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Technical Note

The biomechanical effect of artificial and human bone density on stopping and stripping torque during screw insertion

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ABSTRACT

Orthopedic surgeons apply torque to metal screws manually by "subjective feel" to obtain adequate fracture fixation, i.e. stopping torque, and attempt to avoid accidental over-tightening that leads to screw–bone interface failure, i.e. stripping torque. Few studies have quantified stripping torque in human bone, and only one older study from 1980 reported stopping/ stripping torque ratio. The present aim was to measure stopping and stripping torque of cortical and cancellous screws in artificial and human bone over a wide range of densities. Sawbone blocks were obtained having densities from 0.08 to 0.80 g/cm^3. Sixteen fresh-frozen human femurs of known standardized bone mineral density (sBMD) were also used. Using a torque screwdriver, 3.5-mm diameter cortical screws and 6.5-mm diameter cancellous screws were inserted for adequate tightening as determined subjectively by an orthopedic surgeon, i.e. stopping torque, and then further tightened until failure of the screw–bone interface, i.e. stripping torque. There were weak ($R=0.25$) to strong ($R=0.99$) linear correlations of absolute and normalized torque vs. density or sBMD. Maximum stopping torques normalized by screw thread area engaged by the host material were 15.2 N/mm (cortical screws) and 13.4 N/mm (cancellous screws) in sawbone blocks and 20.9 N/mm (cortical screws) and 6.1 N/mm (cancellous screws) in human femurs. Maximum stripping torques normalized by screw thread area engaged by the host material were 23.4 N/mm (cortical screws) and 16.8 N/mm (cancellous screws) in sawbone blocks and 29.3 N/mm (cortical screws) and 8.3 N/mm (cancellous screws) in human femurs. Combined average stopping/ stripping torque ratios were 80.8% (cortical screws) and 76.8% (cancellous screws) in sawbone blocks, as well as 66.6% (cortical screws) and 84.5% (cancellous screws) in human femurs. Surgeons should be aware of stripping torque limits for human femurs and monitor stopping torque during surgery. This is the first study of the effect of sawbone density or human bone sBMD on stopping and stripping torque.

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1. Introduction

Orthopedic surgeons and researchers are interested in the mechanical stability afforded by various repair methods and implants employed to repair long bone fractures (Alho, 1997; Althausen et al., 2003; Bucholz and Heckman, 2001; Dennis et al., 2000; Emerson et al., 1992; Fulkerson et al., 2004; Kelley 1994; Ogden and Rendall, 1978; Tencer and Johnson, 1994). Extramedullary and intramedullary implants used for such fixation are commonly applied onto the bone with cortical or cancellous bone screws. These screws, however, can potentially fail by a variety of means, such as screw "toggling", screw pullout, screw fracture by torsion or bending, and screw stress risers that cause failure of the host bone (Ansell and Scales, 1968; Fulkerson et al., 2006; Law et al., 1993; Merk et al., 2001).

