used, representing three different fixation concepts.

**Figure 2** – Cervical set (C3 – C7) showing fixation with H-type plate at C4 and C6

**Figure 3** – Cervical set (C3 – C7) showing fixation with Mendonça plate at C4 and C6

PIECE NR.	GROUPS	PLATE TYPE
5	G I	Control
4	G II	Orozco's H
4	G III	1/3 tube
5	G IV	Mendonça

Source: FM – USP

**Table 1** - Number of pieces by type of plate tested.

using a mechanical assay universal machine Kratos 5062, with built-in electronic load cell CCT-10.000 Kgf. All the experiments were followed up by a mechanical graphic recorder SERVOGOR 790 BBC Goerz Metravatt, where abscissa deformation was adjusted as millimeters (mm), and the load, as kilogram-force (Kgf). For the assays, we adopted a scale of 2,500 Kgf and steady speed of the mobile bar at 20 mm/min, with experiment blockage, after the second load peak was observed (Maximum Resistance).

Values for early failure and maximum resistance have been recorded for analysis. Early failure was determined at the first sign of reduced resistance of the studied set, which was recorded on graphs as the first load peak. Then, we proceeded with the assay until a full resistance failure of the set occurred - maximum resistance - which was recorded on graphs as second load peak, as kilogram-force (Kgf).

Mechanical assays were performed at the Medical Investigation Laboratory, LIM – 41, of the Department of Orthopaedics and Traumatology, University of São Paulo's Medical College.

Preliminary tests were performed in an extra cervical set, similar to the one used in the study, aiming to check the method and adjust the involved equipment.

In order to assure the accuracy levels on compression assays, we employed uniform axial loads by means of flat and parallel surfaces between machine's plates and test bodies. In order to achieve this environment and load homogenization without damaging the pieces, we coated the platform-bone interface surfaces with acrylic cement, filling uneven spaces and more appropriately modeling surfaces for the test (Figure 2).

For providing support to the pieces, a special manually adjusted device fixated to the basis of the machine, and composed by two threaded tubes was used. For adjusting platforms approximation, elevation was provided by turning

the tubes counterclockwise. The inner tube is attached by a cylinder at its upper portion and, on the surface of the latter, a tray-type disc is overlaid in order to restrain the movements of the piece, also serving as a cleaning tool after the test.

X-ray studies were performed on cervical segments (C3 to C7) at anteroposterior (AP) and lateral planes, before and after the mechanical assay.

The specific objective of this study was to verify screws position - bending compared to intervertebral discs and non-penetration into vertebral body's posterior wall - and, consequently, to standardize the effects of the set of plates and screws on stabilized vertebral segments.

For statistical analyses of results, the Mann-Whitney's test and the variance analysis were employed, with a significance level of 5% ( $p < 0.05$ ) being adopted for both tests.

## RESULTS

The results of the early failure study when compared to the Control Group showed that the averages for the groups with fixation were lower than those of the Control Group, in an increasing order (Groups IV, III and II – Mendonça, 1/3 tube AO and H). There were no differences between Control Group and Group II (H-type plates). As the difference between both groups (Mendonça ( $p = 0.016$ ) and 1/3 tube AO ( $p = 0.032$ )) and Control Group was significant, we can conclude that these plates produce an earlier failure.

When early failure was compared among groups, a significant difference was found between the Orozco's H plates and the 1/3 tube AO plates ( $p = 0.032$ ), as well as a significant difference between Orozco's H plates and Mendonça's plates ( $p = 0.032$ ). (Table 2)

Concerning the early failure, Control Group showed superior values to the pilot test (one case). This increased resistance is due to the integrity of the lateral walls of the vertebral body. In the absence of intact walls, resistance is much lower, being close to the results of the tests performed with the Mendonça's plate, which, in theory, is the most resistant one, and, thus, the one showing the greater rotation component in axial compression tests.

In the comparison between the 1/3 tube AO plates, Mendonça's plates and H plates Groups with the Control Group, all plates have been shown to present an average lower maximum resistance to the Control Group, although this difference is not significant at the Mann-Whitney's U test, being, in an increasing order, Mendonça's plate with the lowest average, followed by 1/3 tube AO plates (intermediate), and H-type plates with the highest average.

In the assessment of maximum resistance, the comparison between groups showed no statistical differences and occurred, in an increasing order, as follows: Mendonça's plates with the lowest average, the 1/3 tube AO plates with an intermediate average, and the H-type plates with the highest average. (Table 3).

