# THE INFLUENCE OF PILOT HOLE DIAMETER ON SCREW PULLOUT RESISTANCE

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## SUMMARY

The influence of the diameter of the pilot hole compared to the inner diameter of the screw on the pull-out resistance of a pedicular screw was studied. 5-, 6-, and 7-mm USS system screws for vertebral fixation were inserted into wood, polyure¬thane and bone test bodies. The pilot hole for screw insertion was drilled with burrs of smaller, equal or wider diameter than the inner diameter of the screw. Mechanical pull-out assays were performed using a universal testing machine. In the wood, polyurethane and bone test bodies, a pilot hole drilled with burrs of a wider diameter than the inner diameter of the screw produced reduced maximum pull-out strength on the implants, with statistical significance. The drilling diameter of the pilot hole compared to the inner diameter of the screw in¬fluences implant pull-out strength, with an increased pull-out resistance being observed with the use of smaller diameter burrs as compared to the inner diameter, and a reduction of pull-out resistance being observed with the use of burrs of a wider diameter than the inner diameter of the screw.


**Keywords:** *Spine; Bone screws; Biomechanics.*

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## INTRODUCTION

Pedicular screws have been extensively employed in vertebral fixation systems due to its biomechanical advantages over the other kinds of implants, and they have been used for the treatment of injuries resulting from trauma, tumors, degenerations, and deformities on spine(1,2). In the biomechanical constellation of vertebral fixation systems, anchoring implants on bone tissue is the basis or foundation of any vertebral fixation system, regardless of its indication or biomechanical function(2-4). Applying pedicular screws on spine requires preparation of the anatomic structure of the vertebra where the implant will be inserted; this is called pilot hole. The pilot hole can be built by means of drills, probes or curettes; its diameter should be considered according to the diameter of the implant to be used. Hole diameter is key when using pedicular screws, since it can directly interfere on the end result of the therapy. The purpose of the present study was to assess the potential influence of the diameter of the drilled pilot hole compared to the inner screw diameter, on pedicular screws pullout resistance.

## MATERIAL AND METHOD

Bodies of evidence made of polyurethane, wood and bovine bone have been used. Polyurethane bodies of evidence were 27 mm wide, the wooden ones were 13 mm wide, and those made of bovine bone, 17 mm wide. The body of evidence made of bovine bone was constituted of the femoral central and distal metaphyseal portion, which was prepared with the aid of a saw, removing the external cortical bone and building 17-mm wide segments of spongy bone. The implants used in the study were: 5-, 6-, and 7-mm wide USS (Synthes) system's pedicular screws (Figure 1). The screws were implanted into the relevant bodies of evidence following the preparation of the pilot hole using drills with different diameters compared to screws' inner diameter. Thus, for assays on 5-mm wide screws (and inner

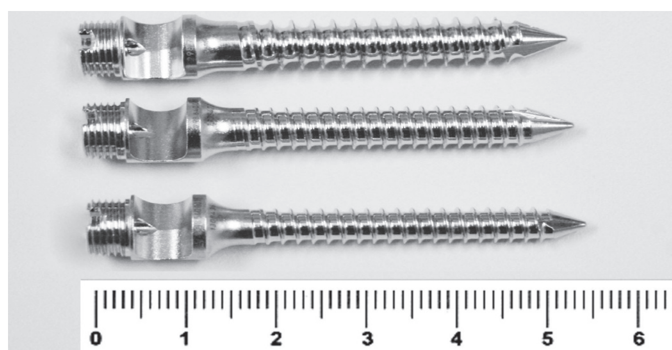


***Figure 1-** Screws employed in the study. From top to bottom, note the 5-mm screw (inner diameter: 3.8-mm), the 6-mm screw (inner diameter: 4.8 mm), and the 7-mm screw (inner diameter: 4.8 mm)*

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diameter of 3,8 mm), 3.2-, 3.8-, 4.0-, and 4.8-mm wide holes were built. For 6-mm wide screws (and inner diameter of 4.8 mm), 4.0-, 4.5-, 4.8-, 5.0-, and 5.5-mm wide holes were built. 7-mm wide screws (with inner diameter of 4.8 mm), 4.0-, 4.8-, 5.0-, 5.5-, 6.0-, and 6.5-mm wide holes were built.

