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Preliminary testing of a novel bilateral plating technique for treating periprosthetic fractures of the distal femur

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ABSTRACT

Background: Current stabilization methods for periprosthetic fractures of the distal femur are inadequate in achieving fracture fixation, with complication rates as high as 29%. A major contributor to poor outcomes is that these methods rely only on screw purchase in the bone to maintain fracture reduction. We designed, manufactured and evaluated a novel plating method that utilizes the femoral prosthesis to enhance stability for treatment of distal femoral periprosthetic fractures.

Methods: Medial and lateral plates were designed and manufactured based on geometry of a synthetic femur and femoral prosthesis. The two plates were linked via a compression screw and a small tab on each plate that inserted into pre-existing slots on the prosthesis. Mechanical tests (500 N compression or 250 N anterior directed cantilever bending), were performed on synthetic femurs with simple transverse fractures (3 mm gap) just superior to the distal femoral prosthesis that were stabilized using either the prototype plates or a single lateral plate. Translational movements of the fracture site during loading were measured using 3D motion tracking.

Findings: With the single lateral plate, the distal fragment experienced a resultant displacement of 0.40 mm under cantilever bending and 0.61 mm under compression (13% and 20% respectively of fracture gap width). With the bilateral plates, fracture gap motion was significantly reduced to 0.13 mm under bending and compression (4.3% of the fracture gap).

Interpretation: Our results indicate that a bilateral plating method is capable of improving stabilization of periprosthetic fractures compared to the traditional lateral plating technique.

1. Introduction

Periprosthetic fractures are fractures that occur around a previously-implanted prosthesis. In patients who have undergone a total knee replacement, periprosthetic fractures occur in the distal femur at a rate of 0.6–2.5% (Bong et al., 2002). In addition to trauma, other risk factors for distal femoral periprosthetic fractures include osteoporosis, wear of the polyethylene tibial insert, anterior femoral notching during total knee replacement, and revision surgeries (Bong et al., 2002; Nauth et al., 2011).

Total knee replacements are becoming an increasingly common procedure; some estimates have forecasted up to a 670% increase (to 3.48 million/year in the United States) between the years 2005 and 2030 (Kurtz et al., 2007). This increase is likely due to a number of factors; most notably elderly patients are living longer and remaining active in their later years (Platzer et al., 2010). These patients have higher performance expectations and demands on the joint that can lead to multiple revisions being performed over the remainder of their lifetime. As the number of procedures increases so too will the prevalence of periprosthetic fractures (Streubel et al., 2010).

With the projected increase in the number of these fractures, proper management of this injury must be achieved to ensure quality of life for patients. Current treatment methods include various types of plates, intramedullary rods, external fixation, condylar screws, and revision arthroplasty with a long-stem femoral prosthesis (Bong et al., 2002). Recent plating techniques have focused on enhancing rigid fixation of the bone fragments, as well as minimally invasive techniques such as LISS (less invasive stabilization system) (Yoo and Kim, 2015). Current nailing techniques use interlocking nails and screws to better resist axial and torsional loading (Yoo and Kim, 2015). Revision TKA is considered when the implant indicates instability, as well as in cases with high comminution or severe malalignment of the prosthesis. While these options are capable of treating some fractures, complication rates are increased for comminuted fractures or in patients with poor distal bone quality (McGraw and Kumar, 2010). Reported complications include nonunion (9%), fixation failure (4%), infection (3%), and revision surgery (13%) (Herrera, et al., 2008). Other issues with these treatment

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methods are that they are not always compatible with the existing prosthesis, and at times the high number of screws required to stabilize the fracture can be invasive and lead to poor healing and increased recovery time for patients (Sonderegger et al., 2010).

Previous biomechanical studies have sought to determine the optimal fixation method for distal femur fractures. The majority of these studies compare the fracture motion observed among two or three different treatment methods using synthetic or cadaveric femurs (Bong et al., 2002; Duffy et al., 2006; Higgins et al., 2007; Otto et al., 2009; Salas et al., 2011a). Devices such as condylar blade plates, distal femoral locking plates, dynamic condylar screws and intramedullary nails have been previously tested. Few of these studies have looked at how the inclusion of a femoral prosthesis would affect the performance of the device (Bong et al., 2002; Salas et al., 2011b), or if a better alternative exists that is capable of improving the fracture stabilization.

