MECHANICAL PROPERTIES OF AN OSTEOSYNTHESIS SYSTEM OF RELATIVE STABILITY

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SUMMARY

In this study, the mechanical properties of a new metallic system for bone synthesis (SPS® - Synthesis Pengo System) were investigated by means of flexion and torsion mechanical tests. The SPS® systems were assembled in cylindrical wood sticks using stainless steel cortical bolts. Nine groups of models were adopted for tests according to the three plate lengths and the three assembly distances. Flexion tests were performed with the SPS® systems positioned laterally to the assay machine's dislocation axis. For the torsion tests, the SPS® systems were placed in no specific position. The SPS® stiffness and deflection results obtained with the flexion and torsion mechanical tests were dependent on the number of holes on the plates and on the distance between the plates mounted in the wood stick, that is, the higher the number of holes and the shorter the distance between plates, the higher the stiffness and the lower the deflection. It can be concluded that stiffness and deflection changed proportionally to the number of the holes in the plates and the distance between them.

Keywords: *Bone plates; fracture, Fixation; fracture, internal fixation*

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INTRODUCTION

The surgical treatment of fractures requires a method of stabilization, neutralization, and, many times, compression between bone fragments. Depending on the anatomical site of the fractured bone and on the kind of fracture, biomechanical and biological concepts are applied for selecting a proper osteosynthesis method and system to be used.

The first studies on osteosynthesis were conducted back in 1949, using rigid plates with modifications on the way screws were tightened(1).

In 2000, studies evidenced that direct reduction and rigid fixation techniques have been replaced by internal fixation techniques with relative stability and indirect reduction (2), thus sparing the tissues surrounding a fractured bone.

The continuous research and understanding about the conditions in which osteogenesis occurs and the new bodies of evidence about a fractured bone union led to an important development of implants used in osteosynthesis. Stiffer systems do not always fit bone regeneration biology. Thus, less rigid osteosynthesis systems are being probed.

PURPOSE

To study, by means of torsion and flexion mechanical assays, the influence of the number of holes on fixation plates and of the different spaces between them on mechanical properties of stiffness and deflexion in a relative stability SPS® osteosynthesis system.

MATERIALS AND METHODS

1. SPS® Models Assembly for Assays

The Pengo Synthesis System® (SPS® - Biomecânica Indústria e Comércio de Produtos Ortopédicos Ltda) is constituted of a folded, "U"-shaped nail, two plates and cortical screws, all of these made of stainless steel F138 (Figure 1).

The folded U-shaped nail is 3.4 mm wide and its shape keeps a mean distance of 7.6 mm between its free ends. The ends are folded at 90 degrees, (Figure 1A), and the lengths selected for this study were: 72.0 mm, 92.0 mm, 96.0 mm, 112.0 mm, 115.0 mm, 120.0 mm, 137.0 mm, 141.0 mm, and 161.0 mm.

The pairs of plates employed in the assays had various lengths according to the number of holes: 2, 3 and 4 holes (Figure 1B). These were 27.0 mm, 40.0 mm, and, 52.0 mm long, respectively. The plates were 5.0 mm thick and 16.0 mm wide. The surface of the plate that faces the wood stick during fixation has two parallel grooves towards the longitudinal end

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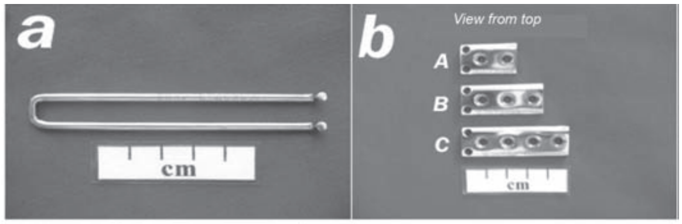
of the plate, 3.5 mm wide and 2.0 mm deep, perpendicularly interconnected to a cross-sectional groove of the same dimension, configuring a "U" shape allowing the U-shaped nail to be locked in (Figure 1C). These crossing grooves have two 3.5 mm-wide holes transversally aligned to the plate, allowing either end of the U-shaped nail to be fit (Figure 2).



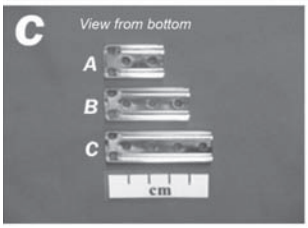


***Figure 1** - Pengo Synthesis System ® (SPS®). a) Folded U-shaped nail. b) Plates view from top. c) Plates view from bottom.*

Source: SPS® - Biomecânica Indústria e Comércio de Produtos Ortopédicos Ltda.

