Cancellous Screws Are Biomechanically Superior to Cortical Screws in Metaphyseal Bone

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Abstract

Cancellous screws are designed to optimize fixation in metaphyseal bone environments; however, certain clinical situations may require the substitution of cortical screws for use in cancellous bone, such as anatomic constraints, fragment size, or available instrumentation. This study compares the biomechanical properties of commercially available cortical and cancellous screw designs in a synthetic model representing various bone densities. Commercially available, fully threaded, 4.0-mm outer-diameter cortical and cancellous screws were tested in terms of pullout strength and maximum insertion torque in standard-density and osteoporotic cancellous bone models. Pullout strength and maximum insertion torque were both found to be greater for cancellous screws than cortical screws in all synthetic densities tested. The magnitude of difference in pullout strength between cortical and cancellous screws increased with decreasing synthetic bone density. Screw displacement prior to failure and total energy absorbed during pullout strength testing were also significantly greater for cancellous screws in osteoporotic models. Stiffness was greater for cancellous screws in standard and osteoporotic models. Cancellous screws have biomechanical advantages over cortical screws when used in metaphyseal bone, implying the ability to both achieve greater compression and resist displacement at the screw-plate interface. Surgeons should preferentially use cancellous over cortical screws in metaphyseal environments where cortical bone is insufficient for fixation. [Orthopedics. 2016; 39(5):e828-e832.]

Cancellous screws are designed to optimize fixation in metaphyseal bone environments where cortical bone density may be poor. Cancellous screw design features a narrow core diameter and a large pitch, resulting in wide, deep screw threads but decreased thread density over a given length. This allows for greater holding capacity in cancellous bone environments. In contrast to cancellous screws, cortical screw design features a relatively larger core diameter with a smaller pitch, resulting in shallower but more densely spaced screw threads. Cancellous screws are frequently used in the stabilization of fractures that occur in metaphyseal bone, where the cortices are thin and cancellous bone provides the majority of fixation. Commonly affected locations include the femoral neck, distal femur, proximal and distal tibia, and distal fibula. In some locations, bicortical fixation may not be desired in metaphyseal bone due to anatomic constraints, such as to prevent screw penetration of articular cartilage or...
Variables such as pullout strength were measured for four-mm outer-diameter cortical (left) and cancellous screws (right). This model was chosen to simulate scenarios of metaphyseal bone in which unicortical cortical screws may not be appropriate for screw purchase. The authors hypothesized that cancellous screws would offer greater pullout strength and maximum insertion torque than cortical screws rather than cancellous screws remain unknown.

Pullout strength and maximum insertional torque are 2 metrics used to evaluate screw performance. Screw pullout strength is a measure of resistance to axial removal of the screw and is affected by thread depth (difference between outer and inner diameters of the screw), thread volume, screw pitch, and the material properties of the testing material. More recently, maximum insertional torque has been advocated as a means to quantify screw fixation quality; this value is proportional to the amount of compression generated underneath the screw head. In patients with osteoporotic bone, screw stripping may occur prior to the generation of sufficient torque to stabilize the construct.

The purpose of the current study is to compare the biomechanical performance of commercially available cortical and cancellous screws in terms of pullout strength and maximum insertional torque in cancellous bone surrogates of various densities. This model is designed to simulate scenarios of metaphyseal bone in which the cortical bone is thin and bicortical screw placement may not be desired. In these situations, the integrity of fixation is dependent on the cancellous bone architecture because the far cortex may not be appropriate for screw purchase. The authors hypothesized that cancellous screws would offer greater pullout strength and maximum insertion torque when used in unicortical fashion in these cancellous bone models, with varying magnitudes of difference based on bone density.

**MATERIALS AND METHODS**

This study was performed as a basic science investigation. Commercially available, fully threaded, 4.0-mm outer-diameter cortical and cancellous stainless steel screws of 50-mm length were used for all testing (Synthes, Paoli, Pennsylvania). The synthetic models consisted of synthetic models representing cancellous bone of varying densities (Sawbones; Pacific Research Laboratories, Vashon, Washington), as recommended by American Society for Testing and Materials (ASTM) standard F1839-08 for testing of orthopedic implants. The synthetic models are composed of solid, rigid polyurethane foam with closed cell content of 96% to 99.9%, with densities selected to represent a spectrum of cancellous bone densities, from normal bone density to osteoporotic (20, 10, and 5 lb/ft³). This model was chosen to represent osteoporotic metaphyseal bone in which the thickness of the cortices is negligible for fixation.

**Pullout Strength Testing**

Each synthetic bone specimen was tested using 8 screws per screw type. A custom drill guide was created to ensure that screw insertion was perpendicular to the surface of the testing material. Insertion sites were predrilled using the manufacturer’s recommended technique and recommended drill diameter (2.9-mm drill for cortical screws and 2.5-mm drill for cancellous screws according to screw design) prior to screw insertion. Screws were then manually inserted to a depth of 20 mm into the testing material, such that the remaining 30 mm of screw length and screw head was protruding from the testing material.

