RADIOLOGY OF LOW-FRICTION ARTHROPLASTY OF THE HIP

A COMPARISON OF SOCKET FIXATION TECHNIQUES

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We studied the radiographs of 211 low-friction arthroplasties, followed for five to 15 years after operation. The first 92 simple hemispherical sockets were fixed with an old technique: eburnated bone in the acetabular roof was removed and only a few large anchor holes were bored for cement fixation. With the next 119 sockets, 111 of which were flanged, the eburnated and subchondral bone was preserved and multiple small anchor holes were used.

The modified technique and the use of flanged sockets significantly improved the late radiological findings as regards socket demarcation and wear. On the femoral side, the intramedullary canal filling ratio, the distal packing of cement, calcar resorption and atrophy of the femoral cortex were correlated with prosthetic subsidence.

Aseptic loosening is the most significant problem in total hip arthroplasty. Long-term reviews of early Charnley low-friction arthroplasties led to the hope that developments in materials, prosthetic design and surgical techniques would provide more successful results in the future (Charnley 1979; Stauffer 1982; Hamilton and Joyce 1986; Loudon 1986; Older 1986; Wroblewski 1986; Eftekhari 1987). In 1979, we made major changes in the fixation technique used for the acetabular component, based on Charnley's theories (1979). We have now investigated the effects of these changes on the long-term radiological results, and at the same time we have assessed the factors affecting subsidence of the femoral component.

MATERIALS AND METHODS

Charnley low-friction arthroplasty was introduced to our department in 1972 by the senior author (KT) after study and training with Sir John Charnley at Wrightington Hospital. From 1972 to 1983, a total of 285 consecutive

low-friction arthroplasties (LFAs) were performed on 230 patients. Clinical and radiographic assessments have been carried out every six months. For this study, 37 LFAs in 33 patients were not available because they had been followed-up at other hospitals for their own convenience. Seven LFAs in six patients were excluded because they had died before the minimum of five years follow-up. One patient with a deep wound infection, which appeared three years after revision surgery and which required a resection arthroplasty, was excluded as were 29 LFAs in 23 patients because of failure of follow-up. This left 211 arthroplasties in 167 patients, followed for an average of 8.4 years (range five to 15 years).

The age at operation ranged from 28 to 74 years (mean 58.5). The youngest patient was a 28-year-old woman with multiple epiphyseal dysplasia. She used a wheelchair because of the involvement of other joints, and her bilateral LFAs functioned well with no sign of aseptic loosening at 12 years. Twenty-three LFAs were in 20 men, and 188 in 147 women; 209 were primary operations, only two were revision procedures.

The diagnosis was osteoarthritis in 172 hips (82%) in 132 patients, rheumatoid arthritis in 11 hips (5%) in 10 patients, and other disorders in 28 hips (13%). In terms of Charnley categories (1979), 108 LFAs were A (unilateral hip disease, no other functional disabilities), 87 LFAs in 45 patients were B (bilateral hip disease, otherwise no functional disabilities), and 16 LFAs in 14 patients were C (hip disease with systemic disease or other functional disabilities).

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Acetabular sockets were fixed by one of two methods. Up to 1979, all eburnated bone or subchondral bone was removed so as to expose the cancellous bone (which was then considered to be the ideal bed for cement). The acetabulum was deepened superiorly, and one or two 12.5 mm anchor holes were drilled in addition to the pilot hole. After 1979, the subchondral bone of the roof was preserved, the acetabulum was deepened transversely at a lower anatomical level, and multiple 6 mm anchor holes were made. Ninety-two LFAs were performed in 74 patients by the old technique (group A); simple hemispherical (non-flanged) sockets were used. In 119 LFAs in 94 patients the new technique was employed (group B). Simple hemispherical sockets were used for eight (7%) in this group, and flanged pressure injection (PIJ) sockets for the other 111 (93%). All sockets in both groups were made from identical high-density polyethylene, and the same bone cement of standard viscosity (CMW 1) was used throughout the series.

The details of the two groups of patients are shown in Table I. Age, sex ratio, category ratio, obesity index (the percentage of body-weight to standard weight), and the ratio of the hips for which bone was grafted in the roof were comparable in both groups.

The effects of the difference between these two surgical techniques on postoperative radiological findings were investigated. Cupic (1979) found that most failures appeared early and could be strongly suspected by the fourth or fifth year, so we used the 5-year postoperative films and compared them in the two groups, also using radiographs taken within one month of operation and at the latest attendance. The measurements taken on radiographs within one month of operation are shown in Figure 1.