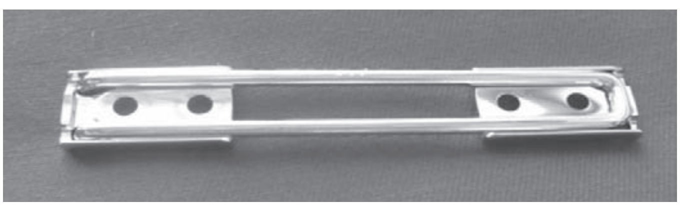


***Figure 2** - Bottom view of a SPS® with two-hole plates.*

In order to simulate a bone-SPS® set, 2 cylindrical sticks made of Itaúba wood measuring 25.0 mm in diameter and 127.50 mm in length were used.

For preparing the models, an osteosynthesis instrument designed for small fragments was used.

2. Preparation of the Experimental Models with SPS® for Assays

The two wood sticks were fixated on a bench vise 5.0 mm apart from each other. Then, both halves of the SPS® were positioned at an equal distance. The wood stick was perforated by using a guide and a 3.2 mm drill. Subsequently to the tapping, screws were introduced. One by one, the screws were introduced, and, as a standard, the insertion of the screws always started at the SPS® end where the HU nail is fit on plates' holes, keeping the other plate locked with reduction tweezers into the wood stick.

3. Experimental Groups

The experimental models were divided into 3 experimental groups, according to the number of holes on the plates. The experimental groups and subgroups are as follows:

Group 1: experimental models prepared with 2-hole plates, constituted of 3 subgroups with 5 models each:
- Subgroup 1A with 20.0 mm intervals;
- Subgroup 1B with 40.0 mm intervals;
- Subgroup 1C with 60.0 mm intervals.

Group 2: experimental models prepared with the 3-hole plates, constituted of 3 subgroups with 5 models each:
- Subgroup 2A with 20.0 mm intervals;
- Subgroup 2B with 40.0 mm intervals;
- Subgroup 2C with 60.0 mm intervals.

Group 3: experimental models prepared with the 4-hole plates, constituted of 3 subgroups with 5 models each:
- Subgroup 3A with 20.0 mm intervals;
- Subgroup 3B with 40.0 mm intervals;
- Subgroup 3C with 60.0 mm intervals.

Figures 3A, 3B and 3C show the experimental models prepared for group 1, group 2 and group 3.

