FEMORAL STEM FIXATION IN HIP REPLACEMENT

A BIOMECHANICAL COMPARISON OF CEMENTLESS AND CEMENTED PROSTHESES

T. W. PHILLIPS, S. S. MESSIEH, P. D. McDONALD

From the University of Western Ontario

A leading problem with cementless hip replacement is thigh pain, probably due to some degree of loosening. This is most pronounced during activities such as stair climbing or getting up from a chair. Our study compares the immediate fixation of three stems in widespread clinical use, using a cadaver test simulation in which the femur was horizontal, and cyclic forces acted vertically downward on the prosthetic head with gradual increments of load. We implanted and tested 18 pairs of femurs, making analyses between stem types by right to left comparisons.

We found no statistically significant differences in loosening between cementless AML and PCA prostheses, but cemented stems withstood greater loads than uncemented stems by a factor of five or more.

It is imperative that secure fixation be obtained for the first three months after the implantation of cementless prostheses (Engh 1983; Callaghan, Dysart and Savory 1988). Restrictions on activity are usually recommended to prevent overloading and early loosening, but full weight-bearing is often unavoidable during manoeuvres such as getting up from a chair or out of a car. In these situations the combined forces of gravity and muscle action have a component which acts vertically downward on the head of the near horizontal femur, causing a torsional moment which tends to twist the stem into retroversion. This force direction may explain why thigh pain, which is most pronounced during the above activities, is more frequent after cementless than cemented hip replacements (Harris 1986; Hedley et al 1986; Engh, Bobyn and Glassman 1987; Callaghan et al 1988; Phillips and Messieh 1988).

Few investigators have studied loosening of hip implants in hip flexion, where torsional loading becomes important. In a stereophotogrammetric study, Mjöberg

found that all of 24 total hip prostheses which were painful during weight-bearing required some rotational loading to demonstrate loosening (Mjöberg, Hansson and Selvik 1984). Radin tested femoral stems cemented in sheep femora, and found that torsion was a reliable testing mode (Radin et al 1982). Fractured stems that have been retrieved at revision surgery show metallurgic defects and plastic deformation patterns which could only be due to torsional overloading (Charnley 1979; Gallante 1980).

In an earlier report we described pure torsional testing of cementless stems in cadaveric femora, using single-cycle destructive testing (Allen, Phillips and McDonald 1986). However, the stem loosened by ultimate fracture of the femur, not at all like the gradual subsidence of the stem which is seen in clinical practice. We have recently developed a new biomechanical test of loosening, using cyclic loading in a position simulating 90° of hip flexion (Messieh 1988, personal communication) and have developed criteria for describing and quantitating loosening. We now apply this new test to compare three commonly used femoral stems.

T. W. Phillips, BSc, MD, FRCS(C), Associate Clinical Professor of Surgery
University of Western Ontario, London, Ontario, Canada N6A 5B8.

S. S. Messieh, MD, Research Fellow
P. D. McDonald, BSc, Mechanical Engineer
Lawson Research Institute, 268 Grosvenor Street, London, Ontario,
Canada N6A 4V2.

Correspondence should be sent to Dr T. W. Phillips.

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MATERIALS AND METHODS

Twenty-six pairs of human cadaver femora previously fixed in formalin were stripped of all soft tissue, transected above the femoral condyles and stored. Radiographs were made, simulating the technique used with patients, positioning the bone on a radiolucent cushion to result in 15% magnification. The degree of osteoporosis was

measured by the Singh index (Singh, Nagrah and Maini 1970). Femora with any abnormality due to arthritis, previous fracture, deformity, tumour or implant were excluded. Femora too small or too large to fit the range of prosthetic stem sizes were also excluded. Eighteen pairs were left for inclusion in the study.

We selected the AML (Anatomic Micro Lock) (Engh et al 1987), and the PCA (Porous Coated Anatomic) (Hedley et al 1986) cementless stems, and compared these to a conventionally cemented HP (Harris Precoat) (Zimmer 1984), as shown in Figure 1. All prostheses had a 32 mm head diameter with equal offset configuration to ensure a consistent moment arm. During implantation, pre-operative templates and surgical technique ensured that the central axis of the stem was aligned with the central axis of the femur.

We used 13 pairs of femora to compare a cementless PCA on one side with a cementless AML on the other. Templating, sizing, bone preparation and implantation were performed by the techniques recommended by the manufacturers. Tightness of fit was assessed from our clinical experience with over 500 cementless stems, being recorded as loose, firm, tight or very tight. We also noted any complications, particularly the intra-operative occurrence of femoral cracks, which we held with a double loop of 18 gauge wire.

Five other pairs of femora were used to compare a cementless PCA on one side to a cemented HP on the other. The cemented stems were implanted using distal canal plugging, cement gun delivery, and proximal finger packing (Harris, McCarthy and O'Neill 1982). After implantation, anteroposterior and lateral radiographs were taken, and scored according to the quality of fixation (Engh 1983).

Fig. 1

Photograph of the three prostheses used. The PCA is on the left, the AML in the centre and the HP on the right. All had the medium neck length and a 32 mm head. The stem sizes shown are in the mid-range for each type, being a number 4 PCA, 13.5 mm AML, and medium HP.

Fig. 2

Photograph of a femur during testing. The cylindrical plunger of the hydraulically driven MTS load actuator is pushing down on the prosthetic head.

