A Comparison of Screw Insertion Torque and Pullout Strength

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Purpose: Pullout strength of screws is a parameter used to evaluate plate screw fixation strength. However, screw fixation strength may be more closely related to its ability to generate sufficient insertion because stable nonlocked plate–screw fracture fixation requires sufficient compression between plate and bone such that no motion occurs between the plate and bone under normal loads. Compression is generated by tightening of screws. In osteoporotic cancellous bone, sufficient screw insertion torque may not be generated before screw stripping. The effect of screw thread pitch on generation of maximum insertion torque (MIT) and pullout strength (POS) was investigated in an osteoporotic cancellous bone model and the relationship between MIT and POS was analyzed.

Methods: Stainless steel screws with constant major (5.0 mm) and minor (2.7 mm) diameters but with varying thread pitches (1, 1.2, 1.5, 1.6, and 1.75 mm) were tested for MIT and POS in a validated osteoporotic surrogate for cancellous bone (density of 160 kg/m³ [10 lbs/ft³]). MIT was measured with a torque-measuring hex driver for screws inserted through a one-third tubular plate. POS was measured after insertion of screws to a depth of 20 mm based on the Standard Specification and Test Methods for Metallic Medical Bone Screws (ASTM F 543-07). Five screws were tested for each failure mode and screw design. The relationship between MIT and compressive force between the plate and bone surrogate was evaluated using pressure-sensitive film.

Results: There was a significant difference in mean MIT based on screw pitch ($P < 0.0001$), whereas POS did not show statistically significant differences among the different screw pitches ($P = 0.052$). Small screw pitches (1.0 mm and 1.2 mm) had lower MIT and were distinguished from large pitches (1.5 mm, 1.6 mm, and the 1.75 mm) with higher MIT. For POS, only the 1-mm and 1.6-mm pitch screws were found to be different from each other. Linear regression analysis of MIT revealed a moderate correlation to the screw pitch ($R^2 = 0.67$, $P < 0.0001$), whereas the analysis of POS suggested no correlation to the screw pitch ($R^2 = 0.28$, $P = 0.006$). Pearson correlation analysis indicated no correlation between MIT and POS ($P = 0.069, r = -0.37$). A linear relationship of increased compression between the plate and bone surrogate was found for increasing screw torque ($R^2 = 0.97$).

Conclusions: These results indicate that the ability of different screw designs to generate high screw insertion torque in a model of osteoporotic cancellous bone is unrelated to their pullout strength. Therefore, extrapolation of results for POS to identify optimal screw design for osteoporotic bone may not be valid. Screw designs that optimize MIT should be sought for fixation in osteoporotic bone.

Key Words: pull out strength, insertion torque, fixation strength

INTRODUCTION

It has been suggested that pullout strength is the biomechanical parameter that should be optimized for nonlocked screw design. However, there is little evidence that screw pullout strength is the biomechanical factor that is most critical to obtaining a stable nonlocked plate–screw construct. When using traditional nonlocked plate constructs, plate–screw fixation requires compression between the plate and bone. These constructs are dependant on friction between the plate and bone to maintain stability. The magnitude of friction is equal to the coefficient of friction between the two surfaces multiplied by the normal force between the two surfaces. The normal force is proportional to the screw’s insertion torque. The amount of screw insertion torque required for construct stability has been estimated to be at least 3 Nm. In some situations such as poor metaphyseal bone or osteoporotic bone, screw stripping can occur before generation of such a sufficient torque, leaving the construct unstable. Therefore, the ability of a screw to generate a sufficiently high insertion torque will influence its ability to obtain a stable construct. The validity of extrapolating existing data for screw pullout strength to situations that require optimal insertion torque is unknown. This study was designed to evaluate the correlation between screw insertion torque and screw pullout strength in a surrogate osteoporotic cancellous bone model.

MATERIALS AND METHODS

Experimental Design Overview

Screws were inserted into an osteoporotic cancellous bone surrogate for the purpose of evaluating maximal screw insertion torque.
insertion torque (MIT) and screw pullout strength (POS). A standard technique used drilled pilot holes of 2.7 mm to match the screw minor diameter followed by hand insertion of screws. To be consistent with the standard clinical technique for insertion of screws into cancellous bone, the holes were not tapped. The only variable for each evaluation was the screw thread pitch. For each pitch, five screws were tested for MIT and five for POS.

