Tohoku J. Exp. Med., 2000, **192**, 41-48

Comparison of Wiring Techniques for Bone Fracture Fixation in Total Hip Arthroplasty

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HAN, S.-M. *Comparison of Wiring Techniques for Bone Fracture Fixation in Total Hip Arthroplasty.* Tohoku J. Exp. Med., 2000, **192** (1), 41-48 —— The objective of this study was to investigate the effect of cerclage wire position and determine the number of wires necessary to prevent crack opening and stem subsidence following a proximal femoral fracture in cementless total hip arthroplasty. A cementless femoral stem one size larger than the templated size was inserted into each femur to initiate a proximal crack. A cerclage wire was wrapped around the fracture in one of two orientations: 1) parallel to the osteotomy (PO) and 2) normal to the fracture line (NF). The femur was compressed to a load of 890 N, 1780 N and 2670 N while crack opening and stem subsidence were measured. A second cerclage wire was placed parallel to NF wire and inferior to the lesser trochanter and a third wire was placed 1 cm distal and parallel to the second wire. The loading was repeated again. The mechanical evaluation of stem subsidence were verified by various computer simulations even using four wires. We have found that placement of the cerclage wires normal to the fracture line prevents stem subsidence and crack opening better than placement of the wires parallel to the osteotomy. Three cerclage wires, placed normal to the fracture line at three locations: 1) adjacent to the superior of the lesser trochanter, 2) adjacent to the inferior of the lesser trochanter and 3) 10 mm distal to the bottom of the lesser trochanter were necessary to achieve stability under higher loads. ——— total hip arthroplasty; fracture; femur; wire

The need to achieve a press-fit between the femoral stem and cortical endosteum in cementless total hip arthroplasty (THA) has resulted in increased incidence of intra-operative femoral fracture during stem insertion (McElfresh and Coventry 1974; Scott et al. 1975; Schwartz et al. 1989). This complication arises from the increased hoop stresses associated with larger stem sizes and the increased stem-endosteal contact that is required to achieve initial stability to facilitate bony ingrowth into the porous coating during cementless THA (McElfresh and Coventry 1974; Scott et al. 1975; Schwartz et al. 1989; Sugiyama et al. 1992).

Received June 3, 1998; revision accepted for publication August 22, 2000.

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The incidence of intra-operative femoral fracture in cementless THA has been reported to be between 4.1% and 27.8% (Schwartz et al. 1989). In comparison, incidence of intra-operative femoral fracture in cemented THA is between 0.4% and 3% (Scott et al. 1975).

Proximal hoops stresses may help prevent subsidence of the femoral stem, however, increase in hoop stresses above the yield stress of cortical bone may result in femoral fractures. Intra-operative fractures of the proximal femur most commonly occur during final broaching and seating of the cementless femoral stem (Scott et al. 1975; Mulliken et al. 1996). Calcar hoops strains have been shown to increase by an average of 25% after stem insertion (Walker and Robertson 1988) and oversized stems may lead to as much as four times an increase in calcar hoop stresses under 1800 N of compression.

There has been considerable controversy regarding the optimal fixation method for proximal femoral fractures. It has been suggested that an incomplete proximal fracture of the proximal femur may remain stable without any additional fixation, while others have utilized cerclage wires, compression plates, bands or revisions to long stem prosthesis (McElfresh and Coventry 1974; Johansson et al. 1981; Andrew et al. 1986; Hedley et al. 1988; Schwartz et al. 1989; Brien et al. 1994; Mulliken et al. 1996; Nercessian et al. 1996). Of these, cerclage wiring remains the most common means of stabilizing cementless stems within a proximally fractured femur. The effectiveness of cerclage wires in management of femoral fracture has been proven both clinically and experimentally (Johansson et al. 1981; Meding et al. 1997). However, despite its common use, the technique of applying cerclage wire to the proximal femur has not yet been explored.

The objective of this study was to investigate the effect of cerclage wire position and determine the number of wires necessary to prevent crack opening and stem subsidence following a proximal femoral fracture in cementless THA.