Screw pullout tests were performed following the methods proposed in ASTM F543-13, Standard Specification and Test Methods for Metallic Medical Bone Screws. Pullout strength was measured using a Model 5944 materials testing machine equipped with a 2 KN load cell (Instron Corporation, Norwood, Massachusetts). The position measurement accuracy of the test machine is ±0.02 mm. The test block was secured to the base of the testing machine in a custom fixture with a grip span of 25 mm as dictated by the ASTM standard. A grip attached to a universal joint was used to affix the screw heads to the testing machine and prevent any rotation of the screws during testing. Screws were pulled at a rate of 5 mm/minute until failure. Axial pullout strength (defined as the peak load observed during testing), stiffness (N/mm, slope of the linear portion of the loading curve), failure displacement (displacement at maximum load), and failure energy (energy absorbed until maximum
load) were determined from the resulting load vs displacement curve. Displacement data were corrected for load string compliance.

Maximum Insertion Torque Testing

Maximum insertional torque tests were also performed on each synthetic test block using 8 screws per screw type. Screw holes were predrilled using an identical technique as described in pullout strength testing. Screws were passed through a clearance hole in a 17.5-mm-thick base block with a stainless steel top plate until manual resistance to insertion was felt. The top plate ensured that the measurements for maximum insertional torque were attributable to the screw thread stripping and not screw head penetration into the synthetic bone (Figure 2B). Screw heads were inserted against the top plate and tightened by a hexagonal key attached to the actuator of the testing machine under a constant axial compressive load of 5 N at a rate of 10 degrees/second until failure. Maximum insertional torque (N/mm) was determined from the resulting torque vs angular displacement curve. All testing was conducted on an ElectroPuls E10000 using a 1 KN, 25 Nm biaxial load cell (Instron Corporation).

Statistical Analysis

For each bone surrogate group tested, unpaired 2-tailed t-tests were performed to compare cancellous and cortical screws in pullout strength, stiffness, failure displacement, failure energy, and maximum insertional torque. Significance was defined as a P value less than .05. Levene’s tests for equality of variances and Shapiro-Wilk normality tests were conducted on all test groups. A power study performed prior to testing using previously published data indicated a minimum of 8 samples were needed to achieve power of at least 0.80.

RESULTS

Screw failure during pullout testing resulted in vertical coring of the testing material at the screw thread–material interface due to shear failure of the test block. No screws were damaged during testing. Screw pullout strength was significantly higher for cancellous screws than for cortical screws in all test material densities, including the 5 lb/ft³ (cancellous: 88±4 N; cortical: 70±4 N; P<.001), 10 lb/ft³ (cancellous: 240±8 N; cortical: 214±7 N; P<.001), and 20 lb/ft³ (cancellous: 792±21 N; cortical: 751±25 N; P=.003) test blocks (Figure 3A). As the density of the testing material decreased, the relative difference in pullout strength between the 2 screw designs was found to increase. In normal density substrate, although cancellous screws still have greater pullout strength than cortical screws, the effect size appears to be.

Figure 2: Experimental setups used for screw pullout (A) and insertion torque (B) tests.

Figure 3: Pullout strength (A), stiffness (B), failure displacement (C), and failure energy (D) of cortical and cancellous screws for various test block densities. Errors bars denote 1 standard deviation. Asterisks (*) indicate statistically significant differences between cancellous and cortical screws.
less than substrate representing osteoporotic bone.

Although no difference was observed in stiffness between cancellous and cortical screws in the 5 lb/ft³ test blocks (cancellous: 310±40 N/mm; cortical: 280±30 N/mm; P=0.999), stiffness was significantly greater in cancellous screws in the 10 lb/ft³ (cancellous: 810±90 N/mm; cortical: 720±60 N/mm; P=0.018) and 20 lb/ft³ (cancellous: 2220±230 N/mm; cortical: 1950±180 N/mm; P=0.023) test blocks (Figure 3B).

Screw displacement prior to failure during screw pullout testing was significantly greater in cancellous screws in the 5 lb/ft³ (cancellous: 0.72±0.06 mm; cortical: 0.43±0.06 mm; P<0.001) and 10 lb/ft³ (cancellous: 0.60±0.04 mm; cortical: 0.41±0.02 mm; P<0.001) density test blocks (Figure 3C). No difference in displacement was detected between cortical and cancellous screws in the 20 lb/ft³ density block (cancellous: 0.67±0.13 mm; cortical: 0.62±0.10 mm; P=0.423).

Total energy absorbed prior to failure during pullout testing was significantly greater for cancellous screws when compared with cortical screws for the 5 lb/ft³ (cancellous: 50±4 mJ; cortical: 22±4 mJ; P<0.001) and 10 lb/ft³ (cancellous: 102±8 mJ; cortical: 55±2 mJ; P<0.001) test blocks (Figure 3D). No difference in failure energy was detected in the 20 lb/ft³ density test block (cancellous: 310±50 mJ; cortical: 280±80 mJ; P=0.315).

