Cement augmentation of intertrochanteric fracture fixation

A cadaver comparison of 2 techniques

Jack Choueka[1], Kenneth J Koval[1], Frederick J Kummer[2] and Joseph D Zuckerman[1]

We evaluated 2 techniques of cement augmentation to enhance fixation of intertrochanteric hip fractures. 4 fixation groups with 6 cadaver femurs in each group were compared: stainless steel lag screw and side plate with and without cement augmentation and a titanium alloy expandable dome plunger and side plate with and without cement augmentation. Gauges were used to establish the mechanical behavior of intact and then fractured femurs to simple uniaxial loads. Subsequent loading to failure allowed determination of maximum fixation strengths and modes of failure.

Cement augmentation of each device increased its load to failure. There was no significant difference between the cemented lag screw and the uncemented dome plunger groups with average loads to failure of 4.0×10^3 N. The greatest average load to failure was in the cemented dome plunger group (5.6×10^3 N) with the lowest in the uncemented sliding hip screw group (3.6×10^3 N). Device cut-out as a cause of failure occurred mostly in the uncemented lag screw group. Sliding was enhanced by those methods that increased the fixation surface area within the femoral head, unless cement encroached in the region of the barrel-screw junction. Strain analysis showed that the dome plunger unloaded the bone at the calcar, regardless of cement augmentation, while the sliding hip screw allowed for compressive stresses in this area.

Proper cement augmentation increases load to failure and minimizes nail cut-out for both devices studied. However, the dome plunger, a device with a large fixation area in the femoral head, was equally effective and eliminated potential cement encroachment. Failure of intertrochanteric fracture fixation in osteoporotic bone may be minimized by an appropriate choice of device or cement augmentation.

Departments of [1]Orthopaedic Surgery and [2]Bioengineering, Hospital for Joint Diseases, Orthopaedic Institute, 301 East 17th St., New York, NY 10003, USA. Tel +1 212 598-6000. Fax -6096. Correspondence: Dr. Kenneth J. Koval
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Superior cut-out through the femoral head remains a complication of the sliding hip screw (SHS), particularly in osteopenic patients (Blanton and Biggs 1967, Harrington 1975, Laros 1980, Pitaser and Samuel 1993, Rokito et al. 1993). An increase in the fixation area in the femoral head can be achieved either by use of a larger device or by cement augmentation.

Methylmethacrylate as an adjunct to fracture fixation has been investigated for use in osteopenic bone (Bartucci et al. 1985, Cheng et al. 1989, Harrington 1975, Muhr et al. 1979). Bartucci et al. (1985) reported that by limiting the use of cement to the proximal fragment one can prevent screw penetration through the femoral head.

The Alta expandable dome plunger system (Howmedica, Rutherford, NJ, USA) (Figure 1) has a built-in mechanism for cement delivery restricting the cement to the femoral head, thus avoiding soft tissue extravasation, leakage into the fracture site and barrel screw junction. The Alta Dome plunger with cement augmentation has been shown to increase the surface area in the femoral head, leading to an increased load to failure and enhanced sliding. However, this configuration was associated with the unloading of bone at the calcar region-making it more of a load-bearing device (Choueka et al. 1995). This study is intended to 1) evaluate the effectiveness of the dome plunger without cement augmentation and 2) to determine whether cement augmentation of a standard SHS is comparable to the dome plunger system.

Material and methods

18 cadaveric femurs were randomly assigned to 1 of 3 fixation groups:

1. Richards Classic SHS (stainless steel) (Smith & Nephew Richards, Memphis TN, USA)

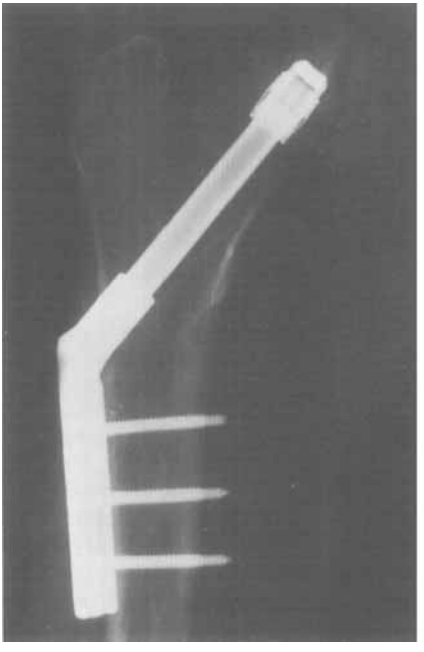

Figure 1. Proximal femur with Alta dome plunger.

