Effects of hole preparation on screw pullout resistance and insertional torque: a biomechanical study

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Object. The authors conducted a study to assess the effect of a pilot hole preparation on screw pullout resistance and screw insertional torque.

Methods. Three different screws were tested: cancellous lateral mass screws, cortical lateral mass screws, and pedicle screws. Synthetic bone blocks were used as the host material. Each screw group was separated into two subgroups. The first subgroup of screws was inserted into the test material following pilot hole preparation. Pilot holes were prepared; a drill bit diameter size smaller than the core diameter of the screws was used. The second group of screws was inserted into the test material without pilot hole preparation (a 3- or 4-mm hole drilled for entrance site preparation only). The insertional torque was measured as the screw was advanced into the material. The screws were axially extracted from the host material at a constant speed of 2.5 mm/minute. The pullout resistances and insertional torques for the pilot hole and the nonpilot hole groups were then statistically compared.

The authors found that preparation of a pilot hole caused a significant decrease in the insertional torque. The screws inserted without a pilot hole showed greater pullout resistances compared with those inserted following a pilot hole preparation; however, there was no statistically significant difference.

Conclusions. The optimum screw insertion technique may involve drilling a short pilot hole and using a drill bit with a smaller diameter than the screw core diameter to increase bone–screw purchase. This applies to cancellous and cortical lateral mass screws as well as pedicle screws.

KEY WORDS • spine • pilot hole • insertional torque • pullout resistance • biomechanics
Pilot hole preparation serves as a guide for the screw hole, creating a larger void and less competent bone for the screw to sit within. This results in a decreased pullout resistance. If tapping reduces pullout resistance in cancellous bone, a similar effect may be expected if a pilot hole is prepared by drilling.

The authors of previous studies have demonstrated a direct relationship between insertional torque and pullout resistance. Pilot hole preparation serves as a guide for screw insertion, and it may also be argued that, without a pilot hole preparation, proper alignment during screw insertion may be difficult to maintain. Conversely, a greater insertional torque may be expected during insertion of the screw when no pilot hole is used. Considering these conflicting factors, a study was designed to assess the effect of pilot hole preparation on insertional torque and screw pull-out resistance for three different screw types.

Materials and Methods

Pilot and Nonpilot Hole Screw Groups

To avoid the inherent variability of biological material and to ensure that the test medium is of low stiffness and strength that is comparable with mildly osteoporotic cancellous bone, porous polyurethane foam was used as the test medium in this study. Uniform, rectangular blocks of synthetic cancellous material with a medium porosity and a 2.26 Nm of compressive performance (25 × 25 × 50 mm) were used.

All screws were placed centrally in the blocks. The pilot holes and the holes for initiating screw insertion (shallow holes) were prepared using a vertical drill press to maintain consistent placement of the screw in a perpendicular orientation with the test medium. The length of the pilot hole was 80% of the screw insertion depth within the test material.

Three different screws were tested. Cancellous lateral mass screws (14-mm overall length, 4-mm outer diameter, 2.8-mm core diameter, and a 1.65-mm pitch) were placed 10 mm into the test material (Group 1). Cortical lateral mass screws (14-mm overall length, a 3.5-mm outer diameter, a 2-mm core diameter, and 0.5-mm pitch), were placed 10 mm into the test material (Group 2). Pedicle screws (30-mm overall length, a 5.5-mm outer diameter, a 3.5-mm core diameter, and a 1.5-mm pitch), were placed 24 mm into the test material (Group 3). In the nonpilot hole groups small shallow holes were drilled (3 mm deep for lateral mass screws and 4 mm deep for pedicle screws). This facilitated the initiation of the screw insertion. A commercially available torque screwdriver (0.01–1.4 Nm) was used to measure the insertional torque of the screws. We modified the torque screwdriver with an attachment that fit the heads of the lateral mass and pedicle screws. The torque was measured as the screw was advanced into the block. In all cases, maximum torque was observed and recorded when the designated depth of insertion for each screw type was reached.