After the hole was built on the body of evidence, the screw was introduced, transfixing the body of evidence and leaving 1 cm of its distal end exposed. Therefore, the number of screw threads in the bodies of evidence was uniform, and the exposed distal end of the screw was used for applying forces on mechanical assays of pullout resistance. The experimental groups were built according the diameter of the screw employed (5.0; 6.0, and 7.0mm), the employed body of evidence, and the diameter of the pilot hole. For 5- and 7-mm screws, wood or polyurethane bodies of evidence were used. For 6-mm screws, wood, polyurethane and bovine bone bodies of evidence were used. Ten mechanical assays were performed for experimental groups with polyurethane bodies of evidence, and 15 mechanical assays for experimental groups with bovine bone bodies of evidence. The mechanical assays were performed on a universal assay machine (EMIC® model, Brazil), connected to a computer and a 200-Kgf load cell. The pullout resistance of the implants was assessed by applying axial load along the screw shaft, applied on the distal end (edge) of the screw, and measuring the amounts required to displace the implant. The results were compared by means of statistical analysis, using the variance analysis (ANOVA) test for detecting statistical differences between the experimental groups, and the Bonferroni´s "post-hoc test" for determining specific differences between studied parameters. A significance level of 5% ($p \leq 0.05$) was adopted for the study.

## RESULTS

The results will be presented according to screw diameter and the nature of the body of evidence. The results concerning the use of 5.0-mm screws on wooden bodies of evidence (Table 1 and Figure 2). The average of the values for maximum pullout force was shown to be reduced with wider hole diameters. Considering the hole diameter corresponding to the inner diameter of the screw (3.8 mm), an increased pullout strength was found with 3.2 mm drills, but no significant statistical difference was found. The values seen with the use of wider drills compared to the inner diameter of the screw (3.8 mm) showed lower values of maximum pullout strength, and a significant statistical difference was found between values. It was not possible to perform mechanical assays on the group of implants with 4.8-mm wide holes. In this group, only with the pre-load, the implants were pulled out of the bodies of evidence.

| Diameter of the drill (mm) | Average Maximum Strength (N) | Standard Deviation | Variation coefficient (%) | Number of tests performed |
|---|---|---|---|---|
| 3.2 | 875.4 | 62.57 | 7.148 | 10 |
| 3.8 | 848.4 | 75.24 | 8.869 | 10 |
| *4.0 | 746.7 | 64.34 | 8.616 | 10 |
| *4.5 | 524.7 | 84.83 | 13.12 | 10 |

***Table 1 –*** *Values of the maximum pullout strength for 5-mm screws applied on wooden bodies of evidence and with the pilot holes built with drills.( *) Statistically significant difference compared to the values for 3.8-mm holes.*

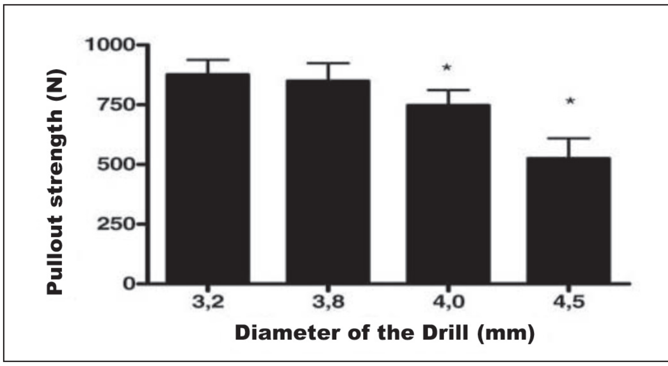


***Figure 2 –*** *The pullout strength values for 5-mm screws and the different diameters of the drill employed for perforating wooden bodies of evidence. The asterisk (*) indicates a statistically significant difference compared to the values for 3.8-mm holes.*

Results concerning to 5-mm screws inserted into polyurethane bodies of evidence (Table 2 and Figure 3): The average of the values for maximum pullout strength was shown to be increased with the use of narrower drills compared to the inner diameter of the screw, and were reduced with wider drills compared to the inner diameter of the screw. A significant statistical difference was found among maximum pullout strength values with the use of wider- or narrower-gauged drills compared to the inner diameter of the screw.

| Diameter of the drill (mm) | Average Maximum Strength (N) | Standard Deviation | Variation coefficient (%) | Number of tests performed |
|---|---|---|---|---|
| *3.2 | 50.24 | 3.807 | 7.578 | 10 |
| 3.8 | 30.23 | 2.582 | 8.542 | 10 |
| *4.5 | 6.117 | 1.486 | 24.30 | 10 |
| *4.8 | 1.181 | 0.325 | 27.53 | 10 |

