

# BEHAVIOR OF CORTICAL SCREWS SUBMITTED TO MANUAL TORSION ASSAY AND AUTOMATED TORSION ASSAY

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## SUMMARY

Cortical screws are submitted to torsional forces during its insertion and removal. Therefore, one of the purposes of this research was to evaluate the mechanical behavior of stainless steel cortical screws submitted to manual torsion test and automated torsion test. The secondary objective was to analyze the fracture area with a scanning electron microscope. Ten cortical stainless steel screws have been used. Five screws were submitted to the manual torsion test and five screws were tested on a torsion machine. Their proper-

ties were calculated and the fracture area was analyzed. The manual torsion test has shown to be inaccurate for the calculation of mechanical properties. Therefore, it is contraindicated for identifying the mechanical behavior of cortical stainless steel screws. The automated torsion test showed a more rigid methodology and therefore more reliable results. Screws fractures, both on manual and automated torsion assays, presented no different patterns.

**Keywords:** *Torsion, Bone screws, Materials testing; Bone plates; Stainless Steel.*

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## INTRODUCTION

Today, the assessment of the mechanical quality of implants as cortical screws is provided through manual torsion tests, using a torquimeter. In those tests, only the values for rupture torque and rupture angle are considered on these implants. The whole mechanical behavior of such implants is regarded as irrelevant. The understanding about the mechanical behavior allows the assessment of those screws' resistance throughout the time they serve as fixators: on the insertion, on implantation and removal. The torsion mechanical assay is not employed for materials specification. Rather, it is indicated for pieces that, in practice, are submitted to torsion efforts, such as: springs, torsion bars, screws, among others<sup>(1)</sup>. This occurs with a cortical bone screw, which, when used for fixating plates on long bones' fractures stabilization, is submitted to a torsional moment or torque<sup>(2)</sup>. This torque is, apparently, responsible for anchoring the screw into the bone, but, if over applied, may cause screw fracture, should this does not have a safety coefficient to afford mechanical loads without breaking., or if it is inconsistent to manufacturing specifications<sup>(3)</sup>. Regarding the kinds of fractures resulting from a load in torsion, in a cylindrical body, subjected to torsion, there are maximum shearing tensions found in two perpendicular planes to each other, with one of these being perpendicular and the other parallel to its longitudinal axis<sup>(1)</sup>. Thus, the rupture of a ductile metal occurs as a result of sliding along the

planes where the maximum shearing tensions are found, therefore, the fracture looks plane. However, a fragile metal is ruptured along a perpendicular plane to the orientation of traction force, i.e., a tension forming a 45° angle with the longitudinal axis of a body of evidence, resulting in a helix-like rupture.

Thus, one of the purposes of this study was to conduct two kinds of torsion assays on stainless steel cortical screws: a manual assay and an automated torsion assay. Another objective of the study was to assess the site of fractures resulting from both assays, by means of electron scanning microscopy.

## MATERIAL AND METHOD

Ten stainless steel cortical screws Cr Ni Mo – ASTM F-138, sourced by Baumer® (a local manufacturer of orthopaedic products and devices) were used. All the screws were of the same type (cortical) and of equal size (4.5 mm in diameter) and randomly selected from three different batches. Of these screws, five were submitted to manual torsion assays and the remaining five, to automated torsion tests.

### Manual Torsion Assay

For manual torsion assays, a digital torquimeter Mackena®, model MK-20XX, with capacity of 10 N.m and precision of 0,01 N.m, was employed to measure the amount of torque imposed to the screw at each angle. This torquimeter model is the same

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used by orthopaedic implants manufacturers to test the mechanical quality of the screws. For performing this assay, the screws were locked onto a bench vise, keeping their hexagonal end upwards, and leaving 5 thread steps free, as required by the NBR ISO 6475:1997<sup>(5)</sup>. A hexagonal connective piece was build with the same dimensions of the screws head, following the standards specified on NBR ISO 8319-1: 1998<sup>(4)</sup>, which was attached to the torquimeter. With the hexagonal connective piece of the torquimeter attached to the six-sided screws head, and keeping a 90° degree angle between the torquimeter arm and the longitudinal axis of the screw, an investigator started a circular clockwise movement, at the speed required by the procedure (1 - 5 rotations/ minute), until the screw was fully ruptured (Figure 1). Torque was simultaneously measured by two investigators, with the first reading the angles and the second recording the torque corresponding to the angle at each 10° of screw angle deformity. Torsion angle was measured by a goniometer, which had its movable arm attached to the torquimeter and its fixed arm locked onto the bench vise (Figure 2).