Figure 2. Intact femur in loading cell held in 25° of adduction in the coronal plane to simulate loading of a one-legged stance. One linear strain gauge and two displacement gauges are affixed as described in the text.

2. Richards Classic SHS with cement augmentation
3. Alta sideplate unit with dome plunger (Ti-6Al-4V alloy) (Howmedica, Rutherford NJ, USA).

The data for a fourth group consisting of the Alta sideplate unit with dome plunger with cement augmentation was taken from our previous study (Choueka et al. 1995) which was performed in an identical manner. This provided a total of 24 femurs with 4 fixation groups for comparison.

All femurs underwent radiographic examination to determine the Singh index (Singh et al. 1970) and neck shaft angle. Dual-energy x-ray absorption scanning (QDR-2000 Supine Lateral X-Ray Bone Densitometer, Hologic, Waltham, MA, USA) was used to obtain the bone mineral density of each specimen.

The distal condyle of each femur was removed and the shafts (cut to equal lengths) were potted with cement in steel tubes. A unidirectional strain gauge (Omega EA-06-125-AC-120; Omega Engineering, Stamford, CT, USA) was affixed to the femoral shaft below the lesser trochanter and attached to a digital strain indicator (Micro Measurements P-3500, Vishay Technology, Inc., Greenboro, NC, USA). 2 digital electronic linear displacement gauges (IDC-25E, Mitutoyo, Tokyo) were affixed to the frame of an MTS 410 servohydraulic testing machine (MTS Systems, Minneapolis, MN, USA) with oversize plunger heads to contact at specific head and shaft positions in order to directly measure lateral shaft bending and inferior head movement (Figure 2).

Load of a one-legged stance was simulated by loading the femurs in 25° of adduction in the coronal plane (Frankel 1960, Chang et al. 1987). The MTS machine was used to load the femoral heads by means of a flat polished plate, in 200 N intervals to 1200 N recording displacement and strain readings at each interval. After sequential loading of the 4-part specimens, loads were continuously applied at a rate of 1 cm/min until specimen failure, and load-deformation curves were then obtained. Failure was defined as a marked discontinuity in the load displacement curve.

All specimens were first tested intact by incrementally loading to 1200 N and recording data for strain and displacement, in order to serve as self-controls. Two-part intertrochanteric fractures were then created by cutting the circumference of the cortical bone with a thin-blade reciprocating saw at the intertrochanteric line, the fracture being completed with a hammer blow. This was followed by osteosynthesis with 1 of the 4 fixation methods. All sideplates had a 135° barrel orientation. Insertion of the devices involved reaming over a guide pin inserted in the center of the femoral neck and head under direct visualization. The paths of the lag screws were pretapped. Cement insertion of the Alta dome plunger model involved placement of a small bolus of doughy cement in the dome,

Table 1. Comparison of test groups. Mean *SD*

	Singh index		Bone mineral density (gms/cm^2)		Neck shaft angle (degrees)	
Group 1 (Richards)	3.5	*0.55*	0.74	*0.10*	134	*3.3*
Group 2 (Richards cement)	3.7	*0.52*	0.69	*0.06*	132	*1.9*
Group 3 (Alta dome plunger)	3.5	*0.55*	0.67	*0.06*	134	*2.3*
Group 4 (Alta dome plunger cement)	3.7	*0.82*	0.70	*0.35*	135	*3.3*

Table 2. Percent of intact femur strain (% *SD*)

