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The effect of interlocking parallel screws in subcapital femoral-neck fracture fixation: a cadaver study

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ABSTRACT

Background: A new locking-plate for femoral-neck fractures that provides angular stability to three screws in an inverted triangle configuration was evaluated. The plate is not fixed to the lateral cortex and therefore represents a new treatment principle.

Methods: Twelve pairs of cadaver femurs (mean T-score −1,95 (range −4,5–0)) with subcapital femoral-neck fractures angulating 60° were randomly allocated to fracture-fixation using either three individual screws or three interlocked screws. Subject-specific axial force and torque were applied by a hip simulator and three-dimensional migrations were recorded. The femurs underwent 10,000 cycles of simulated partial weight-bearing, followed by 10,000 cycles of simulated full weight-bearing and stair climbing.

Findings: On average interlocking reduced femoral-head centre migrations 1.6 mm (95% CI 0.1–3.1, $P = 0.04$). The intra-pair correlation of migration was 0.953 (Pearson's r). Interlocking did not change rotational stability ($P = 0.87$). Adding a locking plate did not affect the risk of failure, however all failed femurs were fixed using the smallest-sized aiming guide.

Interpretations: Adding a lateral interlocking plate to three screws might improve the fracture stability. However, none of the implants were able to resist the unwanted deformation of the proximal femur. Regardless of the fixation, female sex, reduced bone quality and small sized femurs appear to increase risk of failure.

1. Introduction

Internal fixation of femoral-neck fractures is currently the treatment of choice for patients with undisplaced fractures (Parker et al., 2008). It is further indicated for young patients with displaced fractures with a long and active life expectancy to enable restoration of the pre-trauma function and to postpone arthroplasty (Ly and Swiontkowski, 2008; Parker and Johansen, 2006).

The vast majority of femoral-neck fractures are fragility fractures that occur in the elderly population (Parker and Johansen, 2006). In these patients, impaired bone-stock may lead to inadequate fixation stability. This would theoretically increase the risk of failure of the bone-implant construct, new fractures, redisplacements, incorrect unions or non-unions (Goldhahn et al., 2008). Femoral-neck shortening and varus displacement of the femoral head are common after femoral-neck fractures (Zielinski et al., 2013). These deformations reduce the abductor lever arm with subsequent loss of hip function (Zlowodzki et al., 2008). In addition, this shortening causes the implant to protrude into soft tissues and the implant must often be removed due to pain. Avascular necrosis is another feared complication occurring in 6% of patients with undisplaced fractures (Keating, 2010).

A number of head-preserving treatments have been used for subcapital femoral-neck fractures, including multiple screws, pins or a gliding hip screw device (Parker and Johansen, 2006). However, there is no consensus on the best treatment. In order to improve the surgical treatment of patients with femoral-neck fractures, a handful of new implants has been subject to recent research (Brandt and Verdonschot, 2011; Lin et al., 2012; Nowotarski et al., 2012; Parker and Stedtfeld, 2010; Roerdink et al., 2009, 2011; Rupprecht et al., 2011). Except for one (an intramedullary nail), all these new implants are fixed to the lateral cortex, a principle based on the popular gliding hip screw. In this paper, we explore the use of a locking implant that is not fixed to the lateral cortex and therefore represents a new principle in internal fixation of femoral-neck fractures. It provides an angular stability that eliminates individual screw toggling. It further functions as a single-beam construct that reduces the degrees of freedom of the bone-implant construct (Egol et al., 2004). Locking plates have improved treatment of other osteoporotic fractures such as proximal humeral fractures (Miranda, 2007), but the effect and safety of locked fixation of fragility fractures of the femoral-neck are not yet well documented.

The primary aim of this study was to explore whether screw interlocking affected the post-operative migration of the femoral head when compared to conventional fixation by three parallel screws. The

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secondary aim was to explore possible adverse effects, such as new fractures, following fixation with the new implant.

2. Methods

2.1. Preparation of bones

Following ethical approval, twelve pairs of human cadaver femurs from donors >60 years of age (Table 1) were obtained (LifeLegacy Foundation; Tucson, AZ, USA). Specimens were wrapped in saline-soaked cloth, vacuum packed, and stored at −20 °C. To make later computer modelling possible, all femurs were scanned using computed tomography (Somatom Definition Flash, Siemens, Erlangen, Germany). Bones with signs of pathology other than osteoporosis were excluded. Dual-energy X-ray absorptiometry scanning (Lunar iDXA, GE Healthcare, WI, USA) provided bone mineral density (BMD) with accompanying T-scores.

To prepare the bones for testing, the remaining soft tissue was stripped off, the diaphysis was marked 250 mm distal to the uppermost tip of the greater trochanter and the condyles were removed. The bones were then cemented (Meliodent, Heraeus, Hanau, Germany) into a cylinder so that the piriformis fossa was positioned over the centre of the cylinder, with the cement poured from the 250 mm mark down. For each femur, trochanteric strap-guides for the lateral tension band were made of bone cement.