Materials and Methods

Twelve human cadaveric femora were harvested several days after death. The femora were radiographed to exclude any bones with pathology and to template for the "best-fit" cementless femoral stem size. One femur was excluded due to severe osteoporosis and a transverse fracture through the femoral neck. To introduce a proximal crack, a straight tapered, collarless, cementless stem (Natural, Sulzer Orthopedics, Austin, TX, USA), one size larger than the templated size, was inserted into each femur. In one femur a stem two sizes larger than the templated stem had to be inserted. All eleven femoral cracks occurred through the calcar and propagated distally from 50 mm to 165 mm. Two of the femora had additional anterior cracks. A 316 L steel, 1.5 mm cerclage wire (Synthes, Monument, CO, USA) was wrapped around the fracture, adjacent to the superior of the lesser trochanter. The wires were applied in one of two methods: 1) the wire was applied parallel to the osteotomy and 2) the wire was applied

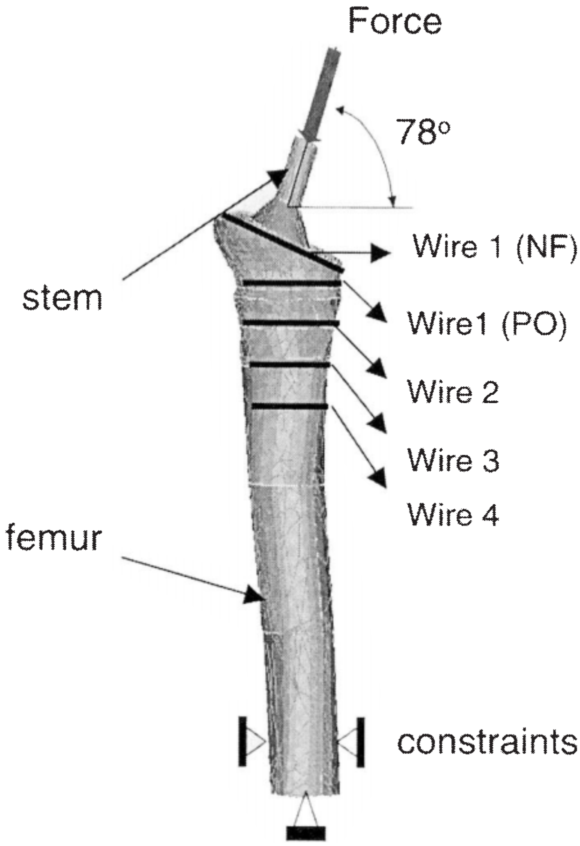

Fig. 1. Placement of cerclage wires. Wire 1(PO) is applied parallel to the osteotomy and Wire 2(NF) normal to the fracture line.

normal to the fracture line. Placement of the wires can be seen in Fig. 1. The second wire was placed parallel to the NF wire, inferior to the lesser trochanter. The third wire was placed 1 cm distal and parallel to the second wire. The cerclage wires were tensioned to 470 MPa, measured by a linear strain gauge (EA-06-031DE-120, Measurements Group, Raleigh, NC, USA) attached to the wire. The distal one third of the femora were cut off and the ends were embedded in methylemthacrylate. The femora were positioned into a custom designed axial compression fixation on an MTS Mini-Bionix (MTS Corporation, Minneapolis, MN, USA). The femora were compressed to a load of 890 N for a 15-second interval, followed by a load of 1780 N for 15 seconds and 2670 N for 15 seconds.

The mechanical evaluation of stem subsidence was also simulated on a computer at the same condition. The femur were scanned to obtain cross sectional images using quantitative computed tomography (QCT) (GE9800, Minneapolis, MN, USA) for computer simulation of subsidence evaluation. The CT images of 1.5 mm thickness were obtained at 3.0 mm intervals. The inner and outer boundaries of cross sectional image were defined utilizing an edge detection program. The obtained coordinate data were used to reconstruct three dimensional image of femur. An optimal fitting program was developed to find a better fitting prosthesis using the three dimensionally reconstructed bone. The geometric reconstruction takes the form of a finite element mesh. The femur has been modeled eight-node isoparametric elements. The mechanical elastic modulus used for the elements was determined to be 12 000 N/mm^2 for cortical and 100 N/mm^2 for cancellous bone. A uniform Poisson's ratio of 0.3 was chosen. Loading conditions and wiring methods were same as in the mechanical tests. The simulation of stem subsidence included the techniques using four wires as well as one, two, and three wires. The fourth wire placed 1 cm distal and parallel to the third wire.

To measure crack opening, a differential variable reluctance transducer (DVRT, MicroStrain, Burlington, VT, USA) was placed across the crack with the two fixation points on opposite sides of the crack. Stem subsidence was measured by the displacement of the MTS cross-head. A unpaired t-test (StatView, Abacus, Inc., Berkeley, CA, USA) was used to compare crack opening and stem subsidence between the PO and NF wires. Significance was accepted at a p-value of 0.05 with a 95% confidence interval.

To determine the number of wires necessary to stabilize the crack, a second cerclage wire was placed parallel to the NF wire and inferior to the lesser trochanter. The loading procedure was repeated to determine crack opening and stem subsidence. A third wire was placed 1 cm distal and parallel to the second wire. The loading was repeated again.