Maximum insertional torque was significantly higher for cancellous screws than for cortical screws in all test material densities, including the 5 lb/ft³ (cancellous: 220±30 Nm; cortical: 170±10 Nm; P=.006), 10 lb/ft³ (cancellous: 590±50 Nm; cortical: 460±40 Nm; P<0.001), and 20 lb/ft³ (cancellous: 2350±180 Nm; cortical: 1640±190 Nm; P<0.001) test blocks (Figure 4).

### Discussion

The goals of open reduction and internal fixation include anatomic reduction and interfragmentary compression of articular fractures and the generation of sufficient friction to create stability between plate and bone during nonlocked plating. Both of these goals are achieved by screw tightening; therefore, sufficient screw purchase is a critical mechanical factor. Differing cortical and cancellous screws are designed to optimize fixation in varying anatomic locations across the body. In metaphyseal bone where the cortices are thin, certain clinical scenarios may result in the exchange of unicortical cortical screws for cancellous screws; however, the biomechanical consequences of such a substitution were previously not defined.

Figure 4: Maximum insertion torque of cortical and cancellous screws for various test block densities. Errors bars denote 1 standard deviation. Asterisks (*) indicate statistically significant differences between cancellous and cortical screws.

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The current study found that cancellous screws had significantly greater maximum insertional torque and pullout strength than cortical screws across all synthetic cancellous bone densities tested, confirming the authors’ original hypothesis. These factors imply that cancellous screws, when used in metaphyseal bone with insufficient cortices, provide both greater initial compression achieved beneath the screw head transferred to the fracture site and greater resistance to loosening of the screw once stability has been achieved. During pullout testing, significant differences were also found in screw displacement prior to failure and total energy absorbed in osteoporotic specimens (5 and 10 lb/ft³ models). In addition, the slope of the pullout loading curves were greater for cancellous screws in the 10 and 20 lb/ft³ density specimens and trended toward significance in the 5 lb/ft³ density specimens. Although the clinical implications of pullout stiffness, displacement, and failure energy remain unclear, it is advantageous to have a construct that retains compression and is able to withstand higher-energy events. Further tests are needed to quantify the loss of compression during screw pullout.

A synthetic bone model was used to provide a consistent testing substrate to isolate differences due to screw design only. Prior biomechanical studies have validated the polyurethane foam substrate as a surrogate for human cancellous bone testing. Patel et al reported that low-density polyurethane foam provided similar values for Young’s modulus and yield strength as cancellous bone. Other studies have confirmed these findings and demonstrated similar compressive strengths between polyurethane foam and cancellous bone. Furthermore, ASTM supports the use of rigid polyurethane foam as an ideal testing analogue for human cancellous bone, and similar published studies evaluating screw design biomechanics use polyurethane foam as their testing material.

Ricci et al evaluated stainless steel screws with varying thread pitches in terms of their maximum insertion torque and pullout strength, using a polyurethane foam model to represent osteoporotic cancellous bone. They found that increased thread pitch allowed increased maximal insertional torque and demonstrated a linear relationship between maximal insertional torque and compressive force under the screw head. In addition, the authors found no correlation between a screw’s pullout strength and insertion torque, arguing that these parameters should be evaluated independently when assessing optimal screw performance. Tankard et al also suggested that no clear relationship exists between pullout strength and screw torque.

Maximum screw pullout strength appears to occur at 50% to 70% of maxi-
imum insertion torque, likely given the effects of screw stripping with further tightening. To achieve the necessary compression underneath the screw head, it is estimated that fracture stabilization requires at least 3 Nm of torque. In patients with osteoporotic bone, screw stripping may occur prior to the generation of sufficient torque to stabilize the construct. The screw designs used in the current study demonstrate different pitch and different core diameters; thus, the findings of improved pullout strength and maximum insertional torque for cancellous screws in this model are likely aggregate effects of both design differences.

There are limitations to this study. Because the primary goal of this study was to compare cortical and cancellous screw design while holding all other variables constant, synthetic bone analogues rather than cadaveric specimens were used. This improved the authors’ ability to isolate biomechanical differences attributable to screw design, but their results may be different from those obtained either in cadaveric bone or in vivo. Further research is indicated to assess the clinical efficacy of cortical screws vs cancellous screws used in unicortical fashion in elderly or osteoporotic metaphyseal bone. Although cortical and cancellous screws had statistically different performances, the absolute differences were variable, and the clinical significance has yet to be determined.

**CONCLUSION**

This study demonstrates that cancellous screws have biomechanical advantages over cortical screws when used in unicortical fashion in cancellous bone, demonstrating greater pullout strength and maximal insertional torque across a range of bone densities. These findings should guide surgeons performing fracture fixation in osteoporotic metaphyseal bone to use cancellous screws whenever feasible. These findings may be applicable in clinical situations where fracture fragment size, anatomic constraints, or available instrumentation precludes bicortical fixation in metaphyseal bone. Relevant scenarios may include avoidance of the articular cartilage during fixation of the distal tibia or fibula, soft tissue irritation from far cortical penetration in the distal femur or tibia, or the treatment of olecranon or metaphyseal humerus fractures. Factors such as screw diameter, screw length, and reduction quality remain important variables in optimizing fracture stability, and further research is indicated to assess the clinical implications of this study’s biomechanical findings.

**REFERENCES**