Mechanical loading. All femora were potted and fixed to a Model 880/858 MTS servohydraulic testing machine as detailed elsewhere (Messieh 1988, personal communication) and shown in Figure 2. A cyclic load was applied to the head and incremented by 50 N every 100 cycles. To detect any slippage or fatigue of the femur in the outer potting fixture, a second transducer (LVDT-2) was attached to the bone on the medial surface of the femoral neck. Prosthetic head displacement, load, medial femoral neck position, and time were monitored and plotted on a Beckman multichannel strip recorder.

From the strip recording, the resting position of the prosthetic head at the end of each 100 cycles was measured and plotted against peak load to determine the loosening load. This load was defined as the point in the displacement versus load graph where the slope equalled or surpassed 0.2 mm per 100 cycles. An example is shown in Figure 3. Differences in loosening load between each pair of femora were then analysed and subjected to statistical analysis using Student's parametric *t*-test.

RESULTS

A proximal femoral crack was produced during implantation in three of the 31 cementless femora. Cracks consistently reduced the loosening load to 60% or less of the contralateral side. The results are grouped into Tables I and II for uncracked and cracked pairs.

Cementless stems. If femoral cracks were avoided, there was no statistically significant difference between the AML and PCA loosening loads ($p > 0.05$). The loosening load did not correlate with the radiological Engh score, or with the Singh index.

The subjective tightness of fit assessed during implantation produced the most consistent correlation

Fig. 3

A typical test result showing the femoral resting position at the end of each 100 cycles of loading. The very steep lines show where the femoral head resting position for the first time subsided > 0.2 mm during 100 cycles. This slope is also shown in the insert in the top right of the figure.

Table I. Results of the 90° torsion test, showing the loosening loads of uncracked cementless pairs

Specimen	Loosening load in Newtons	
	PCA	AML
F6	475	375
F17	625	1 075
F31	475	525
300	475	725
301	425	625
304	525	725
307	625	675
308	175	225
309	1 025	625
3 251	575	275
Average	540.0*	585.0*
s.d.	213.5	250.3

* the difference is not statistically significant ($p = 0.59$)

Table II. Results of the 90° torsion test, showing the loosening loads of uncracked and cracked cementless pairs

Specimen	Loosening load in Newtons	
	PCA uncracked	AML cracked
66	275	175
80	625	275
310	825	475
Average	575.0*	308.3*
s.d.	278.4	152.8

* the difference is not statistically significant ($p = 0.085$)

Table III. Results of the 90° torsion test, showing the loosening loads of cementless and cemented pairs

Specimen	Loosening load in Newtons	
	PCA cementless	HP cemented
313	225	1 425
314	225	925
315	675	2 775
316	375	2 275
317	525	2 675
Average	405.0*	2 015.0*
s.d.	195.6	808.9

* the difference is statistically significant ($p = 0.005$)

with the loosening load. If, during the last few blows, the stem was a little loose or only just firm, the loosening load was always less than 400 N. If it went in very tightly, the loosening load was consistently over 650 N. Also, if one side went in more tightly than the other, this side withstood the highest load before loosening. Tightness did not correlate with the type of stem.

Cemented stems. The results for the cemented stems are summarised in Table III. All cemented stems were much more resistant to loosening than cementless stems. During cyclic testing, loads became high enough to produce slippage at the outer surface of the femur in the potting fixture only in the cemented cases. The 'loosening loads' for the cemented side in two cases were the loads at which the femur loosened in the potting compound rather than the loosening load of the stem in the femur. Had potting slippage not occurred then the true loosening loads for the stem within the femur would probably have been even higher.

DISCUSSION

In our study all the cementless femoral prostheses loosened with posteriorly-directed loads in the range of 175 to 1 075 N. For a 70 kg patient (690 N gravity force) this translates to 25% to 160% of body-weight. The cemented stems maintained fixation to loads in the range of 135% to 400% of body-weight.

The exact value of this posterior torsional force during normal activities in life is difficult to measure or estimate. Rydell (1966) was the first to use an instrumented prosthesis to measure the forces on the femoral head in two patients; he found that the posterior portion of the total force while walking had a maximum value of half the body-weight. Crowninshield et al (1978), using force plate, kinematic and anthropometric data estimated that the maximum posterior component of the hip contact force was about twice the body-weight when walking and about five times body-weight when ascending stairs. Most recently Davy et al (1988) using a telemetrised total

hip prosthesis, determined that the posteriorly-directed component of force on the hip during stair climbing was 480 N. The loosening loads we used thus appear to be within the physiological range. It is of concern that all of our specimens loosened within 1 800 cycles. This compares to a patient going up a 20-step flight of stairs twice per day for three months.

Our results lead us to the following recommendations for application in clinical practice:

- 1) If at operation a cementless stem seats loosely or only just firmly, the surgeon should consider changing to an alternative stem, either larger or with cement. This agrees with Harris (1986), who recommends conventional cementing for older patients with osteoporosis and a large intramedullary canal.
- 2) Radiographic criteria such as the Engh score do not provide a good predictor of implant fixation. While intra-operative films may be of great value in detecting a femoral crack, and checking appropriate stem size and position and neck length, they do not give a reliable measure of fixation.
- 3) Patients who receive a cementless stem have a

dangerously low margin of safety for rotational loosening. All cementless stems should be protected from rotational loading until supplementary fixation by porous ingrowth and/or bone remodelling have had time to occur.

4) Protection from rotational loading in the healing period in cases with a femoral crack incurred during implantation is especially important.

5) Cement fixation provides by far the greatest immediate fixation.

6) Consideration should be given to this type of biomechanical testing in the design of new types of stems before clinical trials are started.

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