By comparing the maximum resistance averages for the four groups with the pieces of the pilot experiment, we found that the maximum resistance of this piece, that is, the vertebral body with disrupted lateral walls submitted to central corpectomy (C5), was slightly superior to the average for Mendonça plate group and inferior to the 1/3 tube plate. Also, the Orozco's H Plate Group showed a higher average of maximum resistance than the pilot case. The Control Group was the one showing the highest resistance when

ORDER OF THE PIECES	CONTROL	H	1/3 TUBE	MENDONÇA
1 <sup>st</sup>	186.0	115.0	155.0	158.5
2 <sup>nd</sup>	172.5	163.0	110.0	96.5
3 <sup>rd</sup>	126.0	175.0	110.0	86.5
4 <sup>th</sup>	137.5	98.0	121.5	112.0
5 <sup>th</sup>	230.0	-	-	106.0
Average	170.4	137.8	124.1	111.9
Standard Deviation	41.4	37.1	21.3	27.8
Mean Standard Error	18.5	18.5	10.6	12.4
Minimum	126.0	98.0	110.0	86.5
Maximum	230.0	175.0	155.0	158.5
N	5	4	4	5

Mann-Whitney's U Test	-----  ñs U=5 p=0.143
	-----  U=2 p=0.032*
	-----  U=2 p=0.032*
Variance Analysis	-----  S=29.28 F=0.87 p=0.868

\* p<0.05 (significant)

**Table 2** – Early failure (Kgf) in all groups.

compared to pilot case, certainly thanks to vertebral body's lateral walls integrity.

## DISCUSSION

The information obtained about the mechanical behavior of vertebral structures is based on biomechanical researches<sup>(24)</sup>, which use concepts, principles, terms, methodologies, calculations, as well as mathematic models for interpreting and assessing anatomy and physiology. New models building should be continuous, though requiring a progressive improvement in terms of accuracy of data resulting from its use and that those methods are increasingly cheaper, producing important statistical results with lower costs<sup>(5,25,26)</sup>.

During the development of a biomechanical research in a threshold area, the study needs to be multidisciplinary, counting on the assistance of physicians, bioengineers, statisticians, engineers and IT technicians<sup>(5)</sup>. In this sense, for everybody to be able to speak the same language, enabling an easy communication between the members of such a multidisciplinary team, it is necessary to know biomechanical terms and concepts<sup>(27)</sup>. In addition, the importance of the research laboratory being located in a medical institution must be emphasized, because this provides an appropriate operating capacity of the research lines, making a rational use of the resources and allowing for a constant knowledge streamlining and better repercussion.

The experimental model used in the current research was developed in our environment and used by other authors<sup>(21-23)</sup>, being equivalent, in vivo, to the early postoperative period of an internal fixation through anterior access. This is an appropriate model to the proposed study, although it is known that the trend is towards performing cyclic studies, which are those that best mimic an individual's daily movements<sup>(24,28,29)</sup>. In vivo, failures are known to occur due to repeated movements, and,

ORDER OF THE PIECES	CONTROL	H	1/3 TUBE	MENDONÇA
1 <sup>st</sup>	238.5	277.5	300.5	281.5
2 <sup>nd</sup>	535.0	236.5	326.5	185.0
3 <sup>rd</sup>	250.0	312.5	223.0	254.5
4 <sup>th</sup>	168.5	372.0	227.5	294.0
5 <sup>th</sup>	381.5	-	-	204.0
Average	314.7	299.6	269.4	243.8
Standard Deviation	145.2	57.4	52.1	47.7
Mean Standard Error	64.9	28.7	26.0	21.3
Minimum	168.5	236.5	223.0	185.0
Maximum	535.0	372.0	326.5	294.0
N	5	4	4	5

Mann-Whitney's U test	-----  U=9 p=0,452 ñs
	-----  U=8 p=0,365 ñs
	-----  U=11 p=0,650 ñs
Variance Analysis	-----  S=52,07 F=1,28 p=0,321 ñs

**Table 3** – Maximum resistance (Kgf) for all Groups.

thus, this would be the optimal situation for performing the tests<sup>(24)</sup>. Despite of the restraints, the model employed enabled to study the early failure and the maximum resistance by simulating an injury by flexion-compression, according to the classification by Allen et al.<sup>(30)</sup>, Denis<sup>(31)</sup>, Eurel and Kazarian<sup>(32)</sup>, Holdsworth<sup>(33)</sup>, Panjabi et al.<sup>(34)</sup>. One of the limitations to this model would be the application of slowly progressive loads and not the use of fast-applied load, mimicking the impact occurring in cervical spine injuries. The loads are applied at a slow speed in order to facilitate the analysis, because similar results are achieved in experiments using fast speeds (impact), according to Roaf<sup>(2)</sup>.