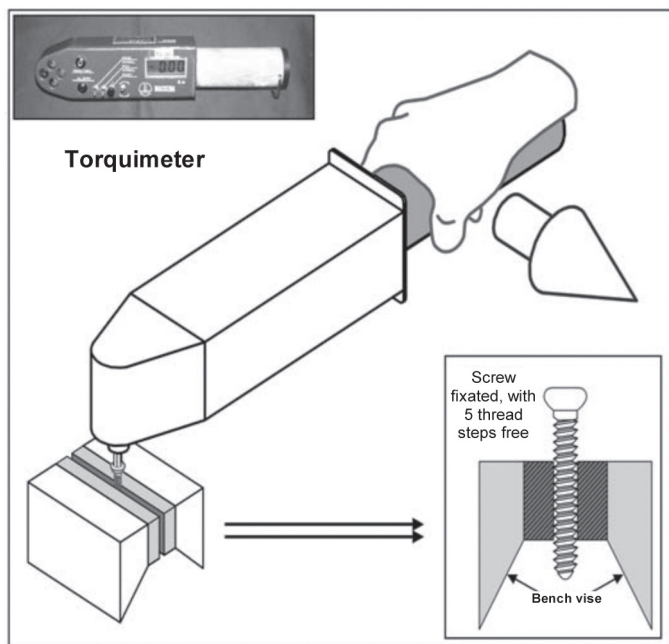


Figure 1 – Details of the torquimeter for performing manual torsion assays.

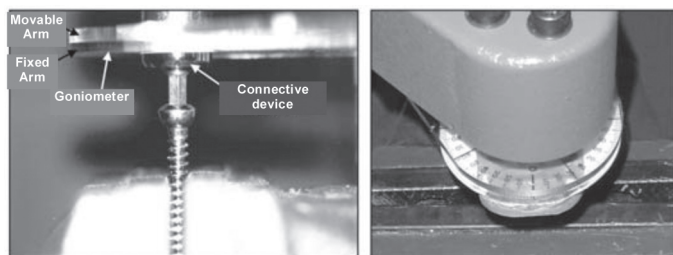


Figure 2 – Positioning of the goniometer for angles reading. The movable arm was attached to the goniometer and the fixed arm locked onto the bench vise.

### Automated Torsion Assay

For performing this assay, we used *Gunt Hamburg*.®- WP 510 – 200N.m torsion machine, attached to a PC at the Laboratory of Mechanical Assays of the Centro Estadual de Educação Tecnológica Paula Souza (Escola Técnica Estadual José Mar-

timiano da Silva). At the Precision Shop of the USP Ribeirão Preto Campus Hall, two accessories were built to be attached at the fixed and rotational ends of the torsion machine. The first accessory was attached to the machine's rotational end, and had a hexagonal edge constructed according to the NBR ISO 8319-1:1998<sup>(4)</sup>, to fit the screw head. At the opposite end (fixed), the other accessory was attached, with a build-in connection to lock down the screw, as a bench vise would do (Figure 3).

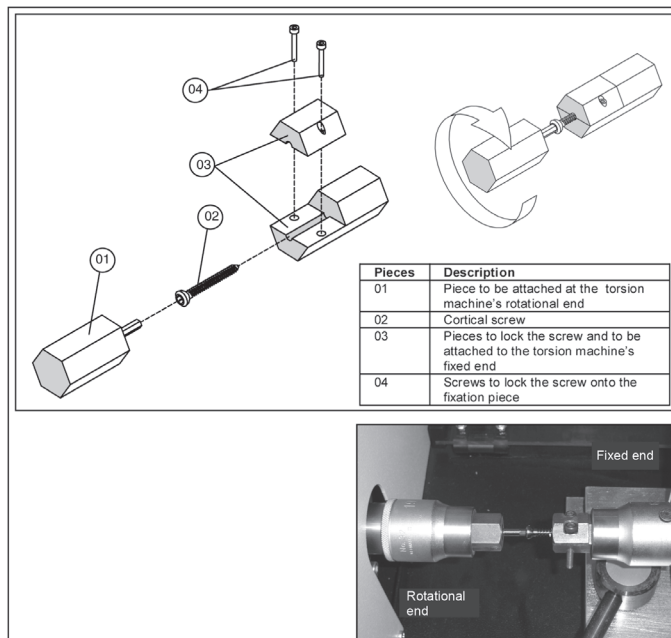


Figure 3 – Details of screw fixation on the accessory, attachment of accessories to the fixed and rotational ends of the torsion machine, and connection of the screw with the hexagonal edge of the accessory.