Three separate studies were performed. Each is described separately.

Study 1. Twelve cancellous cervical lateral mass screws (Group 1) were separated into two subgroups of six screws per group (Fig. 1). For the first subgroup, an 8-mm-deep pilot hole was prepared using a 1.95-mm-diameter drill bit. The screw was placed 10 mm into the test material. For the second subgroup, a 3-mm hole was used to initiate the screw insertion and 10 mm of the screw was placed into the test material.

Study 2. Twelve cortical cervical lateral mass screws (Group 2) were separated into two subgroups of six screws per group (Fig. 1). The pilot holes were prepared using a 1.95-mm-diameter drill bit. Screws were inserted to a depth of 10 mm as described for Study 1.

Study 3. Twelve pedicle screws (Group 3) were separated into two subgroups of six screws per group (Fig. 1). For the first subgroup, a 19-mm-deep pilot hole was prepared with the drill bit diameter size of 3.1 mm. The screws were inserted into the test material to a depth of 24 mm. For the second subgroup, a 4-mm-deep hole was prepared to initiate the screw insertion and 24 mm of the screw was placed into the test material.

Pullout Testing

Fixtures housing the bone blocks were secured onto the base plate of the testing apparatus (load capacity ± 20 kN; Fig. 2). After clamping the upper fixture to the machine and gripping the head of the screw, the screws were axially extracted from the host material at a constant rate of 2.5 mm/minute. The force and time values of each screw extraction were digitally recorded using a digital oscilloscope. From these data, the maximum value of the applied tensile force was determined and defined as the screw pullout resistance.

Statistical Analysis

The screw pullout resistance and insertional torque values for the pilot hole and nonpilot hole groups for each study were then compared. A Student two-tailed unpaired t-test was used to detect significant differences in pullout resistance and insertional torque. A significance level of 95% was considered to be statistically significant.

Sources of Supplies and Equipment

The synthetic cancellous bone blocks are manufactured by Pacific Research (Vashon, WA). Depuy–Acromed (Raynham, MA) manufactures both the cancellous and cortical lateral mass screws used in our experiments. The pedicle screws (TSRH) are produced by Sofamor Danek (Memphis, TN). We obtained the torque screwdriver from Snap-On, Inc. (Kenosha, WI); the testing apparatus (model TT-D) from Instron (Canton, MA); and the digital oscilloscope (model 9304A) from LeCroy (Chesnut Ridge, NY).

Results

The pullout resistance and insertional torque values for cancellous lateral mass screws, cortical lateral mass screws and pedicle screws, with and without pilot hole
Effect of pilot hole preparation

preparation, are presented in Tables 1 to 3, respectively. All values are expressed as the means ± standard deviations unless otherwise indicated.

**Insertional Torque and Pullout Resistance**

**Study 1: Cancellous Lateral Mass Screws.** The mean insertional torques for the cancellous lateral mass screws inserted for the nonpilot hole and pilot hole groups were 0.22 ± 0.02 Nm and 0.16 ± 0.02 Nm, respectively (p < 0.0001) (Fig. 3 upper). The pullout force was not statistically different. The mean pullout resistance was 219.3 ± 20.2 N for the nonpilot hole group and 194 ± 36.5 N for the pilot hole group (Fig. 3 lower). The pullout forces were not statistically different.

**Study 2: Cortical Lateral Mass Screws.** The mean insertional torques for the cortical lateral mass screws inserted for the nonpilot hole group and the pilot hole group were 0.21 ± 0.01 Nm and 0.12 ± 0.02 Nm, respectively (p < 0.0001) (Fig. 3). The mean pullout resistance was 206.1 ± 48 N for the subgroup in which a pilot hole had not been drilled and 185.7 ± 42.6 N for the subgroup in which one had been prepared (Fig. 3 lower). The pullout forces were not statistically different.