Load (N)	Alta		Alta cement		Richards		Richards cement	
2-part fracture								
200	1	*31*	–52	*20*	19	*46*	14	*25*
400	–2	*11*	–22	*30*	31	*34*	9	*17*
600	–6	*7*	–14	*35*	35	*31*	7	*14*
800	–7	*7*	–12	*37*	38	*30*	6	*13*
1000	–8	*7*	–12	*39*	39	*29*	5	*12*
1200	–9	*8*	–13	*40*	40	*29*	5	*12*
4-part fracture								
200	–3	*36*	–15	*27*	22	*60*	6	*4*
400	–8	*9*	–8	*28*	46	*41*	6	*10*
600	–8	*4*	–6	*29*	54	*38*	7	*13*
800	–8	*2*	–4	*29*	57	*37*	7	*14*
1000	–9	*2*	–3	*30*	60	*37*	7	*15*
1200	–9	*3*	–3	*30*	60	*36*	7	*15*

Negative values represent tensile forces in the calcar region.

prior to its placement on the insertion tool. After the instrument was inserted into the femur, the tool was tightened so as to extrude the cement into the surrounding cancellous bone. Cement insertion of the Richards device involved placement of 1 cubic cm of doughy cement into the pretapped canal into the femoral head, with care taken to avoid encroachment on the fracture site. Cement was inserted with a cement gun through the lateral cortex past the fracture site to simulate clinical conditions. The lag screw was then immediately inserted after this and the cement was allowed to cure around the screw threads. Following instrumentation, the specimens were examined radiographically for proper screw placement and then loaded to 1200 N. Four-part intertrochanteric fractures were then created and made unstable by removing the posteromedial fragment and the greater trochanteric fragment, and the specimens were reloaded to 1200 N in the previous manner. Reduction of the fractures was ensured by tightening the compression screw until there was secure contact of the fracture fragments. Because compression screws are not available for the Alta dome plunger, reduction for this group was achieved by manually pushing the plunger within the barrel of the sideplate before testing. Finally, the 4-part unstable fracture was tested to failure, with maximum load to failure measured from the load-deformation curve. The mechanism of failure was determined by gross inspection, x-rays and by slicing the heads in half to examine device position and cement integrity.

Analysis

Each femur served as its own control. Load-deformation and load-strain curves were generated and fitted to a regression equation by the method of least squares. A Pearson correlation coefficient exceeding 0.90 was considered acceptable. Student t-tests were used for statistical analysis of the 3 groups. A p-value of 0.05 or less was considered significant.

Results

The femurs in the 4 groups were comparable and showed no significant difference in their average bone mineral density, neck shaft angle and Singh index. (Table 1)

In the Richards Classic hip screw group, the maximum load to failure was 3.6 (*SD 0.6*) $\times 10^3$ N; with cement augmentation the load to failure was 4.0 (*0.4*) $\times 10^3$ N. The Alta dome plunger group's maximum load to failure was 4.1 (*0.4*) $\times 10^3$ N and with cement augmentation this increased to 5.6 (*1.3*) $\times 10^3$ N. A significant difference existed only between the strength of the Alta dome plunger with cement augmentation and all other groups ($0.01 < p < 0.03$).

5 out of 6 of the Alta dome plunger with cement augmentation specimens failed by crushing the inferior neck or calcar, with the other by separation of the sideplate unit from the femoral shaft. The Alta dome plunger without cement had 1 failure by cutout; the others failed by crushing of the inferior neck. All of the Richards lag screws without cement failed by cutout through the femoral head or neck. The modes of failure in the Richards SHS with cement augmentation were more variable: 2 samples failed by cut-out, 1 sample failed by crushing the inferior neck and the remaining 3 failed by fracture of the femoral shaft in the subtrochanteric region. Postfailure examination showed cement at the barrel-screw junction for those specimens that cut-out.

Strain data were acquired and analyzed as percentages of the intact femur strain. In the calcar region, tensile strains were noted for the Alta device with or without cement augmentation, whereas in the Richards groups, compressive strains were found. The 2- and 4-part fractures demonstrated similar results. The

Table 3. Inferior head displacement (mm *SD*)

