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Lecture

Achievable accuracy of hip screw holding power estimation by insertion torque measurement

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A R T I C L E I N F O

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A B S T R A C T

Background: To ensure stability of proximal femoral fractures, the hip screw must firmly engage into the femoral head. Some studies suggested that screw holding power into trabecular bone could be evaluated, intraoperatively, through measurement of screw insertion torque. However, those studies used synthetic bone, instead of trabecular bone, as host material or they did not evaluate accuracy of predictions. We determined prediction accuracy, also assessing the impact of screw design and host material.
Methods: We measured, under highly-repeatable experimental conditions, disregarding clinical procedure complexities, insertion torque and pullout strength of four screw designs, both in 120 synthetic and 80 trabecular bone specimens of variable density. For both host materials, we calculated the root-mean-square error and the mean-absolute-percentage error of predictions based on the best fitting model of torque-pullout data, in both single-screw and merged dataset.
Findings: Predictions based on screw-specific regression models were the most accurate. Host material impacts on prediction accuracy: the replacement of synthetic with trabecular bone decreased both root-mean-square errors, from 0.54 ÷ 0.76 kN to 0.21 ÷ 0.40 kN, and mean-absolute-percentage errors, from 14 ÷ 21% to 10 ÷ 12%. However, holding power predicted on low insertion torque remained inaccurate, with errors up to 40% for torques below 1 Nm.
Interpretation: In poor-quality trabecular bone, tissue inhomogeneities likely affect pullout strength and insertion torque to different extents, limiting the predictive power of the latter. This bias decreases when the screw engages good-quality bone. Under this condition, predictions become more accurate although this result must be confirmed by close in-vitro simulation of the clinical procedure.

1. Introduction

Surgical treatment is the most common approach to treat intracapsular and trochanteric fractures of the femur (Adam, 2014; Kaplan et al., 2008; Miyamoto et al., 2008). The type of surgery depends on fracture type, fracture pattern and patient conditions (Adam, 2014; Kaplan et al., 2008; Miyamoto et al., 2008; Schipper et al., 2004). Regardless of the implant used for the reduction of the fracture (intramedullary or extramedullary fixation), the options to fix the proximal part of the femur include the use of blades or screws (Schipper et al., 2004; Stern et al., 2011).

Cut-out is one of the most important clinical complications (Baumgaertner et al., 1995; Bojan et al., 2010). The risk of cut-out depends on fracture type (De Bruijn et al., 2012; Geller et al., 2010; Zirngibl et al., 2013) and bone mineral density (Bonnaire et al., 2005; Konstantinidis et al., 2013). However, when a hip screw is used, accurate alignment of the device in the femoral head and appropriate distance of the screw tip from the head apex also reduce the risk of screw cut-out (Andruszkow et al., 2012; De Bruijn et al., 2012; Geller et al., 2010).

Despite specific tools supplied by the manufacturer with the implantable device, accurate driving of self-tapping screws through the femoral head remains a challenge, especially in unstable fractures (Jin et al., 2014). Indeed, the surgeon must maintain the correct position of the proximal fragment during screw driving in order to achieve a good fracture reduction (Hsueh et al., 2010) to optimise stability (Gundle et al., 1995) and avoid the risk of anterior displacement (Mohan et al., 2000). Although anti-rotation wires or pins may be inserted across the fracture before screw driving (Adam, 2014; Saper and Tornetta, 2016), low insertion torque of screw is desirable (Chaturvedi et al., 2015; Georgiannos et al., 2015; O'Malley et al., 2012). It makes the insertion of a self-tapping screw easier, decreasing the need for pre-tapping the hole in good-quality trabecular bone as well as the risk of overcoming the anti-rotation capacity of additional devices or wires used as

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joystick, with consequent rotation of the femoral head fragment.

Since hips screws are headless, the surgeon aims at stopping the screw insertion into the femoral head when the tip-apex distance becomes smaller that 25 mm (Baumgaertner et al., 1995; Baumgaertner and Solberg, 1997; Geller et al., 2010; Pervez et al., 2004). However, if the fixation is not firm enough in the femoral head then the peri-screw trabecular bone may be damaged during rehabilitation; in addition, superior migration, anterior dislocation or cut-out of the screw may occur (Ehmke et al., 2005; Lee et al., 2013; Lenich et al., 2011; Mills and Horne, 1989; Önnerfält, 2010; Syed et al., 2014). Even if post-operative rehabilitation programs can be customised by tuning down the permissible degree of weight-bearing on the basis of the achieved fracture stability to reduce the above-mentioned risk (Lee et al., 2013), it is always desirable to maximise fracture stability, compatibly with bone quality and fracture pattern. This involves good holding power of the screw within the head.