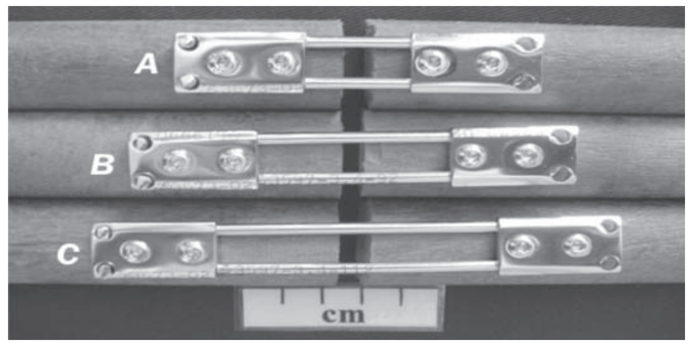


***Figure 3A** - Group 1 models*

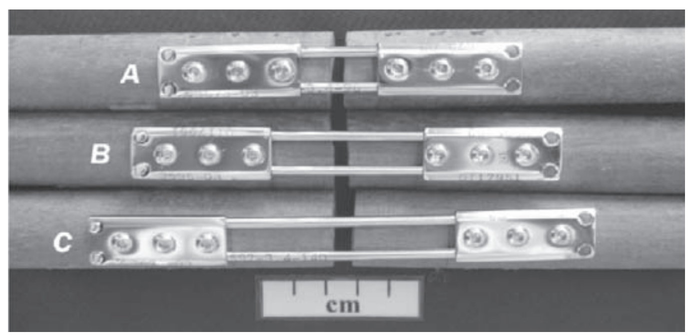


***Figure 3B** - Group 2 models*

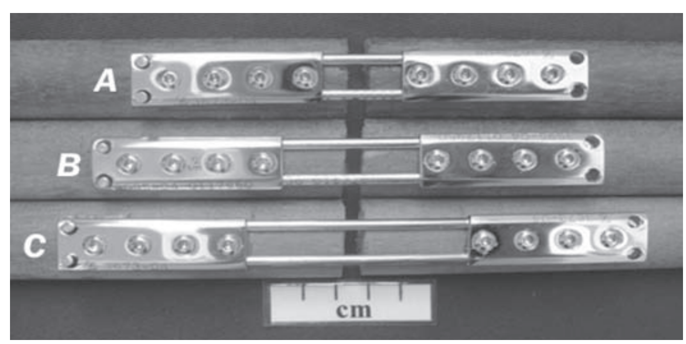


***Figure 3C** - Group 3 models*

4. Mechanical assays

For conducting mechanical assays, the Universal Assay Machine EMIC® of the Bioengineering Laboratory of the Ribeirão Preto Medical School, University of São Paulo, was used.

4.1. Torsion mechanical assays

Torsion assays were performed always positioning experimental models with the SPS® on top. The model was fixated into the device by both ends, one fixed and the other movable (5.0 mm in diameter) where torsion was provided by a steel wire around the device and attached to the movable tray on the assay machine. When the machine was activated, this made the steel wire to apply traction, allowing model torsion at a 5.0 mm/min speed. A maximum force of 200 N was standardized for all assays. The torque moment was calculated by multiplying the force applied to the steel wire by the stick radius (movable device).

4.2. Flexion mechanical assays

Flexion assays were performed by using the fixed device employed on torsion assays, always positioning the SPS laterally. Load was always applied at a distance of 205.0 mm of model fixation. The load application speed was 5.0 mm/min. A maximum force of 50 N was standardized for all flexion assays. The flexion moment was calculated by multiplying the value of each applied force by the distance of model fixation until load application point (lever arm).

5. Mechanical Properties Assessed

For torsion assays, angular deformations (Degrees) for 200 N forces, and torsional stiffness (N.m/degrees) were assessed. The degree of stiffness on each model was measured by a graph (torque vs. angular deformity), by the tangent of the angle formed by the straight line with the abscissa axis.
For flexion assays, deflexion (mm) for 50 N forces and flexion stiffness (N/m) were assessed. The degree of stiffness on each model was measured by a graph (applied force vs. deflexion), by the tangent of the angle formed by the straight line with the abscissa axis.

6. Statistical Analysis

Statistical analyses were provided for the following mechanical properties: angular deformity and torsional stiffness on torsion assays, and deflexion and flexion stiffness on flexion assays. Initially, data normality was assessed by using the multifactorial variance analysis (ANOVA), having as variables the number of holes on the plate (groups) and the interval between plates (subgroups). In *post hoc* comparisons between experimental groups and subgroups, the Bonferroni method was employed. For all analyses, a 5% significance level was adopted.

RESULTS

1. Torsion assay

1.1. Deflexion for 200 N force

By assessing the results of torsion mechanical assays and using the number of holes on the plates as a variable, a significant difference was found on the values for deflexion property between groups ($p = 0.002$)(Figure 4).
In the results of torsion mechanical assays using the interval between plates as a variable, significant differences were found for deflexion property between groups ($p < 0.001$) (Figure 5).

1.2. Torsional stiffness

From the results of the torsion mechanical assays, having the number of holes on a plate as a variable, we can infer that a significant difference exists for stiffness property values between groups ($p = 0.002$)\(Figure 6).

And, when the interval between plates is taken as a variable, we can infer that a significant difference exists for stiffness property values between subgroups ($p < 0.001$) (Figure 7).

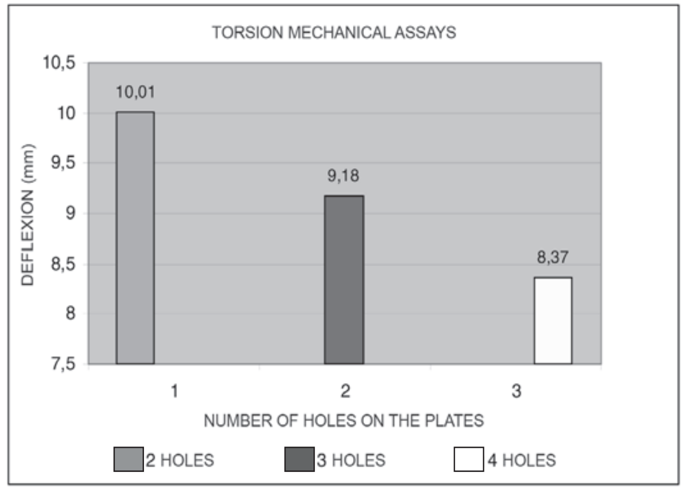


Figure 4 - *Mean deflexion values on experimental groups using plates with 2, 3 and 4 holes.*