**Study 3: Pedicle Screws.** The mean insertional torque of the pedicle screws was 1.08 ± 0.02 Nm for the nonpilot hole subgroup and 0.76 ± 0.02 Nm for the pilot hole subgroup (p < 0.0001) (Fig. 3). The mean pullout resistance for the nonpilot hole subgroup was 995.3 ± 160.3 N and 895.5 ± 154.3 N for the pilot hole subgroup (Fig. 3 lower). The pullout forces were not statistically different.

**Comparison of Study 1 and Study 2 Data**

Preparation of the pilot hole by drilling resulted in a statistically significant decrease in the insertional torque for all sets of screws. The mean pullout force in cases of nonpilot hole preparation was greater than that in cases in which the pilot hole was prepared for all screws. However, this difference was not statistically significant. The difference between pilot and nonpilot hole preparation was greater for cancellous compared with cortical lateral mass screws with respect to pullout force (p < 0.17 and p < 0.45, respectively).

**Screw Toggle**

Screws inserted into a specimen in which a pilot hole was not predrilled were observed occasionally to toggle during the initial insertion process. This caused some difficulties with aligning the screw perpendicular to the test block. These specimens were omitted from pullout testing.

**Discussion**

The method of spinal stabilization in which instrumentation and bone graft are placed has been used to treat a variety of spinal disorders since the early 1900s. Since then, numerous studies have been performed to increase the efficacy of the instrumentation and spinal stability. Much of this work has focused on screws.

Pilot hole preparation decreases the insertional torque. This should, intuitively, be related to a decreased screw pullout resistance. In drilling a screw hole, the debris that remains on the drill bit is removed. Therefore, the character of the screw purchase site is altered.

In this study, a statistically significant decrease in screw pullout force was not observed. There are several potential reasons for this observation. First, the tests in the pres-
both the placement of screws and pilot hole preparation. Polyurethane foam, the material for the synthetic bone blocks, is a homogeneous material with a uniform matrix pattern. A true trabecular pattern is not present in the foam. Both the placement of screws and pilot hole preparation in such a material may cause microfractures. The effect of this microfracture formation may be exaggerated in living cancellous bone (trabecular pattern present) in which pilot holes are drilled, because the microfractures leave larger voids surrounding the screw threads. This is attributed to the nonhomogeneous pattern of trabeculae and the fracturing of trabeculae by the drill.

When a screw is inserted without a pilot hole, the material (bone or foam) is compressed, thus filling the aforementioned voids. The compressed material (bone or foam) therefore creates a stronger interface with the screw compared with that created if a pilot hole had been drilled. The diameter of the drill bit used to prepare a pilot hole that approximates the inner diameter of the screw diminishes this compression advantage. Therefore, it is expected that the diameter of a pilot hole that is the same as that of the core of the screw (as manufacturers often advise) may result in a substantial decrease in insertional torque and pullout resistance when compared with cases in which the pilot hole diameter is substantially smaller than the inner diameter of the screw. A trend toward this was observed herein with respect to pullout resistance in the two lateral mass screws studied (Study 1 and Study 2; \( p = 0.17 \) and \( p = 0.45 \), respectively).

The differences between cancellous and cortical screws is worthy of a brief discussion. Cancellous screws, in general (depending on the manufacturer’s definition), have greater thread depth (and hence smaller inner diameter) and pitch (distance between threads) than otherwise equivalent cortical screws. The pitch is the most important factor in this regard. The manufacturer determined that the screw used in Study 1 was a “cancellous screw,” whereas that used in Study 2 is a “cortical screw,” despite the fact that the cancellous screw used in Study 1 has the lesser thread depth. It has, however, a much greater pitch (1.65 mm for the cancellous screw and 0.5 mm for the cortical screw). Because the core diameter of the cancellous screw used in this study was greater than that of the cortical screw, the insertional torque of the former was observed to be greater, regardless of whether a pilot hole was drilled. This should be expected. A greater pitch, in general, is associated with a greater pullout resistance. In terms of pullout resistance, because the pitch is in many circumstances more important than thread depth, the effect of a greater pitch (but smaller thread depth) resulted in the cancellous screw (Study 1) demonstrating a marginally greater pullout resistance than the cortical screw (Study 2), regardless of whether or not a pilot hole was drilled. In summary, insertional torque appears to be predominantly affected by the difference between the pilot hole diameter and the inner diameter of the screw, whereas pullout resistance is affected by many factors, perhaps the most significant of which is the thread pitch; the thread depth as well as the difference between the diameter of the pilot hole (if used) and the inner diameter of the screw depth also play significant roles.