***Table 2 –*** *Values of the maximum pullout strength for 5-mm screws applied on polyurethane bodies of evidence, and with pilot holes built with drills. (*) Statistically significant differences compared to the values for 3.8-mm holes.*

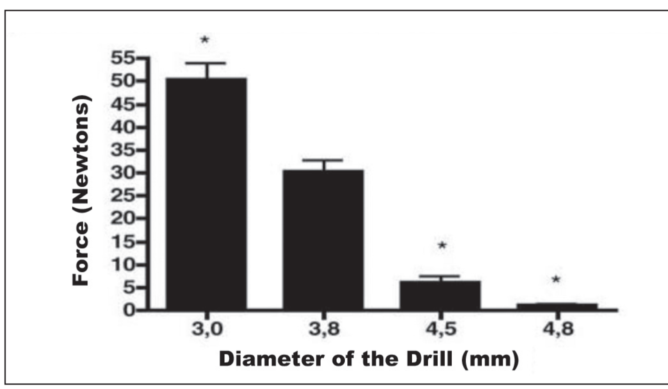


***Figure 3 –*** *Values of the maximum pullout strength for 5-mm screws applied on polyurethane bodies of evidence, and with pilot holes built with drills. The asterisk (*) indicates a statistically significant difference compared to the values for 3.8-mm holes.*

Results concerning the use of 6.0-mm screws on wooden bodies of evidence (Table 3 and Figure 4): the average values for maximum pullout strength was shown to increase with narrower holes. The difference was statistically significant between 4.0-mm holes and the inner diameter of the screw (4.8mm). Although we found differences between 4.5-mm holes and the

| Diameter of the drill (mm) | Average Maximum Strength (N) | Standard Deviation | Variation coefficient (%) | Number of tests performed |
|---|---|---|---|---|
| *4.0 | 1047.0 | 95.43 | 9.116 | 10 |
| 4.5 | 935.7 | 92.25 | 9.859 | 10 |
| 4.8 | 868.1 | 66.82 | 7.697 | 10 |
| 5.0 | 809.8 | 65.93 | 8.142 | 10 |
| *5.5 | 641.7 | 65.49 | 10.21 | 10 |

***Table 3 –*** *Values of the maximum pullout strength for 6-mm screws applied on wooden bodies of evidence, and with pilot holes built with drills. (*) Statistically significant difference compared to the values for 4.8-mm holes.*

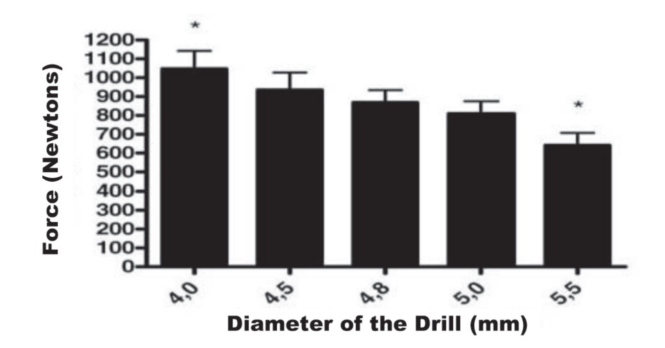


***Figure 4 –*** *Maximum pullout strength of 6-mm screws inserted into wooden bodies of evidence, with holes built with drills. The asterisk (*) indicates a statistically significant difference compared to the value of the inner diameter of the screw (4.8 mm)*

inner diameter of the screw, these were not statistically significant. The average maximum pullout strength was shown to reduce as the hole diameter increased. A statistically significant difference was found between 5.5-mm holes and the inner diameter of the screw (4.8mm). Results concerning the use of 6.0-mm screws on polyurethane bodies of evidence (Table 4 and Figure 5): a trend was also noticed towards increased maximum pullout strength with narrower diameters of the hole compared to the inner diameter, and a reduction trend as it increases. In the group of holes built with drills, a statistically significant difference was found among all values for the hole compared to the inner diameter of the implant (4.8 mm).

| Diameter of the drill (mm) | Average Maximum Strength (N) | Standard Deviation | Variation coefficient (%) | Number of tests performed |
|---|---|---|---|---|
| *4.0 | 63.71 | 5.724 | 8.984 | 10 |
| *4.5 | 49.45 | 3.439 | 6.954 | 10 |
| 4.8 | 39.82 | 3.672 | 9.222 | 10 |
| *5.0 | 24.86 | 1.486 | 5.980 | 10 |
| *5.5 | 12.65 | 1.572 | 12.43 | 10 |