Universal test machines are used for the analysis of several physical properties of materials, and they have also been used to investigate and test the resistance of biological tissues, according to Davis<sup>(35)</sup> and Shimano et al.<sup>(25)</sup>. In this study, the machine employed (Kratos) has shown to be efficient in simulating compression during planned assays, confirming previous experiences by Machado<sup>(21)</sup>, Puertas<sup>(22)</sup> and Rossi et al.<sup>(23)</sup>. Also, pieces' fixation at the machine using acrylic cement was regarded as adequate. This avoided undesirable movements at vertebral sets ends, a fact that has been previously proven by Miller et al.<sup>(36)</sup> and Rossi et al.<sup>(23)</sup>. Freezing the pieces at - 20° Celsius, as described by Miller et al.<sup>(36)</sup>, Panjabi et al.<sup>(34)</sup>, made pieces storage and use easier, as available to the team. The unfreezing at room temperature worked accordingly, causing no significant changes to pieces' biomechanical properties. However, Sedlin and Hirsch<sup>(37)</sup> and Tkaczuk<sup>(38)</sup> consider that freezing and unfreezing pieces cause changes on their structures and biomechanical properties. This aspect, however, was not shown to be relevant in the present study.

The pieces studied have been selected matching an age group ranging between 25 and 40 years, with the purpose

of achieving homogeneous results for bone-ligament resistance. The use of elderly individuals' pieces was avoided because, according to Atinkson<sup>(39)</sup>, there is a progressive bone weakness after the age of 50, which determines a substantial mechanical resistance reduction. It is also worthy to highlight that the extensibility of ligaments is reduced with age, according to Traczuk<sup>(38)</sup>.

The stability lent by muscular, ligamentar capsular and discal structures in vivo is recognized by Beatson<sup>(40)</sup>, Gosh<sup>(41)</sup>, Johnson et al.<sup>(42)</sup>, Nova Monteiro and Giesta<sup>(43)</sup>, Panjabi et al.<sup>(4)</sup>, as of major importance. In the researched model, capsule-ligamentar and discal structures were preserved. Cervical muscles were not taken into account due to the inherent difficult to test them, although the importance of this muscular activity on stability in an awoken individual is recognized, as mentioned by Fielding et al.<sup>(44)</sup>, Gosh et al.<sup>(41)</sup>, Nolan and Sherk<sup>(45)</sup>, Yoganandam et al.<sup>(3)</sup>. Regarding that activity, Halliday et al.<sup>(46)</sup>, White 3rd et al.<sup>(47)</sup> reported just the opposite.

In an experimental study of flexion trauma of the medium and lower segments of the cervical spine, Machado<sup>(21)</sup> found that the anterior longitudinal ligament was not injured in none of the 40 tested pieces, which is consistent to many authors' findings: Davis<sup>(35)</sup>, Holdsworth<sup>(33)</sup>, Johnson et al.<sup>(42)</sup>, Panjabi et al.<sup>(48)</sup>, Tkaczuk<sup>(38)</sup>, White 3rd et al.<sup>(47)</sup>. It is clear that injury in this ligament may occur as a result of hyperextension trauma, with the posterior longitudinal ligament remaining intact in most of the cases. In unstable flexion injuries, the whole posterior ligament complex is damaged, with the anterior longitudinal ligament remaining intact most of the times, as per Danis<sup>(31)</sup> and White 3rd et al.<sup>(47)</sup>. When anterior decompression (corpectomy) is indicated, resection of the anterior longitudinal ligament, at this level, seems to be a nonsense, which could cause instability. In these cases, osteosynthesis would lend enough stability to the fixated vertebral set after corpectomy.

Regarding the capsule-ligamentar complex of vertebral sets, few changes have been seen during tests performed in flexion-compression. As a rule, ruptures occurred essentially at the bone structure level, within the limit of loads applied to test maximum resistance, when the test was then stopped. Several studies showed that in spinal cord injuries, the most compromised vertebrae of the cervical spine are C5 and C6, but mostly on C5<sup>(21,49,50,51)</sup>. This was one of the reasons for selecting the level for corpectomy and, also, the experimental model was shown to be more appropriate because two vertebrae above and two vertebrae below central corpectomy level (C5) were left, so that the lever arm was similar both above and below that level. With the ends at C3 and C7 fixated with acrylic cement on the platforms, C4 and C6 were left free for fixation with plates and screws, while C5 was free to receive corpectomy.

Central corpectomy performed on models was similar to the ones performed in surgical practice<sup>(6-8, 11, 17-20, 52-58)</sup> with the central portion of vertebral body, as well as upper and lower discs and anterior and posterior walls being removed, and lateral walls being preserved. This corpectomy was performed on the least resistant area of the vertebral body - the central area - according to Brown et al.<sup>(59)</sup>, with lateral regions (the most resistant ones) being left intact. Oppositely, in fractures by vertebral body explosion, the lateral walls will also be fractured. This research intended to perform the tests with intact lateral walls; yet, because of questions regarding

this detail, a pilot case was established in order to study the behavior of an experimental model in which lateral walls were sectioned.