On the 5-year and the latest radiographs, socket demarcation was graded by the method described by Charnley (1979); grade I had no demarcation, grade II had slight or moderate demarcation affecting the upper quadrant only, grade III was severe demarcation involving the whole circumference, and grade IV was migration of the socket. Wear of the socket was measured using the technique developed by Charnley and others (Charnley and Cupic 1973; Charnley and Halley 1975); wear of 2 mm or more was regarded as definite (Stauffer 1982). Statistical analysis of the differences between group A and group B was performed on the results for the 1-month and 5-year films.

As regards the femoral components, we analysed five features on the radiographs taken within one month (Fig. 1). In addition we classified the position of the prosthetic stem as valgus or varus in relation to the axis of the proximal femoral shaft. A stem in a valgus position with a cement thickness of more than 1 cm at the calcar was recorded as being in an exaggerated valgus position (Bocco, Langan and Charnley 1977). In the intramedullary canal, the stem filling ratio was the percentage of stem width to intramedullary width at the mid-point of

Fig. 1

Measurements made on the radiographs taken within one month of operation. The protrusion of a socket from the bony edge of the acetabular roof (a) is the length of wire marker from its lateral end (A) to the line (OE), drawn from the centre of the prosthetic femoral head (O) to the lateral bony edge of the acetabular roof (E). Cement thickness at the acetabular roof (b) is the distance from the lateral bony edge of the acetabular roof (E) to the wire marker. Socket height (c) is the vertical distance from the distal end of the socket wire marker (B) to a line drawn through the distal ends (D) of both tear-drops. The socket angle (sT) is the angle of the ends of the wire marker (AB) to the tear-drop line. The bony acetabular angle (bT) is the angle of the line DE from the tear-drop line.

On the femoral side, the remaining calcar length (d) is the length of the medial femoral cortex above the lesser trochanter. The collar-calcar gap (e) is that between the edge of the collar and the stump of the calcar. The calcar cement thickness (f) is the thickness of cement between the calcar and the stem. The false cement length (tD) is the distance from the prosthetic tip to the distal end of the cement, and the true cement length (tD) is that from the tip to the level at which cement fills over 80% of the canal. When cement does not reach the prosthetic tip, the lengths are recorded as minus values.

the stem. The thickness of the femoral cortex was recorded as a percentage of the total width of the femoral shaft 4 cm above the prosthetic tip (Charnley, Follacci and Hammond 1968).

On the 5-year radiographs and those taken at the latest attendance we measured subsidence of the femoral component by the method of Loudon and Charnley (1980); more than 2 mm was regarded as significant

Table I. Details of the patients in group A and group B, using the *t*-test for averages and the chi-square test for ratios

	Group A (92 hips in 74 patients)	Group B (119 hips in 94 patients)
Age at operation (years)	56.5	60.0*
Sex (female: male) (number of hips)	80:12	108:11*
Category (A: B: C) (number of hips)	45:37:10	63:50:6*
Obesity index (<i>per cent</i>)	110.8	105.1*
Use of flanged socket (<i>per cent</i>)	0	93.3†
Bone graft in the roof (<i>per cent</i>)	11.0	9.2*
Follow-up period (years)	10.6	6.8†

* no statistical difference between groups

† statistical difference ($p < 0.05$)**Table II.** Number and *percentage* of 211 hips, graded for socket demarcation at 5 years, and at the latest follow-up

Radiological grade (see text)	5 years	Latest review (8.4 ± 2.69 years)
I	125 59.2	127 60.2
II	33 15.6	25 11.8
III	41 19.4	38 18.0
IV	12 5.7	21 10.0

Table III. Number and *percentage* of acetabular sockets in each radiological grade at 5-year follow-up for group A, old technique and group B, new technique

Radiological grade (see text)	Group A n = 92	Group B n = 119
I	30 32.6	95 79.8
II	22 23.9	11 9.2
III	32 34.8	9 7.6
IV	8 18.7	4 3.4

(Charnley 1979; Hamilton and Joyce 1986). A clear zone at the cement-bone or the cement-stem interface was judged as significant when its width was 1 mm or more. We noted the presence of a cement fracture at the tip of the prosthesis (Weber and Charnley 1975; Salvati et al 1976; Bocco et al 1977; Beckenbaugh and Ilstrup 1978). The extent of calcar resorption was assessed by change in the remaining length (Charnley et al 1968; Charnley and Cupic 1973; Stauffer 1982).

Cortical change was classified into four types: normal, atrophy with normal outline, hypertrophy with normal outline and external hypertrophy (Charnley et al 1968). The external outline of the femoral cortex was examined; any fusiform hypertrophy near the prosthetic tip was classified as external hypertrophy. When there was no change in the outline of the femur, the cortical thickness was evaluated 4 cm above the prosthetic tip. Variation of cortical thickness of less than 5% compared with the 1-month film was classified as normal. When cortical thickness had increased or decreased by 5% or more, the femur was classified as hypertrophic or atrophic with normal outline. Statistical analysis was performed to assess differences in all these factors between the group of femoral components without subsidence and those with subsidence.