Both assay rotations (clockwise and counterclockwise) and speeds were preset on the WP 510 *Torsional Tester* software in the PC. Only four speeds were available for the assay: 50°/min, 100°/min, 200°/min, and 500°/min. During the assay, the screw remained with five thread steps free and the other steps fixed into the fixation piece, as required by NBR ISO 6475:1997<sup>(5)</sup>. The rotation orientation was clockwise, and the rotational speed employed was 500°/min, also as required by NBR ISO 6475:1997<sup>(5)</sup>. The software provided the torque vs. angle deformity graph. From these graphs, the following mechanical properties could be calculated: maximum torque; torque at the proportionality threshold, torsional stiffness, and torsional tenacity.

### Electron Scan Microscopy

For a further detailed analysis of the screws' fractures after torsion assays, an electron scan microscopy was performed. This analysis was performed at the Laboratory of Electron Microscopy, of the Department of Cellular and Molecular Biology and Pathogenic Bioreagents, Ribeirão Preto Medical School, USP. The microscope employed was the *Scanning Microscope*.®, model JSM – 5200, with maximum magnification capacity of up to 200,000 x. The magnification employed for the analysis of screws images was the standard one for metal assessments. Photographs were taken using an 120-mm B&W film (Kodak.®, model T<sub>máx</sub> 100).

## Statistical analysis

For the statistical analysis, the SigmaStat® v.2.03 software was employed. First, normality and variance equivalence analyses were performed. For comparison purposes between the manual torsion group and the automated torsion group, the Student's t-test was used, with 5% adopted as significance level.

## RESULTS

Torque vs. angle deformity graphs were drawn, where torque values (N.m) were recorded on the ordinate and, the values for angle dislocation (in degrees) were recorded on the abscissa. From these graphs, some mechanical properties were calculated (Table 1). The statistical analysis of mechanical properties reported that among the screws submitted to manual torsion and those submitted to automated torsion a difference was found for screws submitted to manual torsion on torque at proportionality threshold, and, for screws submitted to automated torsion, on torsional tenacity. However, no differences were found for torque at maximum limit and torsional stiffness. By comparing the images obtained with the electron scan microscopy, no differences were found between fractures on screws submitted to manual torsion and fractures on screws submitted to automated torsion assay, but the helix-like rupture of the screws can be seen – which is a characteristic of a ductile metal – with striae and deformation of the thread adjacent to the fracture area.

**Table 1 – Averages of the mechanical properties obtained from torsion assays on stainless steel cortical screws**

Mechanical Properties	Manual Torsion	automated torsion	p
Torque at the Proportionality threshold (N.m)	4.26 ± 0.63	2.96 ± 0.29	0.012
Maximum torque (N.m)	5.60 ± 0.80	5.72 ± 0.16	0.625
Torsional stiffness (N.m/degree)	0.379 ± 0.07	0.350 ± 0.13	0.673
Torsional tenacity (N.m/degree)	1691 ± 306	2431 ± 215	0.002

## DISCUSSION

The manual torsion method was selected because it is used by companies to test the screws they manufacture, but it presented some important challenges, such as:

1. For reading the angle deformity and the corresponding torque value, due to the speed of the assay and to the lack of torquimeter's capacity to store data, three people were required: one to apply the torque, another to read the angle, and a third person to record the torque of the corresponding angle.
2. Maintaining perpendicularity between torquimeter's arm and the screw's axial shaft, submitting it to other forces such as flexion, not constituting a pure torsion assay. A great part of the torque may have been lost with the change of the angle between the torquimeter's arm and the screw's axial shaft.
3. Variations of the assay speed, because, after exceeding the proportionality threshold, the resistance provided by the material is reduced, thus increasing assay speed, which is manually

controlled, thereby being not uniform. Even by following the NBR ISO 6475:1997<sup>(5)</sup>, which determines a speed variation of 1rpm to 5 rpm, this speed variation may alter mechanical properties results. Therefore, the determination of a uniform assay speed should be specified on a formal procedure so that the results obtained from these kinds of assay could be more reliable.

4. The torquimeter design, which required the investigator to switch the support hand at approximately 200° of angle deformity, thus decelerating the assay.