Results

The subsidence measured at different wiring techniques ranged from 1.1 to 1.8 mm under a load of 890 N, from 1.8 to 4.9 mm under 1760 N, and from 2.5 to 9.9 mm under 2670 N. The measurements of crack opening included values from 23 to 42 μm under 890 N, from 34 to 419 μm under 1760 N, and from 65 to 761 μm under 2670 N. Wires placed in the NF orientation allowed less crack opening and stem subsidence compared with PO wires. As the load was increased, NF wires resisted crack opening (Table 1) and prevented stem subsidence (Table 2) more than PO wires. The greatest differences between NF and PO wires were seen under a load 2670 N. Under this load, the NF wire allowed the cracks to open by an average of 653 μm, while the PO wires allowed the cracks to open by a mean of 761 μm (Fig. 2). PO wires allowed an average stem subsidence of 9.9 mm under 2670 N of load compared to 8.8 mm for NF wires. A similar trend was also

Table 1. *Average values (μm) of crack openings measured at different wiring techniques under three different loading conditions (N)*

	890	1760	2670
Wire 1 (PO)	42	419	761
Wire 1 (NF)	36	401	653
Wire 2	25	185	412
Wire 3	23	34	65

TABLE 2. *Average values (mm) of subsidence of femoral stems measured at different wiring techniques under three different loading conditions (N)*

	890	1760	2670
Wire 1 (PO)	1.8	4.9	9.9
Wire 1 (NF)	1.7	4.0	8.8
Wire 2	1.5	2.6	5.1
Wire 3	1.1	1.8	2.5

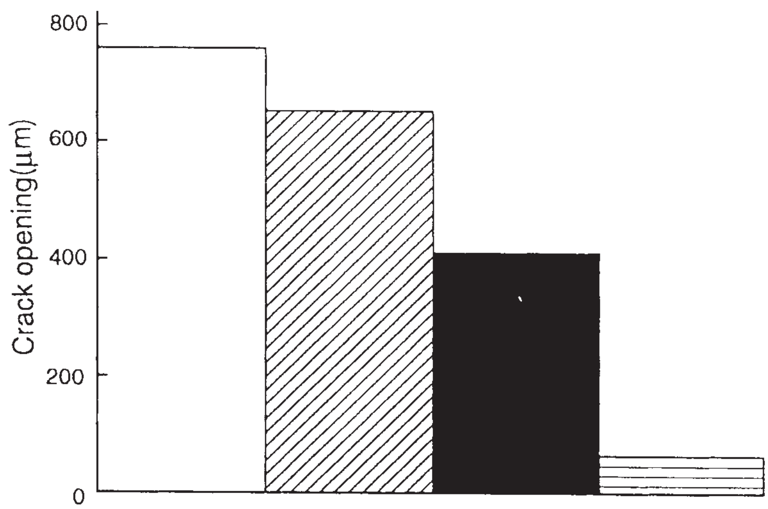

Fig. 2. Comparison of the applied wiring techniques in crack openings under a load of 2670 N.
□, Wire 1(PO); ▨, Wire 1(NF); ■, Wire 2; ▤, Wire 3.

found in computer simulation of the subsidence as loading conditions and wiring techniques changed. However, the magnitude of subsidence was significantly different (Table 3).

Crack opening was greatest when only one cerclage wire was used and least for three wires. Crack opening was significantly smaller ($p<0.05$) using three wires compared to a single wire under 1780 N and 2670 N of load. However, there

TABLE 3. *Average values (mm) of subsidence of femoral stems simulated at different wiring techniques under three different loading conditions (N)*

	890	1760	2670
Wire 1 (PO)	0.42	4.19	7.61
Wire 1 (NF)	0.36	4.01	6.53
Wire 2	0.25	1.85	4.12
Wire 3	0.24	0.41	1.02
Wire 4	0.23	0.34	0.65

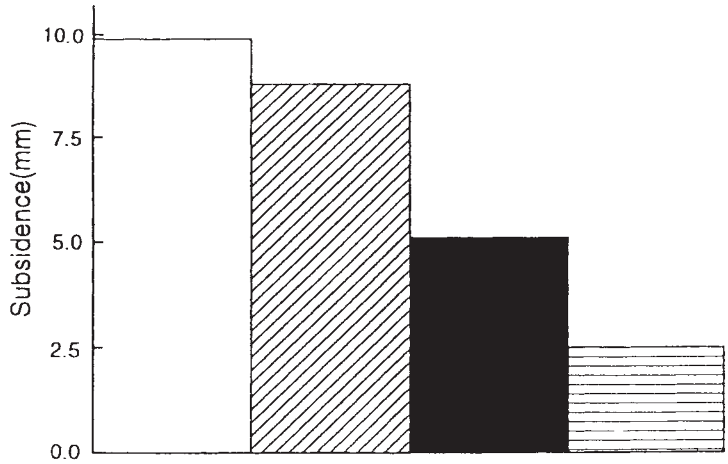

Fig. 3. Subsidence of femoral stems measured at different wiring techniques under a load of 2670 N.
□, Wire 1(PO); ▨, Wire 1(NF); ■, Wire 2; ▤, Wire 3.