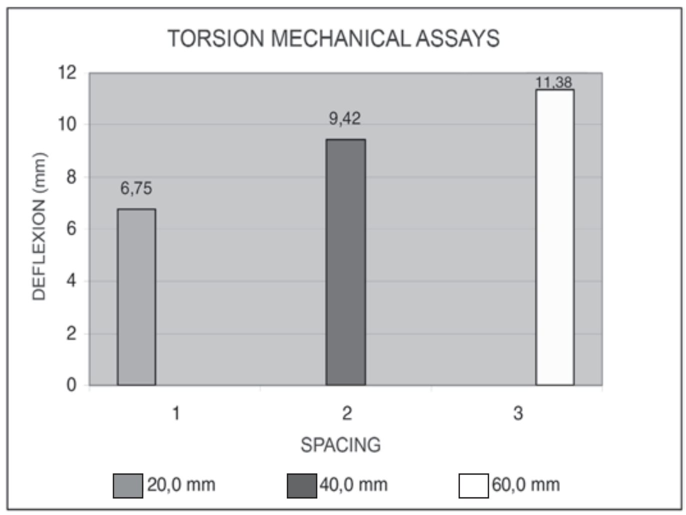


Figure 5 - *Mean deflexion values of subgroups taking the space interval between plates as a variable.*

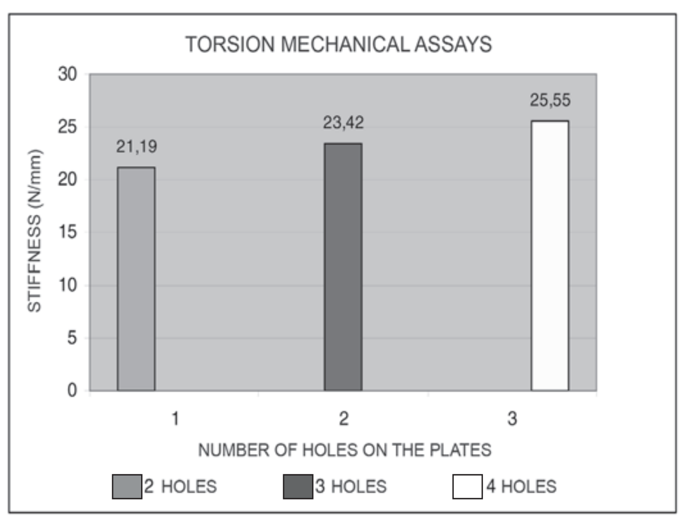


Figure 6 - *Mean torsional stiffness values for experimental groups.*

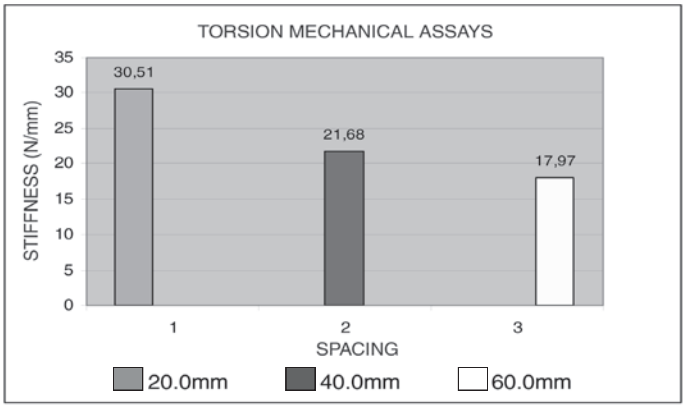


Figure 7 - *Mean torsional stiffness values of the subgroups.*

2. Flexion Assays

2.1. Deflexion for 50 N force

From the results of the lateral flexion mechanical assays using the number of holes on a plate as a variable, we can see that a significant difference exists for deflexion property values between groups ($p < 0.001$), (Figure 8).

From the results of the flexion mechanical assays using the interval between plates as a variable, no significant difference is found (Figure 9) for deflexion property values between subgroups A, B and C ($p = 0.38$).