***Table 4 –*** *Values of the maximum pullout strength of 6-mm screws applied on polyurethane bodies of evidence, with pilot holes built with drills. (*) Statistical difference compared to the values for 4.8-mm holes.*

Results concerning the use of 6.0-mm screws on bodies of evidence made of bovine bone (Table 5 and Figure 6): a trend was also noticed towards increased maximum pullout strength with narrower diameters of the hole compared to the inner diameter,

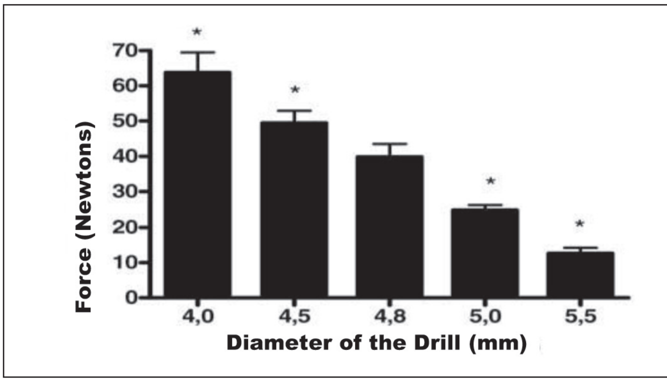


***Figure 5 –*** *Maximum pullout strength of 6-mm screws inserted into polyurethane bodies of evidence, with holes built with drills. The asterisk (*) indicates a statistically significant difference compared to the value of the inner diameter of the screw (4.8 mm)*

and a reduction trend as it increases. A statistically significant difference was found among all values for the hole compared to the inner diameter of the implant (4.8 mm).

| Diameter of the drill (mm) | Average Maximum Strength (N) | Standard Deviation | Variation coefficient (%) | Number of tests performed |
|---|---|---|---|---|
| *4.0 | 786.1 | 146.8 | 18.67 | 10 |
| 4.8 | 504.2 | 145.9 | 28.94 | 10 |
| *5.5 | 235.4 | 50.34 | 21.39 | 10 |

***Table 5 –*** *Values of the maximum pullout strength of 6-mm screws applied on bovine bone, with pilot holes built with drills. (*) Statistically significant difference compared to the values for 4.8-mm holes.*

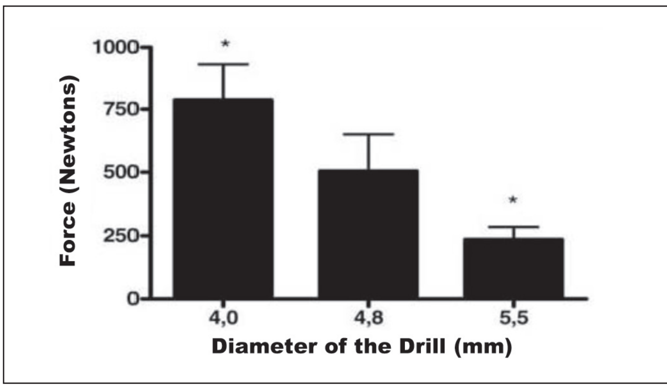


***Figure 6 –*** *Maximum pullout strength of 6-mm screws inserted into bovine bone, with holes built with drills. The asterisk (*) indicates a statistically significant difference compared to the values for the 4.8-mm hole*

Results concerning the use of 7.0-mm screws on wooden bodies of evidence (Figure 7 and Table 6). No statistically significant difference was found for increased pullout strength resistance with reduced diameters of the drill compared to the inner diameter of the screw. (hole built with 4.0-mm drill). Also, no statistically significant difference was found for pullout strength values with increased hole diameter for 5.0-mm and 5.5-mm. However, the values concerned to 6.0-mm and 6.5-mm holes showed a statistically significant difference compared to the inner diameter of the screw (4.8 mm). Results concerning the use of 7.0-mm screws on polyurethane bodies of evidence (Figure 8 and Table 7): a trend was also noticed towards increased maximum pullout strength with narrower diameters of the hole

| Diameter of the drill (mm) | Average Maximum Strength (N) | Standard Deviation | Variation coefficient (%) | Number of tests performed |
|---|---|---|---|---|
| 4.0 | 1134 | 90.23 | 7.954 | 10 |
| 4.8 | 1096 | 84.66 | 7.727 | 10 |
| 5.0 | 1094 | 73.69 | 6.734 | 10 |
| 5.5 | 1004 | 71.05 | 7.079 | 10 |
| *6.0 | 890.5 | 94.87 | 10.65 | 10 |
| *6.5 | 861.9 | 80.79 | 9.374 | 10 |