RESULTS

The incidence of grades of socket demarcation for all 211 LFAs are shown in Table II. All of the 125 sockets which showed grade I demarcation at the 5-year review remained in grade I at their latest attendance. Nine of the 41 sockets which showed grade III demarcation at five years had deteriorated to grade IV at their latest attendance. Twenty-one femoral components had sunk more than 2 mm at five years, but none had newly subsided after five years.

Grade IV demarcation of the socket and subsidence of the femoral component were described as radiological failure by Charnley (1979). In only two LFAs did we find both acetabular and femoral components showing radiological failure. We found no correlation between acetabular and femoral radiological failure. The development

Table IV. Comparison between the radiographs in group A and group B, using the *t*-test for averages and the chi-square test for ratios

	Group A (92 hips in 74 patients)	Group B (119 hips in 94 patients)
Within 1 month		
Protrusion of socket (mm)	3.7	6.4†
Cement thickness (mm)	9.1	11.7†
Socket height (mm)	6.7	5.4*
Socket angle (degrees)	47.2	44.5†
Acetabular angle (degrees)	44.4	46.5†
At 5 years		
Socket demarcation		
I:II:III:IV (hips)	30:22:32:8	95:11:9:4†
Mean wear (mm)	0.88	0.40†
Definite wear (hips)	20	7†
At latest review		
Socket demarcation		
I:II:III:IV (hips)	31:16:29:16	96:9:9:5†
Mean wear (mm)	1.77	0.53†
Definite wear (hips)	33	8†

* no statistical difference between groups

† statistical difference ($p < 0.05$)

of acetabular failure took from 0.5 to 12 years (mean 4.4), and that of femoral radiological failure from one to five years (mean 2.7). Five revision operations had been performed for four loose sockets and one loose femoral prosthesis by the time of our study.

In the entire series, socket wear measured on 5-year radiographs was from 0 to 4.6 mm (mean 0.61); 27 sockets showed definite wear of 2 mm or more. At latest attendance, socket wear was from 0 to 8 mm (mean 1.07), and 41 sockets showed definite wear.

Comparison of the radiological findings in group A (old fixation technique) and group B (new technique) is shown in Table III, and a statistical breakdown of the detailed results is given in Table IV. On the 1-month radiographs lateral protrusion of the proximal end of the wire marker and cement thickness at the acetabular roof were statistically larger in group B than in group A. Socket angle was smaller in group B than in group A, although the bony acetabular angle was larger in group B than in group A. There was not enough difference in socket height between group A and group B to be statistically significant.

Analysis of the 5-year radiographs showed a statistical correlation between socket demarcation and socket fixation technique (Table IV). Grade I, no demarcation, was seen in 80% of group B, but in only 33% of group A. There was also a statistical difference in the degree of wear between group A and group B.

Statistical comparison of the results for femoral components without and with subsidence is shown in Table V. Of the features analysed on the 1-month films, only the stem filling ratios, false cement length and true cement length showed a statistically significant difference between the two groups. All the items analysed on the 5-year radiographs and the latest films, including clear zones, cement fracture, calcar resorption and cortical change, correlated with femoral subsidence.

DISCUSSION

Stauffer (1982) reported that the incidence of the appearance of radiological loosening of the femoral component decreased after five years, while the incidence of new acetabular loosening remained the same. The acceleration of socket demarcation with time was observed in the 5- to 15-year study of Charnley (1979) and in the 15- to 21-year study of Wroblewski (1986). In our series, 12 sockets developed radiological failure within five years and eight sockets after this, while all the radiologically unsuccessful femoral prostheses had sunk more than 2 mm by five years. The way in which radiological failure develops in the acetabulum may be different from that in the proximal femur. Wroblewski (1986) found a linear correlation between time and wear, and an exponential relationship between the depth of socket wear and the percentage of cases of socket migration. We also found a statistical correlation between

Table V. Comparison of patients and radiological findings for the femoral prostheses without and with subsidence, using the *t*-test for averages and the chi-square test for ratios