Common sense suggests that high screw holding power is achieved when a high insertion torque is experienced. This notion has been supported by experimental studies showing that insertion torque and pullout strength are correlated (Ab-Lazid et al., 2014a; Hitchon et al., 2003; Inceoglu et al., 2004; Zdeblick et al., 1993). Therefore, the insertion torque is used intraoperatively as feedback to estimate the achieved holding power of the hip screw, and when judged unsatisfactory, to evaluate the need for further insertion into the femoral head – reducing the tip-apex distance, eventually increasing the screw length, with the aim of engaging good-quality bone tissue located closer to the articular surface (Chiba et al., 2013; Li and Aspden, 1997; Munemoto et al., 2016) – or for some kind of trabecular bone augmentation (Lee et al., 2010; Sermon, 2015; Szpalski et al., 2004). However, if the hip screws are designed to reduce the insertion torque while trying to maximise the holding power for said reasons, then small changes in the insertion torque may correspond to large changes in the screw holding power. Therefore, although theoretically possible, it may not be practically feasible to correctly estimate the screw holding power from the insertion torque experienced (Siddiqui et al., 2005; Stoesz et al., 2014). Additionally, since the hip screw designs are different, different relationships may exist between the insertion torque and the holding power values, even for similar screw designs. Finally, synthetic materials are commonly used in experimental studies. Synthetic materials are suitable for comparative evaluation among different screw designs (ASTM F543 standard). However, if the pullout strength-insertion torque correlation achieved when using synthetic material was similar to those achieved in trabecular bone, the constraints regarding collection, handling and heterogeneity of bone tissue would be eliminated.

Using an experimental model designed to maximise test repeatability but not intended to simulate the clinical procedure, this study investigated the relationship between insertion torque and pullout strength of commercially available hip screws to assess: i) the type of relationship between screw insertion torque and holding power; ii) whether the relationship achieved using polyurethane foam is comparable with that determined using trabecular bone tissue; iii) whether the same relationship between the two parameters can suitably be applied to different screw designs; iv) whether the relationship can be used to predict the screw holding power from its insertion torque.

2. Methods

2.1. Screw designs

Four commercial hip screws were selected for this study: two solid core and two cannulated screws (Fig. 1). The two screw groups were chosen because of their completely different designs. Conversely, intra-group differences were more related to specific features rather than screw dimension.

2.2. Type of host materials

Hip screws were tested both in polyurethane foams and in trabecular bone tissue samples to determine the relationship between insertion torque and pullout strength in the two host materials. It has been demonstrated that insertion torque and pullout strength depend on the material quality, both in synthetic foam and trabecular bone tissue (Ab-Lazid et al., 2014b). Therefore, three low-density (0.16, 0.24 and 0.32 g/cm^3) polyurethane foams (Sawbones Europe AB, Malmö, Sweden) were chosen to simulate trabecular bone of different quality (Calvert et al., 2010; O'Neill et al., 2012; Patel et al., 2008). Similarly, human and bovine trabecular bone tissue was used to achieve a wider variety of tissue quality (Han et al., 1996). Ten test repetitions were performed for each host material, i.e. a total of 50 tests for each screw design.

Trabecular tissue cubes with 30 mm sides were extracted from the distal condyles of human or bovine femora. A cube was extracted from each condyle, i.e. two cubes were extracted from each femur. In preparation of this, a vertical line was marked on the posterior aspect of each condyle to mark the midline in mediolateral direction. Each femur was placed at 30° of flexion and neutral rotation with respect to the horizontal plane (Fig. 2). The adduction angle was set by placing the cartilage of the two distal condyles in contact with the surface of a vertical rotary saw. The first cut was performed shifting the femur by 15 mm perpendicularly to the rotary saw plane. A horizontal line was marked on the cut surface. A second cut was performed at 30 mm, increased by the blade thickness, from the first cut to achieve a 30 mm-thick bone slice. The slice was placed with the proximal surface down and the line previously marked on the distal surface perpendicular to the rotary saw. For each condyle, two parallel cuts were performed one 15 mm medially and the other 15 mm laterally, both values increased by half the blade thickness, from the vertical condyle midline. Finally, two parallel cuts, perpendicular to previous ones, were performed replicating the previous step in anteroposterior direction. This procedure was implemented considering bone stock available and aiming at extracting a cube of pure trabecular tissue in a repeatable way. While it has always been possible to extract the desired cube from each bovine condyle, the extraction of human trabecular cubes of the desired dimension was difficult. The achieved cubes may have one or more rounded corners with a residual cortical shell.

All the cubes were scanned with a dual energy X-ray absorptiometry (DXA) machine (Discovery Wi, Hologic, Bedford, MA) in anteroposterior direction with the mediolateral direction aligned with the longitudinal axis of the scanner. All the scans were performed using the spinal array mode. Bone mineral density (BMD) was calculated for the central slice (20 mm high, 30 mm wide) of each cube. Therefore, BMD value was not affected by rounded corners – if any – and it was representative of the trabecular tissue where the screw thread was to be engaged. The cubes were divided into four groups according to the BMD values in order to obtain homogeneous groups. The screw designs were assigned randomly to the four groups (Table 1).

2.3. Screw insertion

Pilot holes were drilled in polyurethane foam or trabecular bone cubes before screw insertion. The pilot hole size was equal to the screw shaft diameter increased by 0.2 mm, to avoid any contact pressure between the screw shaft and the hole surface. Therefore, any effect of trabecular bone or polyurethane compression due to screw shaft insertion was deleted. This approach was chosen to ensure high test repeatability. A 25 mm deep pilot hole was drilled in the centre of the face on the distal cube side. A pillar drill was used to ensure that the hole axis was at 90° with the top surface. A vacuum cleaner was used during the drilling process to remove any particulate. The holes in polyurethane were further cleaned using air jet. The holes in trabecular bone were rinsed using saline solution and immediately tested to avoid

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