TORSIONAL STABILITY OF THE FEMORAL COMPONENT OF HIP ARTHROPLASTY

RESPONSE TO AN ANTERIORLY APPLIED LOAD

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Torsional instability of femoral components has not received much attention, and is difficult to detect in conventional radiographs. To test this we designed a system to apply a load in an anteroposterior direction to the head of a femoral component, implanted into a cadaveric femur. Rotation within the bone was measured, using a purpose built transducer, with and without preservation of the neck, with and without cement, and with longitudinal ridges but no cement.

The results show that torsional instability may be a problem in uncemented replacement. Preservation of the femoral neck and the use of a ridged prosthesis increases resistance to rotation. Rotational movements occurring in vivo during such activities as climbing stairs and rising from the seated position may contribute to mechanical loosening.

Aseptic loosening and migration of the femoral component remain a problem after hip replacement surgery. During a conventional hip arthroplasty much of the femoral neck is excised. This removes undiseased bone, and has been continued largely for an historical reason, namely, that femoral prostheses were originally used in the treatment of intracapsular fractures of the femur, where the neck had to be replaced. The mechanical advantages of retention of the femoral neck have been discussed by Freeman (1986): as regards the vertical component of the load on the femur, the compressive element would be distributed over a larger area of bone with, as a consequence, lower stresses. The varus turning moment would also be reduced. The validity of the first mechanical proposition was confirmed by laboratory testing (Carlson, Albrektsson and Freeman 1988).

Rotational instability of femoral components has attracted little attention. Wroblewski (1979) suggested that torsional loading on the proximal part of the stem was the causative mechanism in its fracture. It is

virtually impossible to detect rotational movement of prostheses from plain radiographs, but a stereophotogrammetric study has demonstrated rotational movement of an uncemented prosthesis of approximately 4° at one year after implantation (Nistor et al. 1987).

The magnitude of the rotational force acting on the

Fig. 1

The neck-retaining prosthesis. Right, smooth version; left, variant with longitudinal ridges.

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anterior aspect of the femoral head has been variously estimated. Rydell (1966), using an instrumented hemiarthroplasty, measured loads of around half body weight (approximately 400 N) during level walking. His patients were known to have weak flexors and abductors when tested six months after surgery, and this estimate is probably low. A recent study, using a telemeterised femoral replacement, measured a peak force of 480 N in the anteroposterior plane while ascending stairs (Davy et al. 1988). The electronics failed one month after surgery, while the patient was still using crutches, and this estimate is also likely to be low.

Crowninshield et al. (1978) estimated the greatest loads to be during stair climbing, when the resultant was predicted to be over seven times body-weight, with the component of force acting on the pelvis in the anteroposterior direction being up to five times body-weight. They commented that this force affects the torque which is transmitted to the bone-cement interface of a hip prosthesis and may be related to implant loosening. Berme and Paul (1979) considered the load in the anteroposterior axis during level walking and calculated this to be about 1800 N at 50% of the cycle time from heel-strike. Even in the apparently relaxed position of sitting in a chair it has been calculated that the resultant force on the hip joint was 1.76 times body weight, angled at 40° anterior to the vertical, giving 1.35 times body-weight in the anteroposterior direction (Robinson, Bohne and Burstein 1982). It has been suggested that retention of the femoral neck would increase the resistance to these torsional forces (Freeman 1986).

We have measured the movement of prostheses inserted into cadaveric femora in response to an anteriorly applied load, and studied the effect upon

rotational stability of the prosthesis of femoral neck retention, cemented and cementless fixation, and the addition of longitudinal ridges to an uncemented implant.

MATERIALS AND METHODS

Proximal sections of cadaveric femora were obtained at routine autopsy and stored at -20°C . After thawing, they were prepared in standard fashion to accept a Freeman prosthesis, which retains the neck (Fig. 1) (Albrektsson et al. 1987). Bones with obvious disease were rejected, as were those where the cortical thickness of the femoral shafts was less than 5 mm.