Finally, the effect of the cortical shell should also be considered. In this study, we used synthetic bone that is similar to cancellous bone without a cortex. Thus, a greater relationship between insertional torque and screw pullout resistance might be observed in the presence of healthy cortical bone. Daftari and coworkers used bicortical synthetic bone material and bovine spine to investigate the relationship between insertional torque and screw pullout resistance, which they found to be significantly correlated. They showed that the strength of fixation is dependent on the combined strength of the cancellous bone and the cortical bone and concluded that if the cortex is removed, the strength of fixation relies on the strength of the cancellous bone alone, which is relatively weak. On the other hand, Kwok, et al., did not find a significant correlation between these factors in their osteoporotic specimens; however, they did observe pullout resistance to be greater in cortical bone than in cancellous bone. They concluded that the insertional-

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**Table 2**

Pullout force data for the cortical lateral mass screws

<table>
<thead>
<tr>
<th>Pilot Hole Screw</th>
<th>Insertional Torque (Nm)</th>
<th>Pullout Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.09</td>
<td>217.6</td>
</tr>
<tr>
<td>2</td>
<td>0.14</td>
<td>153.2</td>
</tr>
<tr>
<td>3</td>
<td>0.11</td>
<td>114.1</td>
</tr>
<tr>
<td>4</td>
<td>0.11</td>
<td>205.4</td>
</tr>
<tr>
<td>5</td>
<td>0.11</td>
<td>204.1</td>
</tr>
<tr>
<td>6</td>
<td>0.14</td>
<td>219.5</td>
</tr>
</tbody>
</table>

**Table 3**

Pullout force data for the pedicle screws

<table>
<thead>
<tr>
<th>Pilot Hole Screw</th>
<th>Insertional Torque (Nm)</th>
<th>Pullout Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.76</td>
<td>963.5</td>
</tr>
<tr>
<td>2</td>
<td>0.76</td>
<td>704.8</td>
</tr>
<tr>
<td>3</td>
<td>0.79</td>
<td>1080.7</td>
</tr>
<tr>
<td>4</td>
<td>0.74</td>
<td>788.8</td>
</tr>
<tr>
<td>5</td>
<td>0.76</td>
<td>1042.7</td>
</tr>
<tr>
<td>6</td>
<td>0.76</td>
<td>792.3</td>
</tr>
</tbody>
</table>

* \( p < 0.001 \), t-test; significant value.
† \( p < 0.045 \), t-test.

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al torque measurement is not a reliable predictor of pullout resistance in cadaveric bone. Although the results of these two studies were different, both groups of authors demonstrated the importance of cortical bone in enhancing the screw pullout resistance and insertional torque. These observations suggest that cancellous bone integrity affects the relationship between insertional torque and pullout resistance. This phenomenon may have played a role in the results obtained in this study.

Toggling during screw insertion was occasionally observed in this study. As already mentioned, this is expected (and was observed) when a pilot hole was not used. It is intuitive that a “starter” hole helps guide a screw in the initial turns of the screw during insertion and is therefore useful.

Conclusions
In this study, the preparation of a pilot hole resulted in a significant decrease in the insertional torque in the three screws tested. An insignificant response (trend) was observed for pullout resistance. It is concluded that the optimum screw insertion technique may involve the use of a short pilot hole for entrance site preparation only, as well as the use of a drill bit with a smaller diameter than that of the screw core.

References

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