Surrogate Bone Model
Foam blocks (Item 1522-01; Pacific Research Laboratories, Vashon, WA) with a density of 160 kg/m$^3$ (10 lbs/ft$^3$) were used for all testing. These were to simulate osteoporotic cancellous bone and therefore did not include a cortical shell. Foam rather than cadaver bone was used to provide uniformity between the multiple testing groups.

Screws
Custom-made 316-L stainless steel screws were used for all tests. All screws had an identical major diameter of 5.0 mm and an identical minor diameter of 2.7 mm. Thread pitch was the variable evaluated. Screws with pitches of 1 mm, 1.2 mm, 1.5 mm, 1.6 mm, and 1.75 mm were tested.

Maximal Insertion Torque Testing
Screws were inserted through a one-third tubular plate (PERI-LOC; Smith & Nephew, Memphis, TN) into the surrogate bone. The plate was used to function as a washer so that the limiting factor in developing maximum insertion torque was related to screw thread stripping rather than the ability of the head to resist sinking into the surrogate bone (Fig. 1). A digital torque meter (Snap-On VERSATORQ with a 0–50 in-lbf torque cell VERSA1S50 [Kenosha, WI] with accuracy of ±1% of reading from 10% to full scale of torque cell) was used to measure the maximum insertion torque generated.

Pullout Strength Testing
Screws were inserted to a depth of 20 mm into the surrogate bone. Pullout strength was measured using a materials testing machine (MTS 93 Biaxial Bionix [BIONIX-93-V121681-310.57] with TestStar Ilm control system and 0–1000 lbf MTS load cell with +/− 1% of reading through full scale [Eden Prairie, MN]). Screw pullout rate was 5 mm/min (0.2 in/min). Screws were placed a minimum of five diameters from the nearest edge. All testing parameters were according to the Standard Specification and Test Methods for Metallic Medical Bone Screws ASTM F 543-07 (Fig. 2).

Compression Force Testing
Based on results of the insertion torque testing, the 1.75-mm pitched thread screws were chosen for evaluation of the relationship between insertion torque and plate–bone compression force. These screws were inserted through a straight plate into a predrilled 2.7-mm pilot hole. Plate–bone compression testing included 12 screws inserted into the same low-density (160 kg/m$^3$ [10 lbs/ft$^3$]) foam blocks used for MIT and POS testing. Rotational loading was applied manually using the torque-measuring hex driver described previously. The amount of compression (kPa) gained between plate and bone (or bone surrogate) at various insertion torques between 800 N-mm and 2000 N-mm was measured using Tekscan pressure-sensitive film (Boston, MA).

Statistical Analysis
Significance was defined as $P < 0.05$. A one-way analysis of variance was used to evaluate differences among MIT and POS means based on screw pitch. The Tukey’s studentized range (honestly significant difference) test was used to determine differences among means for both MIT and POS. Linear regression analysis was used to compare MIT with pitch and POS with pitch. Pearson analysis was conducted to evaluate the correlation between MIT and POS. Post hoc power analysis was performed using the tables presented by Cohen.5

FIGURE 1. Photograph depicting screw inserted through plate into surrogate cancellous bone for insertion torque testing.

FIGURE 2. Photograph depicting screw inserted into surrogate cancellous bone for pullout testing.
RESULTS

Maximal Insertion Torque

The average maximal insertion torque generated was 1299 N-mm for the 1.0-mm screw pitch, 1277 N-mm for the 1.2-mm screw pitch, 3130 N-mm for the 1.5-mm pitch, 2712 N-mm for the 1.6-mm pitch, and 3039 N-mm for the 1.75-mm screw pitch (Table 1).

Pullout Strength

The average pullout strength generated was 398 N for the 1.0-mm screw pitch, 386 N for the 1.2-mm screw pitch, 386 N for the 1.5-mm pitch, 373 N for the 1.6-mm pitch, and 377 N for the 1.75-mm screw pitch (Table 1). Screws did not exhibit rotation on pullout from the foam media, because they were rotationally constrained by the wedge grips and load platen. The mode of failure on screw pullout from the test media was primarily conical “buttoning” observed in the foam closest to the screw head in the direction of applied force, but this “buttoning” often took a spiral form during testing until shear forces became great enough such that material was removed, even then no amount of “coring” was observed, because the material removed was restricted to the first 1 to 3 mm of depth into the foam media.