The bones were mounted in a steel cylinder using polymethylmethacrylic cement for fixation. The cylinders were then fixed horizontally in an adjustable jig on the base of a Schenck Trebel materials testing machine, and a load applied to the anterior surface of the prosthetic head, via a load cell (Fig. 2). A strain-gauged cantilever was screwed to the greater trochanter so that it was parallel to the prosthetic femoral neck. A pointer attached to the free end of the cantilever rested on the prosthetic neck via a hole drilled through the bone. Movement of the prosthesis relative to the bone could thus be measured by deflection of the pointer (Fig. 3). The strain gauges were the active parts of a Wheatstone bridge and the output of the strain-gauge amplifier was fed into one channel of a Hewlett Packard x-y plotter. The output of the load-cell was fed into the other channel.

The bones were then tested using the following variations of prosthesis and fixation:

1. A smooth prosthesis inserted as a press-fit without cement.

Fig. 2

Fig. 3

Figure 2 – The adjustable jig with bone and recording system in place. A load is applied via a load-cell (not shown) and a polyethylene cup (a) which rests on the anterior surface of the prosthetic head. Figure 3 – A cantilever arm is screwed to the anterior surface of the greater trochanter. The pointer from this rests on the surface of the prosthetic neck. The femoral neck has been resected in this specimen.

2. The same prosthesis with the addition of a complete, pressurised cement mantle with a minimum thickness of 2 mm.

3. A variant of the prosthesis with longitudinal ridges on the stem, implanted without cement. The ridges project 1 mm from the stem, and cut into the subcortical cancellous bone on insertion (see Fig. 1).

Each bone was loaded to 400 N and the deflection recorded. Load application was repeated until a reproducible trace was obtained, and a minimum of five cycles was then performed. The bone was then loaded to 800 N, that is to an average full body-weight, and the process repeated.

The femoral neck was then excised, by a cut extending superolaterally from a point midway between the lesser trochanter and the head-neck junction to the base of the greater trochanter, as for a conventional hip replacement. The loading cycles were then repeated. Twelve bones were used, four in each group.

RESULTS

The mean displacements for each test on each bone are shown in Table I and the means and standard deviations of the results for each condition tested are shown in Table II. The displacements were compared using Student's *t*-test.

cemented prosthesis with the neck excised, but these differences were not statistically significant ($p = 0.12$ and $p = 0.1$ respectively). The difference in displacement of the ridged component with the neck intact compared with the neck excised was just significant ($p = 0.052$).

It was found that bones with an uncemented smooth prosthesis fractured at loads only a little above 400 N with the neck intact, and that they often fractured at loads of around 200 N with the neck excised. Therefore the uncemented smooth implants were not loaded above 400 N.

Several bones with an uncemented smooth prosthesis (not included in the results) fractured at loads below 400 N with the neck intact. It may be that some of these bones were abnormally weak, or that technical errors were made in their preparation. If neither of these factors applied, then the results of the uncemented smooth prosthesis would have been biased in favour of those bones which were unusually strong, and the difference in torsional stability between the smooth and the ridged implants would have been greater.

All the bones with ridged implants fractured at loads between 400 N and 800 N with the neck resected, but none fractured with the neck intact. All the bones with cemented prostheses were capable of withstanding loads up to 1800 N without fracture. Failure commenced with

Table I. Displacement in millimetres in 12 specimens on sequential testing (see text)

Applied load (N)	State of the neck	Condition of the specimen											
		Cemented				Uncemented							
						Smooth				Ridged			
400	Intact	0.10	0.09	0.07	0.14	0.70	0.94	0.35	0.45	0.24	0.37	0.18	0.46
400	Excised	0.24	0.08	0.24	0.45	F	F	0.83	F	1.09	*	0.49	1.22
800	Intact	0.22	0.17	0.17	0.35	F	F	F	F	0.99	0.72	0.42	1.54
800	Excised	0.64	0.24	0.56	*	F	F	F	F	F	*	F	F

* technical fault
F fracture

The displacement of a ridged cementless prosthesis with the neck intact was not statistically different from that of a cemented prosthesis with the neck excised (the 'conventional' situation) at 400 N ($p = 0.6$) nor 800 N ($p = 0.3$), although at both loads, there was a trend in favour of the cemented prosthesis.