2.2. Fractures and implants

The fracture line was marked 60° to the horizontal from the superior head/neck border down, in accordance with Pauwel's method (Keating, 2010). A cortical saw cut was made along the marked fracture line. In the medial neck the cut continued into the cancellous bone to avoid femoral-head attachment of the inferior buttress. Finally, a mallet blow to the head produced a rough fracture surface, simulating a stable subcapital femoral-neck fracture.

The aiming guide used provided three standardised sizes of the inverted-triangle configuration. The first femur of each pair was randomly allocated to one of the two fixation methods by coin toss after guide-pin insertion, to fracture fixation with three individual screws (screw group) or to three interlocked screws (interlocking group) (Fig. 1). The interlocking system is commercially available in Europe (Dynaloc System; Swemac Innovations, Linköping, Sweden), and consists of a lateral plate supporting three screws. The screws are locked in the plate by set-screws at 130° in an inverted-triangle configuration.

Table 1

Demographics, cycles to failure and implant size (available: 6, 9, 12).

	Age (gender)	Bodyweight (Newton)	Side	T-score[d]	Implant[b]	Cycles to failure[a]	Implant size
1	83 (F)	451	L	−4.5	i[c]	10,150	6
			R	−4.5	s	10,000	6
2	60 (F)	664	R	−2.5	i[c]	10,100	6
			L	−2.9	s	–	6
3	67 (M)	1010	L	0.0	s	–	12
			R	−0.3	i[c]	–	12
4	67 (M)	638	R	−4.0	s	–	12
			L	−3.7	i[c]	–	12
5	75 (F)	437	L	−2.3	s	–	6
			R	−2.5	i[c]	–	6
6	61 (M)	446	R	−1.3	s	–	12
			L	−1.3	i[c]	–	12
7	80 (F)	406	L	−1.5	i[c]	–	6
			R	−1.2	s	–	6
8	71 (M)	897	R	0.0	i[c]	–	12
			L	−0.5	s	–	12
9	81 (F)	923	R	−1.0	s	5800	6
			L	−0.5	i[c]	–	6
10	68 (M)	540	L	−0.7	i[c]	–	12
			R	−0.1	s	–	12
11	98 (F)	424	R	−4.5	i[c]	13,200	6
			L	−4.3	s	12,300	6
12	65 (F)	513	R	−1.5	i[c]	10,000	6
			L	−1.3	s	–	6

[a] – = did not fail.

[b] s = screws.

[c] i = interlocked screws.

[d] = total hip.

All bone screws were 6.7 mm in diameter, partially threaded, cannulated and made of titanium alloy (Dynaloc Bone Screws; Swemac Innovations, Linköping, Sweden). Screw length and plate size were selected following fluoroscopic controlled guide-pin insertion. The screws were securely fixed approximately 5 mm from subchondral bone, with the inferior screw riding the inferior buttress and the posterior screw set along the posterior cortex.

2.3. Experimental set-up

The femurs were mounted with 12° of adduction in a hip jig (Fig. 2a) built with reference to data presented by McLeish and Charnley (McLeish and Charnley, 1970). This jig mimicked the range of motion of the hip joint *in vivo*, with the exception of the anterior–posterior tilt. A lateral tension band simulated the hip abductors. The jig was fitted into a materials-testing machine (MTS 858 MiniBionix II; MTS Systems Corporation, Eden Prairie, MN, USA) with two actuators for axial loading and torque. A subject-specific torsional moment was induced by a wire-pulling construct acting on the cylinder bed to simulate *in vivo* torque (Bergmann et al., 2001). The hip simulator (Fig. 2b) therefore delivered a combined subject-specific axial load and torque. For load control and to enable calculation of the joint resultant force (JRF), active load cells were placed in the axial actuator and in the torque actuator and passive load cells were placed in the acetabular cup and in the tension band.

Donor bodyweight (BW) was used to calculate the forces to be applied. During the first 10,000 cycles the axial load simulated partial weight-bearing in the fracture-healing period $\left[F_{axial} = \left(0.8BW \cdot \frac{5}{6}\right)\right]$ (Koval et al., 1998) with 1.8% BW-meter torque corresponding to normal walking (Bergmann et al., 2001). For cycles 10,001 to 20,000, the axial force simulated full weight bearing $\left[F_{axial} = \left(1.0BW \cdot \frac{5}{6}\right)\right]$ and 2.2% BW-meter torque as measured during stair-climbing (Bergmann et al., 2001). Minimum axial load and torque in the load-valley of each load cycle were set to 15% of normal loading during walking.

An optical three-dimensional (3D) measurement system (Polaris Spectra, NDI, ON, Canada) was used to measure bone migrations. For 3D-measurements rigid body marker tools (Polaris Passive 4-Marker Rigid Body, NDI, ON, Canada) consisting of four retro-reflective passive markers with a minimum distance of 50 mm were attached to the femoral head and the proximal anterior diaphysis. The markers were fixed to the bone by screws and glue (X60, HBM, Darmstadt, Germany) and the anchorage of the markers was checked to make sure they had not

Fig. 1. Fixation principles used in the screws group and the interlocking group.