Load (N)	Alta		Alta cement		Richards		Richards cement	
2-part fracture								
200	0.89	*0.36*	0.87	*0.35*	0.18	*0.13*	0.59	*0.53*
400	1.44	*0.57*	0.96	*0.51*	0.30	*0.21*	0.88	*0.67*
600	1.98	*0.81*	1.05	*0.70*	0.42	*0.29*	1.18	*0.85*
800	2.53	*1.07*	1.15	*0.91*	0.54	*0.37*	1.48	*1.03*
1000	3.07	*1.33*	1.24	*1.12*	0.66	*0.46*	1.78	*1.23*
1200	3.62	*1.59*	1.33	*1.34*	0.78	*0.54*	2.08	*1.44*
4-part fracture								
200	0.70	*0.39*	0.55	*0.33*	0.26	*0.23*	0.47	*0.39*
400	1.09	*0.45*	0.56	*0.41*	0.34	*0.18*	0.60	*0.30*
600	1.48	*0.55*	0.57	*0.52*	0.41	*0.24*	0.74	*0.37*
800	1.87	*0.66*	0.58	*0.64*	0.49	*0.37*	0.87	*0.54*
1000	2.26	*0.78*	0.59	*0.78*	0.56	*0.51*	1.00	*0.75*
1200	2.65	*0.92*	0.60	*0.92*	0.64	*0.65*	1.14	*0.97*

Richards SHS with cement showed significantly less compressive strain than the group without cement (Table 2).

Comparison of the slopes of the load-displacement curves showed that cement augmentation did not affect the overall rigidity of either device; 8×10^{-4} mm/N in both the Richards groups and 4×10^{-4} mm/N in both dome plunger groups. The inferior head displacement gauge readings showed that the Alta dome plunger system without cement showed significantly greater displacement than the other groups for both the 2- and 4-part fractures (Table 3). There was no significant difference in inferior head displacement between these other 3 groups.

Discussion

The purpose of the cement augmentation is to enhance fixation of the implant in the femoral head in patients with severe osteopenia. In this experiment, we tried to limit cement fixation to the femoral head, as one would try to do under clinical circumstances.

The maximum load to failure of both devices was increased by augmentation with cement. With the Alta dome plunger, cement augmentation increased the load to failure by 37%, but only by 12% in the Richards group. The Richards SHS, which does not have a cement delivery system, had difficulty in achieving reproducible cement placement. Containment of the cement in the head was not always obtained. On examination, cement was sometimes found either in the fracture site or at the screw barrel junction. Inability to optimize fixation with cement often transformed a sliding device into a rigid nail device, thus negating its inherent biomechanical advantages.

Inferior head displacement, which was used as a measure of sliding in this study, is in actuality a combination of sliding and crushing. In neither of the dome plunger groups was there any movement of the device in the head on loading; this left sliding as the major component of inferior head displacement. In both of the Richards SHS groups, there was movement in the head as the device cut-out which certainly contributed to the displacement in these groups. The Alta dome plunger groups showed better sliding ability than the Richards groups. The Alta dome plunger without cement demonstrated the best sliding abilities in the four groups tested, illustrating that enhanced fixation in the femoral head can improve sliding, but cement also can inhibit sliding by intruding into and obstructing the barrel-screw junction if improperly used.

The Alta dome plunger, with or without cement, usually failed by crushing the inferior neck and calcar region. The Richards SHS without cement failed by cutting out the head or neck in all instances; with cement augmentation the causes of failure varied from cut-out to crush to subtrochanteric fractures. The variability in cement delivery in the Richards cement group seen by post-failure examination is probably the cause of the different types of failure observed.

Although both Alta dome plunger groups had a higher load to failure, less cut-out and improved lag screw sliding, this behavior may be at the expense of using a stiffer, more load-bearing device that results in unloading of the calcar region.

Study limitations

Use of embalmed specimen. Although fresh-frozen specimens may resemble more the physiologic condition, embalmed bone has been found to have similar mechanical properties (McElhaney et al. 1964).

Uniaxial testing model. This method of testing has been used in many experiments with SHS biomechanics because it simulates the major component of physiologic loading during ambulation (Chang et al 1987, Clark et al. 1990, Meislin et al. 1990, Rosenblum et al. 1992). The loads to failure in this study, although appearing quite high for osteopenic bone, are similar to those found in those studies.

Tapping of lag screws. Although clinically, tapping of osteopenic bone is frequently unnecessary and may weaken fixation, all specimens in the Richards SHS groups were tapped prior to instrumentation, in an effort to maintain reproducibility of fixation techniques.

Inferior head displacement as a measure of sliding. As explained, in addition to sliding, crushing is a component of inferior head displacement. Direct measurement of sliding was not found to be a reproducible measurement in this model, and therefore this more indirect measure was employed.

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