The displacement of the smooth cementless prosthesis with the neck intact was significantly greater than that of the cemented prosthesis with the neck intact ($p < 0.05$). The displacement of the smooth prosthesis with the neck intact was also greater than that of the ridged implant with the neck intact and that of the

irreversible crushing of the subcortical cancellous bone in the neck remnant, followed by a longitudinal fracture of the cortex of the medial neck (Fig. 4).

DISCUSSION

The experimental findings provide relative values which demonstrate the effect of cement, longitudinal ridges, and retention of the neck on the rotational stability of an implant in the cadaver.

Rotationally, the stiffest preparation (producing on average 0.22 mm of movement at 800 N) was achieved

Fig. 4

A specimen after failure of the subcortical cancellous bone in the posterior part of the femoral neck. A gap can be seen anteriorly between the prosthetic neck and the bone (arrow).

Table II. Mean displacement in millimetres $\pm$ 1 s.d.

Applied load (N)	State of the neck	Condition of the specimen		
		Cemented	Uncemented	
			Smooth	Ridged
400	Intact	0.1 $\pm$ 0.03	0.61 $\pm$ 0.26	0.31 $\pm$ 13
400	Excised	0.25 $\pm$ 0.15	Fracture	0.93 $\pm$ 0.39
800	Intact	0.23 $\pm$ 0.09	Fracture	0.92 $\pm$ 0.48
800	Excised	0.48 $\pm$ 0.21	Fracture	Fracture

by combining cement with neck retention. Resection of the neck, to produce a 'conventional' cemented prosthesis, increased the displacement at 800 N to 0.48 mm. Although double the initial value, this difference was not statistically significant ($p = 0.11$). Without cement, the best result was achieved by combining ridges with neck retention. This combination exhibited slightly more displacement than cement plus neck resection but the difference was not significant at 400 N ($p = 0.57$). At 800 N the difference appears more marked, but is still not significant ($p = 0.26$).

No other preparation withstood a load of 800 N. Retention of the neck, however, enabled a smooth uncemented stem to withstand 400 N with a mean displacement of 0.61 mm, whereas with the neck resected the femur fractured at this load. Similarly, although the ridged stem supported 800 N with the neck intact, fracture occurred at this load when the neck was excised.

It was established that, for a prosthesis inserted into cadaveric bone without cement and after neck resection, and loaded torsionally, the femur fractures when the load applied to the front of the head reaches an average of

about 400 N. Since the physiological load applied has been estimated to be at least 400 N (Rydell 1966; Davy et al. 1988), and since clinically the femur does not fracture when replaced after neck resection and without cement, then the absolute values of force are not comparable. This difference probably relates to the different loading modes with pure rotation in vitro, contrasting with the simultaneous rotation, axial compression and lateral displacement which occurs in vivo.

We believe that our study permits three conclusions:

1. Cement fixation provides the best rotational fixation of the methods tested.
2. With or without cement or ridges, the retention of the neck enhances rotational strength and stiffness.
3. The addition of ridges to the metaphyseal region of the prosthesis further improves rotational fixation without cement when the neck is retained to produce a preparation statistically equivalent to a 'conventional' cemented stem with neck resection.

This suggests that, if femoral prostheses are to be inserted without cement, the neck should be retained and the metaphyseal region of the prosthesis should be provided with ridges. If the prosthesis is cemented, retention of the neck increases the rotational stiffness of the preparation and provides the stiffest preparation we have studied. With or without the use of cement therefore, retention of the neck improves femoral stability.

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