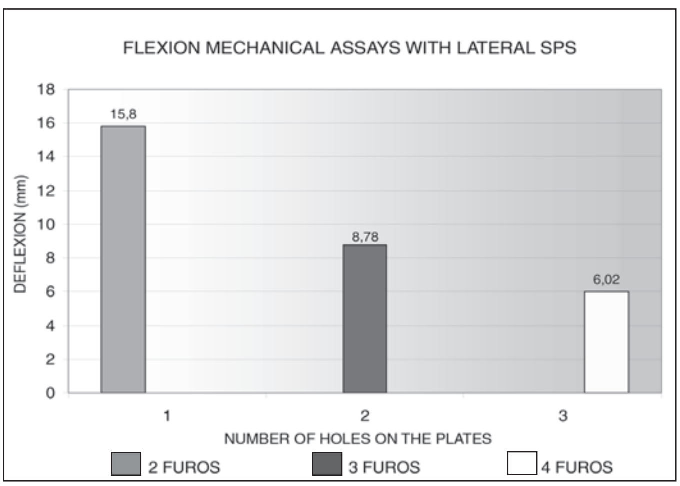


Figure 8 - *Mean deflexion values for experimental groups.*

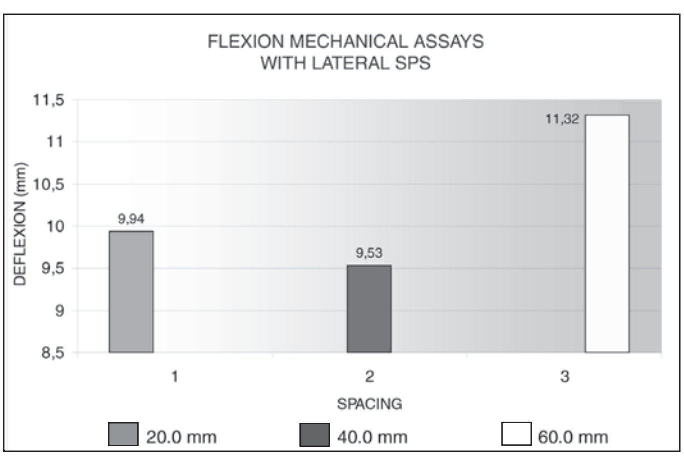


Figure 9 - *Mean deflexion values*

2.2. Flexion stiffness

From the results of the lateral flexion mechanical assays using the number of holes on the plate as a variable, we can infer that a significant difference exists for stiffness mechanical property between groups ($p < 0.001$) (Figure 10).

From the results of the lateral flexion mechanical assays using the interval between plates as a variable, we can see that a significant difference exists for stiffness mechanical property between subgroups ($p = 0.035$) (Figure 11).

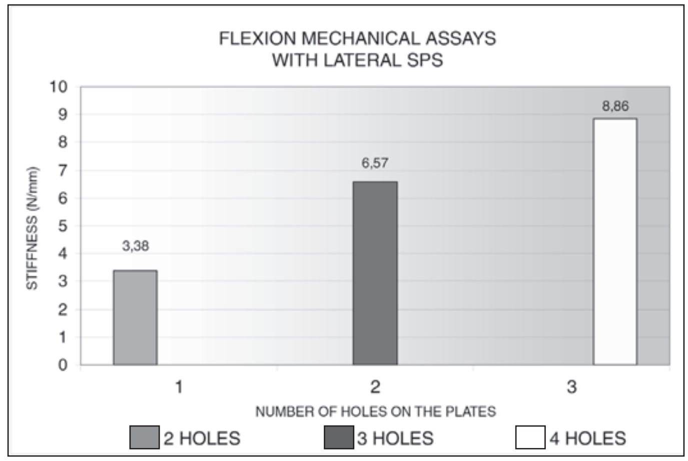


Figure 10 - *Mean flexion stiffness values*

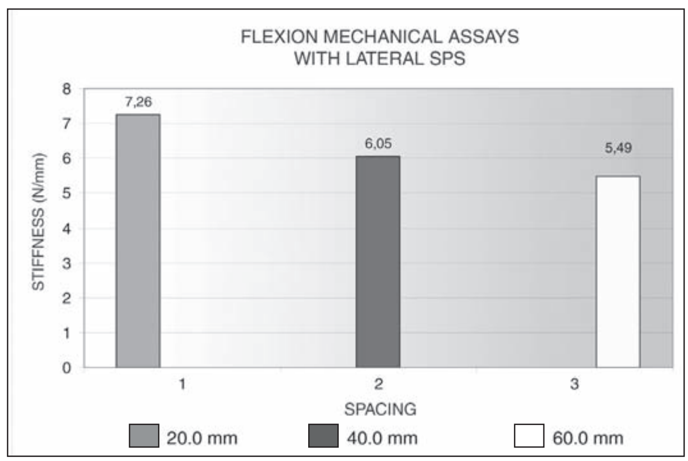


Figure 11 - *Mean stiffness values of the groups.*

DISCUSSION

Osteosynthesis surgical methods suggested for addressing fractures are well known, the most frequently used ones being rigid plates, and its use with more biological application techniques have shown to provide better outcomes[3].