Statistical Analysis of Maximum Insertion Torque and Pullout Strength

Analysis of variance analysis of MIT found statistically significant differences among the means based on screw pitch ($P < 0.0001$). Analysis of variance of POS did not show statistically significant differences among the different screw pitches ($P = 0.052$). Tukey’s studentized range (honestly significant difference) test distinguished the MIT into two groups: small screw pitches (1.0 mm and 1.2 mm) and large screw pitches (1.5 mm, 1.6 mm, and 1.75 mm) in that the MIT for the 1.0-mm and 1.2-mm screw pitches were significantly different (at 95% confidence limit) from the MITs for the 1.5-mm, 1.6-mm, and the 1.75-mm screw pitches. For POS, Tukey’s studentized range (honestly significant difference) test showed a significant difference (at 95% confidence limit) only in the comparison between the 1-mm and the 1.6-mm screw pitches. Linear regression analysis of MIT revealed a moderate correlation to the screw pitch ($R^2 = 0.67$, $P < 0.0001$), whereas the analysis of POS suggested no correlation to the screw pitch ($R^2 = 0.28$, $P = 0.066$) (Fig. 3). Pearson correlation analysis indicated no correlation between MIT and POS ($P = 0.069$, $r = -0.37$). Post hoc analysis of POS, using two-tailed calculations, showed a power of 66% under a common standard deviation of 13 N at 95% confidence limit. The assumed common standard deviation is consistent with a study by Chapman.

Compression Force

Greater plate–foam and plate–bone compressive force was found at each increasing torque level in both surrogate and osteoporotic bone (Fig. 4). There was a linear relationship between torque generation and compressive force ($R^2 = 0.97$).

DISCUSSION

One of the goals of open reduction internal fixation of long bone fractures with plates and screws is to maintain construct stability throughout the healing process. The plate–screw–bone interface is critically important to maintaining this stability. Recent advances in locked screw technology have brought about renewed interest and scrutiny of plate–screw–bone biomechanics. It is clear that traditional nonlocked plate screw constructs rely on friction between plate and bone for construct stability. The frictional force is proportional to the normal force between plate and bone. The normal force, in turn, is generated by screw tightening. Data from the current study indicate that once a screw head engages the plate, further increases in insertion torque of a given screw resulted in increasing compression between plate and the surrogate used to simulate osteoporotic cancellous bone. This validates the clinical practice of using the tightness of a screw as a surrogate for evaluating normal force.

Failure of nonlocked plate–screw constructs is often evidenced by loss of integrity of the bone–screw interface by what is typically described as pullout of the screws. It has therefore been suggested that POS is the biomechanical

| TABLE 1. Maximum Insertion Torque (MIT) and Pullout Strength (POS) for Different Screw Pitches |
|---------------------------------------------|-----------------|-----------------|
| Pitch (mm) | MIT in N-mm (SD) | POS in N (SD) |
| 1           | 1299 (260)       | 398 (23)      |
| 1.2         | 1277 (129)       | 386 (9)       |
| 1.5         | 3130 (610)       | 386 (8)       |
| 1.6         | 2712 (362)       | 373 (4)       |
| 1.75        | 3039 (633)       | 377 (13)      |

SD, standard deviation.
It has been demonstrated that the POS of a screw is related to its major diameter, the length and engagement of the thread, the shear strength of the material into which the screw is embedded, and the thread shape factor. Given the importance of force generation between the plate and bone, it is logical that insertion torque rather than POS is the parameter that should be optimized. The concept that stripping torque is critical to construct stability is supported by biomechanical results from a model using a 135° four-hole dynamic hip screw construct. In this study, 0.9 to 1.8 Nm of torque insertion was required for the plate–screw construct to successfully withstand single-leg stance loads indicating that stripping torque is a predictor of successful internal fracture fixation. Our data from testing in an osteoporotic cancellous bone surrogate indicate varying screw pitch while keeping all other screw design parameters constant significantly influences the ability of a screw to generate insertion torque. Greater screw pitch was found to be associated with higher torque generation.