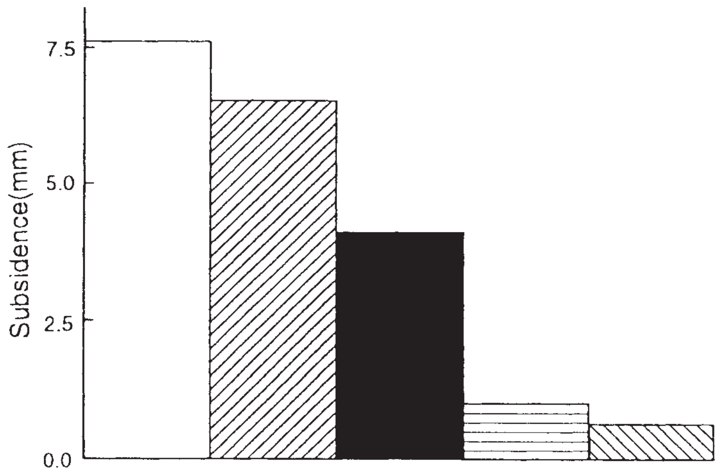

Fig. 4. Simulated subsidence of femoral stems at different wiring techniques under a load of 2670 N.
□, Wire 1(PO); ▨, Wire 1(NF); ■, Wire 2; ▤, Wire 3; ▧, Wire 4.

were no significant differences in crack opening ($p > 0.05$) between using one wire or three wires under 890 N of compression. Subsidence was also least using three wires and greatest using one PO wire. Addition of the second and third cerclage wires significantly reduced stem subsidence under 1780 and 2670 N of compression (Fig. 3) but did not significantly reduce subsidence under 890 N compared to the single NF wire. The computer simulation showed that addition of the fourth wire did not significantly reduce stem subsidence when compared to three wires (Fig. 4).

Discussion

Improper fixation of femoral fractures during THA may result in painful non-union or aseptic loosening of the femoral stem (Scott et al. 1975; Morita et al. 1997). Intra-operative fractures resulting in instability of the stem may be treated by revision to cemented or cementless long-stem revision prosthesis (Engh et al. 1988; Grustilo and Pasternak 1988; Hedley et al. 1988; Katz et al. 1995; Mulliken et al. 1996; Meding et al. 1997), however, stability is rarely achieved. Cerclage wires in conjunction with a long-stem revision have been shown to be the optimal fixation method for intra-operative femoral fractures during THA (Johansson et al. 1981; Meding et al. 1997).

The inclination angle of fixation devices relative to the fracture line has been shown to greatly affect fracture stability (Kim and Kim 1994). The optimal orientation of a lag screw is perpendicular to the fracture line or bisecting the angle of the fracture planes in a spiral fracture. A small deviation in screw angle of 20° may actually displace the fractured components and result in instability. Positioning of cerclage wires following intra-operative proximal femoral fracture in cementless THA may also have a profound effect on the consequent stability of the femoral stem. We have found that placement of the cerclage wires normal to the fracture line prevents stem subsidence and crack opening better than placement of the wires parallel to the osteotomy. This may be due to the length of wire needed to circumvent the proximal femur. Since the NF wires were placed below the femoral neck, they were roughly the length of PO wires which wrapped completely around the greater trochanter. The shorter length resulted in a smaller deformation of the NF wires compared to the PO wires under the same tension.

One wire, placed in the NF orientation, is sufficient to provide stability when compression load of 890 N is applied. However, loads greater than three times the body weight are often applied on the hip stem during daily activities such as strain climbing or sitting up from a chair. To provide adequate fracture fixation in these high loading conditions, our results suggest that three cerclage wires would be required.

Many femoral fractures are not detected intra-operatively. These fractures occur distally, at the stem tip, or they might be obscured by muscle tissue. If a fracture is undetected, yet stem stability is not compromised, clinical results have shown that patient outcomes are not affected. For unstable fractures of the proximal femur, we recommend the use of these cerclage wires placed normal to the fracture line at three locations: 1) adjacent to the superior of the lesser trochanter, 2) adjacent to the inferior of the lesser trochanter and 3) 10-mm distal to the bottom of the lesser trochanter.

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