Osteosynthesis methods of relative stability are used in the surgical treatment of fractures due to its properties' mechanical behavior, once a lower level of stiffness enables fragments to move on fracture core, thus stimulating osteogenesis, and this fact has led to the development of a number of experimental studies comparing rigid plates to blocked intramedullary nails of relative stability[4-8]. External fixation systems may be used as an osteosynthesis method of relative stability and are dependent on the kind of assembly and on the accessories employed to enhance stability[9]. In line with studies addressing systems of relative stability, we can find biomechanical studies comparing rigid and flexible fixation[10], reporting a better osteogenesis with flexible fixation systems with cyclic compression on fracture core, while in a continuous-compression system, signs of bone resorption on fracture core were reported; experimental studies addressing osteosynthesis of femoral fractures with plastic nails[11] assessing osteogenesis; experimental study addressing an internal metal fixation and thermoplastic plates analyzing and comparing its results[12] concluding that the osteosynthesis system of relative stability favors a more biological osteogenesis; experimental study where mechanical flexion-compression assays are performed using variable loads on osteotomized human femurs and fixated with plates of different stiffness degrees and variable thickness in design, concluding that the strongest force is applied on screws closer to the osteotomy core and achieved the highest stiffness of the metallic system used on models with plates of higher and more uniform profiles[13].

In this experimental study, we adopted flexion and torsion forces because these are the most demanded and critical involving human humerus at frontal and saggital planes. On flexion mechanical assays, we noticed that the values for stiffness were statistically significantly higher on the group with 4-screws plates and the lowest stiffness was seen on the group with 2-screws plates. When alternating the interval between plates, models that were 20.0 mm apart from each other showed superior stiffness values compared to the remaining models on other groups. This evidenced that the control of the space between plates is important for an assembly's stiffness: the larger the interval the lower the stiffness of the SPS®. The results of the deflexion study considering the number of holes on a plate as a variable was superior for the group with 2-screws plates, but, for groups with 3 and 4-screws plates, those values were comparable. When the interval between plates was considered, no significant difference was noticed for deflexion values between groups.

On torsion mechanical assays, we set the SPS® on a top position when the accessories of the assay machine were attached. We did not discuss other positions for the SPS® on this kind of mechanical assay, since this would be irrelevant for torsion movements. By studying the values for stiffness, we noticed that, for this kind of assay, the number of screws used on the assemblies was important, because the greater the amount of screws the greater the stiffness. The group with 4-screws plates showed significantly lower stiffness values compared to the group with 3 and 2 screws, the latter showing the lowest stiffness value. When the interval between plates was used as a variable, we found that the spacing has also influenced on assembly stiffness: the shorter the space interval the higher the stiffness. The subgroup with 20,0 mm intervals between plates showed significantly lower values than other subgroups, with the subgroup with 60.0 mm intervals presenting the lowest degree of stiffness. But we didn't find significant differences for deflexion values between groups when the number of holes on a plate was taken as a variable. The group with 4-screws plates showed significantly lower deflexion values compared to other groups, with the group with 2-screws plates showing the highest values. When the space interval between plates was taken as a variable, we found that the larger the space the higher the deflexion values. Deflexion values for the subgroup with 20.0 mm intervals between plates were significantly lower than other subgroups, with the subgroup with 60.0 mm intervals showing the highest deflexion value. Thus, we noticed that, for torsion mechanical assays, the highest stiffness with the lowest deflexion was seen on models with 4-screws plates and placed 20.0 mm apart from each other, i.e., the group 3A.

CONCLUSIONS

1. Stiffness was proportional to the number of screws on each plate and to the space intervals on plates. The higher the number of screws on plates and the shorter the space interval between them the higher the stiffness of the system.
2. Deflexion was proportional to the number of screws on each plate and to the space intervals on plates. The higher the number of screws on plates and the shorter the space interval between them the lower the deflexion of the system.
3. Group 3A, with the SPS®, presented the highest level of stiffness and the lowest deflexion on mechanical assays of torsion and flexion.

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