Optimal secondary fracture healing is thought to occur when total fracture motion is within 2–10% of the total fracture gap size (Egol et al., 2004). Therefore, by normalizing the observed translational motion by size of the fracture gap we can obtain a measure of clinical performance of the treatment method.

One option for enhancing the stability of the fracture is to take advantage of the rigidity of the femoral prosthesis. Small slots are located on the medial and lateral sides of several commercially available prostheses that could serve as attachment points for a plating system. Therefore, two plates (medial and lateral) were envisioned attaching to the prosthesis to further improve the stability of distal femoral fractures. The purpose of this study was to evaluate this novel bilateral plating technique to determine if it improves stabilization of a distal femoral periprosthetic fracture relative to a common existing technique.

2. Methods

Medial and lateral plates were designed with tabs that insert directly into pre-existing slots on the sides of the femoral component of a total knee replacement (Fig. 1). The plates were held in place by a transverse compression screw inserted through the distal bone and several additional locking screws inserted into each plate. The plates were specifically designed to match the contours of the medial and lateral femur as well as to minimize the disruption of the collateral ligament origin sites (Otake et al., 2007). The completed design was manufactured from 316 stainless steel using a 5-axis waterjet cutter and CNC machining.

Fourth generation synthetic femurs were used with composite epoxy resin "cortical bone" material and polyurethane foam to mimic cancellous bone in the metaphyseal regions (model #3403, Sawbones; Pacific Research Laboratories, Vashon, WA). The femurs were implanted with the femoral component of a Scorpio total knee replacement system by an experienced orthopedic surgeon (Scorpio 7L PS [71-4507L]; Stryker Orthopaedics, Mahwah, NJ). The proximal end of the implanted femur was cut off 40 mm distal to the lesser trochanter and potted in a section of aluminum tubing using dental cement (Denstone®; Heraeus Kulzer, South Bend, IN). The long axis of the femur was aligned with the cylindrical axis of the tubing, and potted such that 230 mm of the distal portion of the femur remained exposed. A 3 mm transverse osteotomy was created in the distal femur 5 mm proximal to the anterior aspect of the prosthesis. Orientation of the osteotomy was not strictly controlled but was intended to be approximately perpendicular to the long axis of the femur. A custom drill guide clamp was used to create the clearance hole for the transverse compression screw through the metaphyseal region of the distal femur.

Three of the prepared femurs were implanted with a commercially-available single lateral locking plate (AxSOS distal lateral femur locking plate [437510]; Stryker Orthopaedics, Mahwah, NJ) (Fig. 1a). The remaining three femurs were fixed with the manufactured bilateral plates (Fig. 1b). An experienced orthopedic surgeon performed each of the treatment procedures using standard tools and techniques.

Six 1.5 mm diameter reflective markers (B&L Engineering, Santa Ana, CA) were attached to the samples, with three on each of the femoral segments (Fig. 2a). The markers on the proximal segment were glued directly to the femoral surface using cyanoacrylate. These markers were used to define the axes for the local coordinate system of the proximal femur (Fig. 2b). The remaining three markers were glued to a removable piece of Velcro® in a triangular configuration and attached to the distal fragment. This allowed the same distal markers to be used for all the samples.

Loads were applied to the femurs using a materials testing machine (eXpert 5601; ADMET, Norwood, MA) with a 300 lb load cell (SML-300, Interface, Scottsdale, AZ). The loads were applied to the prosthesis via a tibial tray (7376-0007; Stryker Orthopaedics, Mahwah, NJ) and polyethylene insert (72-13-0708; Stryker Orthopaedics, Mahwah, NJ) that matched the femoral component to simulate a complete total knee replacement (TKR) system. Four infrared cameras (Raptor-4, 200 fps, 2532×1728 pixels full resolution; Motion Analysis, Santa Rosa, CA)

A

B

Fig. 1. Femur samples fixed with one of two options: (A) distal lateral femoral locking plate or (B) novel bilateral locking plates. The bilateral plates included a transverse compression screw through the femoral condyles and eight locking screws (four on the proximal lateral side, two on the distal lateral condyle, and two on the medial diaphysis). Tabs at the distal ends of the bilateral plates inserted into the existing slots on the sides of the femoral prosthesis.