5. When interpreting the data obtained from the assays and from the calculation of mechanical properties, we noticed that the number of points used for drawing the graphs was too small, probably causing inaccurate results. For example, in most of the graphs, there is only one pair of coordinates (X, Y) until the point regarded as proportionality threshold, a fact that may blind the investigator to important data. Nevertheless, this graphic trace was employed by authors such as Browner et al.<sup>(6)</sup>. Such inaccuracy in obtaining the data may have masked the real value of the torque at proportionality threshold, which showed statistically different values compared to the groups submitted to automated torsion. However, this methodology for obtaining torque and angle deformity values is the one recommended by NBR ISO 6475:1997<sup>(5)</sup> and it is used by several authors such as Browner et al.<sup>(6)</sup>, Müller et al.<sup>(7)</sup>, and Abel and Sun<sup>(8)</sup> for assessing mechanical properties of implants. Authors like Collinge et al.<sup>(9)</sup> usually limit their studies to assess only the rupture torque and rupture site. Others, like Abel and Sun<sup>(8)</sup>, although using a torsion machine, had to make a manual record of the measurements, which also makes the method difficult and may mask results. A frequent question when applying this recommended methodology, but not justified by NBR ISO 6475:1997<sup>(5)</sup> was the reason why five thread steps should be kept out for applying torque since, in practice, the screw remains fully inserted. With this methodology, fracture occurs approximately at the third thread step. This could occur on the area it connects to the plate or just below the screw head if this was securely fixated onto the bench vise, leaving only its head exposed. Studies such as the one by Abel and Sun<sup>(8)</sup> reported a slight deformation of the screws head found at a more central region of the plate after torsion assays applied on a plate-screw set. The use of a different methodology from the current one should obtain results closer to these by submitting only the cortical screw to torsion. On the other hand, the torsion machine is user-friendly and interpretation of data is easier with it. However, the limited control over the assay speed (only four values available), could make the use of this machine difficult in assays with different implants, since these should comply to speed values as pre-determined by standards. As discussed by Abel and Sun<sup>(8)</sup>, there is no satisfactory standardized methodology for torsion tests on bone plates. The same problem is seen with bone screws. There was some limitations regarding determining the elasticity module or the torsional moment on screws, because their circular section could not be determined. Thus, we determined only the following mechanical properties: torque at proportionality threshold, maximum torque, torsional stiffness, and torsional tenacity of screws. Regarding the me-

chanical properties obtained from the calculations based on graphs torque vs. angle deformity, we noticed that: for torque at *proportionality threshold*, the statistical difference found between screws submitted to manual torsion and those submitted to automated torsion does not evidence a superior quality of the screws, but a methodological issue previously addressed in this discussion (about the small number of points used for drawing the graphs, causing a potential inaccuracy of results). On a graph with a higher number of points, we can accurately observe the last point where torque and angle deformity values proportionally increase. For *maximum torque*, the statistical similarity shows the absence of issues in the calculation of this mechanical property, which, by routine, is the only value assessed by cortical screws manufacturers to appraise the mechanical quality of that implant. For *torsional stiffness*, a slight superiority was noticed on the values for screws submitted to manual torsion, which was not confirmed by the statistical test, probably due to high standard deviations. We suspect that a bigger sample could evidence some statistical difference between screws submitted to manual torsion and those submitted to automated torsion, and, thus, the methodological issue of the manual torsion assay would be evident again showing that the calculations of the mechanical properties related to the material's elastic zone, such as stiffness, will likely present inaccuracy of results as opposite to those submitted to automated torsion. For *torsional tenacity*, the significant difference for less in screws submitted to manual assays compared to those submitted to automated assays may have occurred as a result of the methodology of manual torsion assay, where the investigator subjectively controls speed. This variable speed may have further overloaded the screws on this group, thus presenting a lower torsional tenacity. From the ESM images, we found no qualitative differences between the results of both methodologies employed. Therefore, other quantification methods are required.

For performing a mechanical assay, there are no significant differences between methodologies recommended by global associations of technical standards<sup>(1)</sup>. However, standards with a too generalized methodology enable the use of a number of methods that fit into the specifications determined by the stan-

dard. Such variety results in different data that cannot be compared to data obtained in other assays, which may ultimately lead to a misclassification of an implant, attributing to some features that are not typical to it. According to Laing<sup>(10)</sup>, the organization of international standards and of the procedures to write them is made through a collaborative effort among surgeons, manufacturers, and researchers. Those standards set forth methodologies and values to be followed and met by manufacturers (in order to assure implants' physicochemical quality), by researchers (so that the experimental results can be compared and discussed), and by surgeons (in order to assure a higher percentage of positive postoperative outcomes). Therefore, the population – the patients – will be the ones most benefited by this. As Brazilian standards determine only the rupture torque and rupture angle, the analyses on the present research offer other mechanical properties values obtained from a methodology presenting few variables, because we determined the positioning at a same axis of the key and screw, as well as a uniform speed. Thereby, a more reliable analysis of the mechanical behavior was enabled. Thus, as previously addressed by Laing<sup>(10)</sup>, in order to achieve a desired purpose such as the analysis of the mechanical behavior, one should first determine which the critical points are, and then elaborate a new method. Therefore, subsequent studies are allowed to follow a more rigid and detailed specification, providing more reliable results and comparisons among different studies.

## CONCLUSION

The manual torsion assay has shown to be inaccurate for calculating the mechanical properties of cortical screw-type implants and, therefore, contraindicated for determining a mechanical behavior. Automated torsion showed a more rigid methodology and, thus, more reliable results. Screws' fractures, both on manual and automated torsion assays, showed similar patterns.

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