***Table 6 –*** *Values of the maximum pullout strength of 7-mm screws applied on wood, with pilot holes built with drills. (*) Statistically significant difference compared to the values for 4.8-mm holes.*

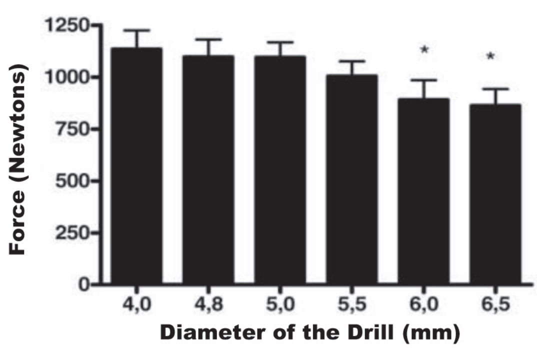


***Figure 7 –*** *Maximum pullout strength of 7-mm screws inserted into wood, with holes built with drills. The asterisk (*) indicates a statistically significant difference compared to the value of the inner diameter of the screw (4.8 mm)*

| Diameter of the drill (mm) | Average Maximum Strength (N) | Standard Deviation | Variation coefficient (%) | Number of tests performed |
|---|---|---|---|---|
| *4.0 | 74.72 | 2.460 | 3.293 | 10 |
| 4.8 | 70.97 | 4.419 | 6.227 | 10 |
| *5.0 | 61.56 | 3.570 | 5.800 | 10 |
| *5.5 | 43.92 | 3.366 | 7.664 | 10 |
| *6.5 | 5.50 | 1.268 | 23.03 | 10 |

***Table 7 –*** *Values of the maximum pullout strength of 7-mm screws applied on polyurethane, with pilot holes built with drills. (*) Statistical difference compared to the values for 4.8-mm holes.*

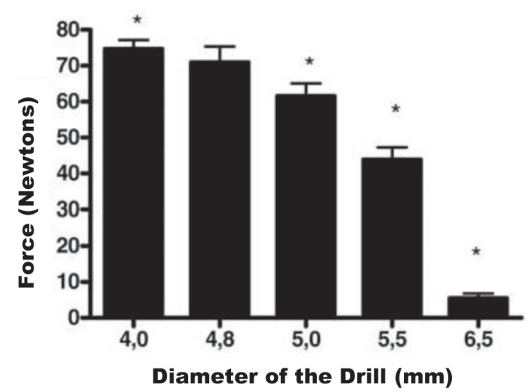


***Figure 8 –*** *Pullout strength values for 7-mm screws inserted into polyurethane bodies of evidence, with holes built with drills. The asterisk (*) indicates a statistically significant difference compared to the inner diameter of the screw (4.8 mm).*

compared to the inner diameter, and a reduction trend as it increases. A statistically significant difference was found among values for 4.0-mm hole (narrower than the inner diameter) and for all values above the inner diameter of the screw (5.0mm; 5.5mm, and 6.6mm).

On the summary of the results (Table 8) for all bodies of evidence and screw diameters used in the mechanical assays we could notice that the pilot hole diameter was inversely proportional to screws pullout resistance, and statistically significant differences were found for all pilot hole values above the inner diameter of the screw. For pilot holes narrower than the inner diameter, a statistical difference was found related to the inner diameter of the screw in assays performed on bodies of evidence made of polyurethane and bovine bone for all screw diameters studied.

## DISCUSSION

Vertebral fixation systems are constituted of different components: anchorage components (screws, hooks, cerclage wires), longitudinal components (nails, plates), cross-sectional connectors and accessories (washers and nuts)[2]. The anchorage components may be penetrating-type (screws) and non-penetrating-type (hooks and cerclage wires) and they work as an anchorage point for fixation systems on the vertebrae, over which

| | | Diameter of the drill (mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| screw | body of evidence | 3.2 | 3.8 | 4 | 4.5 | 4.8 | 5 | 5.5 | 6 | 6.5 |
| 5 mm | wood | | | * | * | | | | | |
| | polyurethane | * | | * | * | * | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| 6mm | wood | | | | | | | * | | |
| | polyurethane | | | * | * | | * | * | | |
| | bone | | | * | | | | * | | |
| | | | | | | | | | | |
| 7mm | wood | | | | | | | | * | * |
| | polyurethane | | | * | | | | * | | * |