In this sense, the analysis of this comparison with Control Group, in which lateral walls were intact, and the pilot case, in which lateral walls were sectioned, that resulted in an early failure occurring with a much lighter load in the pilot case, which stressed the importance of those intact walls for this set resistance. Due to those results, the pilot case was maintained with this isolated behavior, subjected to criticisms only for discussion purposes, but not being taken into account for conclusions.

Still regarding lateral walls integrity, one can clearly conclude that a corpectomy performed in cases of channel stenosis, provided lateral walls are intact, would make this procedure more stable than in case of a fracture by explosion where corpectomy and fixation with plate and screws were performed.

An X-ray study was conducted in order to allow for the observation of screws' non penetration into the posterior cortical of vertebral body and its bending compared to intervertebral discs. We did not intend to analyze X-ray images with the purpose of interpreting results.

In this study, three kinds of fixation of the vertebral sets were established using three different concepts of osteosynthesis, which encompass the vast majority of commercially available plates.

The H-type plate described by Orozco and Llovetapiés<sup>(8)</sup> employs the concept of double proximal and distal fixation, determining an anti-rotational effect. The 1/3 tube AO plate<sup>(6,7)</sup> is a straight plate with a single proximal and distal fixation. Although it had not been used, both the 1/3 tube plate and the H-type one had holes available corresponding to corpectomy space, where a graft could be eventually fixated. Differently, the Mendonça plate<sup>(20)</sup> does not have the intermediate hole, in addition to be thicker and count on two proximal and two distal jaws.

From a conceptual point of view, the Mendonça plate would be the most resistant one, not presenting a weak point on its medial portion, in addition to its built-in jaws with an alleged anti-rotational effect. In fact, this apparently increased resistance resulted in a lower load absorption capacity, producing an early failure with lower values when gradually compared to the 1/3 tube and H-type plates.

Fixation in a single axis as observed in 1/3 tube and Mendonça plates, when associated to flexion and compression movements, determined a rotational effect that caused the rupture of vertebral bodies (C4 and C6) adjacent to corpectomy (C5) from the screws fixation point. On the other hand, the thinner H plate, counting on double fixation with screws in an anterolateral position, better absorbed load, thanks to that anti-rotational design. For this reason, bone rupture in these plate groups occurred in average with heavier loads than those seen with the other two kinds of plates.

The H-type plate followed the deformation experienced by the set when submitted to compression loads, a fact being also reported by Ulrich<sup>(60)</sup>.

Therefore, based on these results, the load required for causing early failure and the maximum resistance was greater for the group fixated with H-type plates, although this result is not statistically significant compared to those found for the other two plate models.

When comparing the Groups with 1/3 tube and Mendonça plates with the Control Group, we found that the loads requi-

red for producing the early failure and maximum resistance were statistically lighter. Nevertheless, the H-type Plate Group behaved statistically similarly to the Control Group, better bearing compression loads.

The results support the claim that the better biomechanical performance of the Group with the H-type plates compared to the Group with 1/3 tube plates and to the group with Mendonça plates is due to its design, since its fixation does not occur in a single axis, as happens with the other two plates. This would preclude the early occurrence of associated rotation movement, which, ultimately caused the 1/3 tube and Mendonça plates to pull out with lighter loads.

The better performance of Control Group over the others is related, as paradox as it may seem, to absence of fixation, because it was evident that the presence of synthesis material caused a rotational effect which, added by screw holes - bone weakness areas - produced rupture of the set fixated with synthesis material escape.

Although the tests could not reproduce close-to-real movements, that is, small repeated movements (cyclic forces), but a single and progressive load, the tests provided interesting information, such as the rotational effect that happened with

osteosyntheses setup, especially those fixated in a single axis.

The evolution of this research line will certainly add new data to this discussion, forging progresses on cervical spine internal fixation concept.

## CONCLUSIONS

1. The osteosyntheses employed did not increase resistance to compression when compared to controls, since the presence of internal fixation material reduced stability, causing an earlier initial failure, with lighter loads compared to Control Group.
2. Regarding initial failure, significant differences were found between Control Group and groups with 1/3 tube and Mendonça plates, but no difference was found in the H-type plates Group.
3. Regarding maximum resistance, no significant difference was found when comparing osteosyntheses groups and Control Group.
4. Osteosynthesis using H-type plate, showed better stability when compared to other osteosyntheses, although these differences were not significant.

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