There is a paucity of data to indicate whether pullout strength is a valid predictor of a screw’s ability to generate high insertion torque. In fact, recent evidence suggests the contrary. In studies comparing conical screws and cylindrical screws used for pedicle fixation, an observed increase in torque did not correlate with a commensurate increase in pullout strength. Our data indicate that screw POS was unrelated to that screw’s ability to generate high insertion torque when tested in an osteoporotic cancellous bone surrogate. Furthermore, POS was not influenced by the screw pitch in this model.

Several details of the study design and potential limitations of extrapolating these biomechanical data to the clinical scenario deserve discussion. Although the generation of sufficient insertion torque is critical to nonlocked plate screw construct stability, excessive force may be detrimental. The detriments have been pointed out for relatively dense healthy cortical bone where increased frictional force seen with high insertion torque leads to cortical damage than has been postulated to contribute to screw failure. This relates to the choice of an osteoporotic cancellous model for the current study. Investigation of maximizing force generation in a healthy cortical bone model would be of limited clinical use. In such circumstances, generation of sufficient insertion torque is not an issue and efforts to maximize insertion torque are potentially harmful. A clinical situation in which generation of sufficient insertion torque may be difficult is in osteoporotic metaphyseal bone in which screw stripping might occur before sufficient force generation is accomplished. Hence, a model without a cortical shell was chosen. A surrogate was used rather than cadaver bone to provide uniformity between test specimens that could not be achieved with human cadaver bone given the large number of comparative groups. The obvious limitation of a surrogate bone model is the potential loss of validity when extrapolating results to human bone. A further limitation in this study was that pullout force was used as the main criterion for assessment. However, pullout force does not take into account screw motion or the amount of screw engagement at the screw–foam interface. Screw displacement, energy, and shear stress on screw extraction should be considered in future studies.

There are many factors that might influence insertion torque other than screw pitch, including bone density, depth of screw insertion, major and minor screw diameter, and pilot screw size among others. Typically, pilot holes match the screw minor diameter. Battula et al, when studying screws with a pitch of 1.25 mm and major diameter of 3.5 mm, increasing the pilot hole from the minor screw diameter of 2.5 mm (71.5% of the major diameter) to 2.8 mm (80% of the major diameter) resulted in a 40% reduction in insertion torque and approximately a 20% reduction in POS. The magnitude of the insertion torques in this study (350–580 N-mm) was somewhat less than those seen with the current study (1200–3100 N-mm) possibly as a result of the difference in major diameters and pilot screw hole size relative to the major diameter. We chose to use a consistent pilot hole size (2.7 mm) that was equal to the screw minor diameter to mimic standard clinical practice and manufacturers’ recommendations.

The method used to determine POS was a static load to failure test. It was chosen because it is an ASTM standard that is used by the Food and Drug Administration to compare the strength of screws as part of the approval process, although the standard has limitations in properly replicating the clinical scenario. Although the current study was primarily to evaluate the correlation of insertion torque and POS rather than to evaluate the magnitudes of these forces, this standard test also allows comparison of our data to POS presented in the existing literature. The range of pullout forces seen in our study (373–398 N) was slightly greater than those seen in another study (177–230 N) using 3.5-mm screws in an osteoporotic bicortical surrogate and lower than those seen in another (1000–1600 N) using a similar bicortical osteoporotic surrogate. A notable limitation of this test is the prohibition of screw rotation. This likely affected the observed mode of failure in the current study, which was found to be primarily conical buttoning. In contrast, rotational backout of a screw may be seen clinically if the bone substrate has adequate holding power to resist the shear forces sometimes seen in poor-quality bone and if the physiological loading patterns are such that torsional forces about the screw
are induced. A more clinically relevant testing mode might incorporate cyclic loading that allows screw rotation, but this is beyond the scope of the present study, which was to evaluate insertion torque relative to pullout.

The results of the current study clearly indicate that the ability of different screw designs to generate high screw insertion torque in an osteoporotic cancellous bone model is unrelated to that screw’s POS. Therefore, extrapolation of results for POS to identify optimal screw design may not be valid. We recommend that a screw’s ability to generate insertion torque be considered independently of POS whenever stripping of the screw is a potential such as in osteoporotic cancellous bone.

REFERENCES