***Table 8 –*** *Distribution of pilot holes' diameters, bodies of evidence, and diameter of the screw employed and the indication of statistical difference found on implants pullout assays compared to the inner diameter of the screw (3.8mm – 5-mm screws, and; 4.8-mm –6- and 7-mm screws).*

correction or neutralization forces are applied. Thus, anchoring a screw on a vertebra is of critical importance for the good performance of a fixation system's mechanical function[3,5,6]. Screw anchorage on the vertebra and its mechanical pullout resistance are influenced by several factors such as quality of bone tissue (osteoporosis), implant's design and diameter and pilot hole building (diameter, depth and tapping of the hole)[3-9]. Pilot holes are built to guide and enable the introduction of screws into the vertebra, and building it implies on removing some of the spongy bone from the vertebra with the use of perforation drills. The way a pilot hole is constructed depends on the kind of bone (cortical or spongy bone) where the implant is inserted[2,10]. Cortical bones are more rigid, and drilling a narrower pilot hole than the inner diameter of the screw causes micro fractures on the surrounding bone and compromises the quality of fixation. Due to this fact, a pilot hole is drilled with a slightly wider diameter than screw's diameter; tapping is provided and cortical screws have a narrower thread diameter and less space intervals between thread steps and wider inner diameter[2,10-12]. The stress caused on the bone adjacent to cortical-type screws is proportional to the excess of the implant's diameter compared to the pilot hole, and should not exceed 0.005 in order to avoid micro fractures[2,10,12]. The spongy bone is less rigid when compared to cortical bone and has fewer cavities due to the arrangement of bone trabeculae. The introduction of a screw on a spongy bone causes compression of the adjacent bone, increases its density and screw's pullout resistance[2,13]. Due to those characteristics, spongy screws have bigger threads, thread steps more distant from each other, and narrower inner diameter[2,10]. On spine, pedicular screws rarely are anchored on pedicle's cortical bone and touch the spongy bone of the pedicle and vertebral body[2,14], thus, the insertion of a screw with a narrower pilot hole diameter than the inner diameter of the screw causes higher spongy bone compaction and reinforces the interface between bone and implant, thus increasing implant's pullout resistance[12,13]. However, the late biological or biomechanical effect of such micro fractures produced around the implants is still unknown.

The results found in our assays confirm the hypothesis that the compaction of spongy bones around pedicular screws increases implants´ pullout resistance on different bodies of evidence, and these results can serve as an alert for considering the pilot hole diameter in relation to implant's diameter when using this vertebral fixation modality. Literature addressing this topic shows inconsistent results, with reports of experimental studies where the pilot hole has not influenced pullout resistance, but an influence of the outer cortical diameter[15]. Although the uncountable parameters mentioned on implants' pullout resistance, the inner diameter of the screw is not being emphasized[5,15-17]. The experimental model used in this study deserves some considerations, because, due to the restraints in using human vertebrae of homogenous density and osteoporosis-free, the use of wooden, polyurethane and bovine bone bodies of evidence was required, following the trend of the studies conducted on this matter[3,5,17]. The use of these kinds of bodies of evidence allows for inserting screws in homogenous materials with a uniform matrix pattern[17,18]. The assays performed assessed only screws´ pullout resistance upon axial forces applied, a condition that do not correspond to that of cyclic physiological loads usually applied on implants, with the performance of flexion movements. However, this was the simplest and most practical way to study one of the variables involved on screws' pullout resistance, which is complex and associated to many factors directly related to the quality of bone tissue and implants´ characteristics[2,8]. The way the mechanical assays are performed may influence the results of pullout resistance assessments, and the way the body of evidence is fixated and the force is applied for performing these assays are important variables[19]. Applying forces on implants' edges has made tests easier in terms of fixation of the bodies of evidence, and the problems described with the use of this kind of assay could be overcome[19].

## CONCLUSIONS

Building a pilot hole with narrower drills compared to the inner diameter of the screw has increased the maximum pullout strength of implants on mechanical assays. Statistically significant values were found on polyurethane and bovine bone bodies of evidence. The use of drills with wider diameter than the inner diameter of the screw for building a pilot hole has reduced implants´ maximum pullout strength on mechanical assays. A statistical significance was found for this parameter on assays performed on wooden, polyurethane and bovine bone bodies of evidence. The diameter of the pilot hole in relation to the inner diameter of the screw influences screws´ pullout resistance.

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