Cortical and cancellous screw purchase in artificial and human femurs is a critical element in the mechanical stability of fracture fixation implants during in-vitro biomechanical studies (Ahmadi et al., 2013; Cheal et al., 1992; Cheung et al., 2004; Cusick et al., 2000; Ebrahimi et al., 2012; Emerson et al., 1992; Heiner and Brown, 2001, 2003; Sawbones; Zdero et al., 2008b, 2010). Some of the present authors are the only ones to have measured screw purchase for artificial and human femurs (Zdero et al., 2008a, 2009). Clinically, cortical and cancellous screws are inserted and tightened up until the point of providing adequate compression of the fracture site and/or fixation device against the host bone, i.e. "stopping" torque. Orthopedic surgeons do this manually by "subjective feel" without quantifying the actual torque applied, which can be about 86% of the maximum allowable torque needed for screw–bone interface failure, i.e. "stripping" torque (Cleek et al., 2007; Cordey et al., 1980a). This produces stresses along the length of the screw and leaves only a small margin for error. Only one older investigation from 1980 reports on the stopping torque achieved subjectively by expert surgeons during clinical fracture repair (Cordey et al., 1980a). Additionally, only one previous study assessed stripping torque in 3 densities of polyurethane foam block but only correlated it to screw pullout strength rather than density (Edwards et al., 2005). Substantial research, though, has been done on stripping torque in artificial, human, and animal bone (Bahr, 1992; Boyle et al., 1993a, 1993b, 1993c; Cleek et al., 2007; Cordey et al., 1980b; Daubs et al., 2007; Edwards et al., 2005; Hsu et al., 2005; Lawson and Brems, 2001; Lin et al., 2001; Lin and Hou, 2002; Nicayenzi et al., 2012; Ricci et al., 2010; Roe et al., 1988; Thomas et al., 2008). However, no researchers have comprehensively assessed the effect of a wide range of bone densities on stopping torque, stripping torque, and the stopping/stripping torque ratio.

The present aim was to biomechanically measure the stopping and stripping torque of cortical and cancellous screws in sawbone blocks and human femurs. It was hypothesized that there would be a linear correlation of stopping and stripping torque parameters vs. bone density and that stopping/stripping torque ratio would be relatively constant regardless of bone density.

2. Methods

2.1. General study design

Sawbone blocks and human femurs were obtained having a range of material densities. Specimens had cortical and cancellous screws inserted manually by the same orthopedic surgery resident until adequate screw tightness was subjectively identified as representing adequate fracture fixation in clinical practice, i.e. "stopping" torque, and the torque level was recorded. Then, screws were further tightened until the screw–bone interface failed, i.e. "stripping" torque, and the torque level was recorded. Stopping and stripping torque, respectively, simulated adequate fracture fixation and accidental over-tightening of screws that can happen during surgery. The two main research questions were: Does bone density affect stopping and stripping torque? What is the relationship between stopping vs. stripping torque? In addition to human femurs, sawbone material was used because of its prevalence in biomechanics studies, necessitating a comparison against human bone.

2.2. Sawbone blocks and human femurs

Sawbone blocks made of polyurethane foam (Model 1522-12, Sawbones, Vashon, W.A. (USA)) with dimensions of 180 mm × 130 mm × 40 mm were obtained having 8 different densities: 0.08, 0.16, 0.24, 0.32, 0.40, 0.48, 0.64, and 0.80 g/cm^3. This covers most of the range of human cancellous bone density of 0.1 to 1.0 g/cm^3 (Tencer and Johnson, 1994). Fresh-frozen human femurs were obtained by permission of the authors' institutional research ethics board (Table 1). Femurs had soft tissue removed and were visually inspected to ensure no bone pathology. Donor medical histories, if accessible, were consulted to verify absence of bone pathology. Femurs were thawed at ambient room temperature for 12 h before testing. Cortical screw specimens were obtained from the midshaft segments of left femurs, whilst cancellous screw specimens were obtained from the condyles of right femurs. Using the ProdigyTM system and enCORE software 8.80 (Lunar Corp., Madison, WI, USA), DEXA (dual energy x-ray absorptiometry) scans completed of the femoral neck, Ward's region, and trochanter. For the ProdigyTM system, donor weight and height define scan mode, though this did not make any difference presently, since body fat and muscle were absent; thus, the standard scan mode was used. Rice bags were employed as surrogates to eliminate measurement artifact. DEXA values from this system were converted to standardized bone mineral density (sBMD) and clinical T-scores to allow for inter-study comparison.

2.3. Cortical screw insertion tests

Sawbone blocks were cut into 10-mm thick sheets and human femoral shafts were cut into 40-mm long segments at midshaft, which were secured in a clamping system (Fig. 1A and B). A drill press was used to drill undersized pilot holes of 2.78-mm diameter completely through the sawbone blocks and through the anterior cortex of the