	No subsidence (190 hips in 147 patients)	Subsidence (21 hips in 20 patients)
Age at surgery (years)	58.3	60.0*
Sex (female: male) (hips)	169:21	17:4*
Category (A:B:C) (hips)	95:80:15	13:7:1*
Obesity index (<i>per cent</i>)	107.5	107.7*
Use of flanged stem (<i>per cent</i>)	36.3	28.6*
Intramedullary plug (<i>per cent</i>)	25.3	28.6*
Follow-up (years)	8.4	8.4*
Radiographs taken within 1 month		
Remaining calcar length (mm)	6.5	7.4*
Collar-calcar gap (mm)	1.0	0.7*
Calcar-cement thickness (mm)	4.4	4.2*
Prosthetic position (hips)		
(valgus: exaggerated valgus: varus)	158:15:17	17:0:4*
Stem filling ratio (<i>per cent</i>)	77.8	72.5†
False cement length (mm)	37.5	16.7†
True cement length (mm)	30.9	1.8†
At 5 years		
Clear zone/cement-bone (<i>per cent</i>)	17.9	85.7†
Clear zone/cement-stem (<i>per cent</i>)	0.5	28.6†
Cement fracture at tip (<i>per cent</i>)	1.1	42.9†
Calcar resorption (mm)	1.1	7.4†
Cortical change in proximal femur (hips)		
None	96	8†
Atrophy with normal outline	11	8†
Hypertrophy with normal outline	10	2†
External hypertrophy	73	3†
At latest review		
Clear zone/cement-bone (<i>per cent</i>)	18.4	85.7†
Clear zone/cement-stem (<i>per cent</i>)	1.1	33.3†
Cement fracture at tip (<i>per cent</i>)	1.6	42.9†
Calcar resorption (mm)	1.5	8.1†
Cortical change in proximal femur (hips)		
None	93	6†
Atrophy with normal outline	12	10†
Hypertrophy with normal outline	12	1†
External hypertrophy	73	4†

* no statistical difference between groups

† statistical difference ($p < 0.05$)

socket wear and socket migration, and agree that wear is an important factor in the long-term results.

Another important factor was the socket fixation technique. We found differences between the two groups on radiographs taken within one month: greater protrusion of the proximal end of the socket wire from the bony edge of the acetabular roof, greater cement thickness at the acetabular roof, and a smaller socket angle in spite of a larger bony acetabular angle in group B than in group A. These changes may be due to the predominant use of flanged sockets in group B, but the improved radiographic findings at the 5-year review in group B was probably influenced both by the new flanged socket and by the new technique of acetabular preparation.

In recent years, better results have been reported after low-friction arthroplasty due to improved materials, design and cement techniques. Breakage of the stem has been eliminated by new supermetals (Brady and McCutchen 1986). An exaggerated valgus position of the femoral prosthesis appears to reduce destructive

changes in the calcar, cement tip fracture, and demarcation at the convex border of the prosthesis, all indicative of subsidence of the prosthesis within the cement (Bocco et al 1977). A stem with a dorsal flange (Cobra pattern) has reduced the incidence and amount of subsidence of the prosthesis (Loudon and Charnley 1980).

During the past two decades the main changes have aimed at improving cement technology (Eftekhar and Tzitzikalakis 1986; Eftekhar 1987). Charnley himself called the old method of socket fixation an unsophisticated technology (Charnley 1979). Eftekhar and Tzitzikalakis (1986) noted that the preservation of subchondral bone with multiple anchor holes offered greater resistance to torque, increased distribution of load-bearing forces, reduced local stress concentration, and also conserved bone. Increased stiffness might reduce micromotion, and thus late acetabular loosening. They also postulated a vicious cycle which could follow removal of the subchondral bone of the acetabular roof.

Charnley (1979) discussed the virtues of the flanged (pressure injection) socket: a simple hemisphere is unable to exert injection pressure on acrylic cement, and being loose in the acetabulum, can continue to wobble until the cement has hardened. The flanged design stabilises the socket while the cement is soft and the pressure injection rim is able to exert an element of hydraulic pressure. Oh, Sander and Treharne (1985) and Shelley and Wroblewski (1988) have proved experimentally that a socket with an accurately fitting flange can generate high injection pressures and greatly improve cement intrusion into cancellous bone. The radiological results we obtained with the new technique proved the efficacy of the improved acetabular preparation and the flanged design of the socket.

As regards factors related to subsidence of the femoral component, Griffith et al (1978) reported that patients with subsidence were on average 9 kg heavier. Beckenbaugh and Ilstrup (1978) reported that if the stem diameter was less than half the width of the femoral canal at its mid-portion, the incidence of loosening was 2.5 times higher than if the stem diameter was larger. They also found that the extent of the cement past the tip of the prosthesis was inversely related to subsidence. In our series both the stem-filling ratio and the distal packing of cement in the 1-month radiographs, were correlated with stem subsidence. Loudon (1986) showed that subsidence was associated with four postoperative radiological signs: fracture of the cement tip, resorptive changes in the medial femoral neck, demarcation around the cement and a gap at the convex border. In our series also, all these signs correlated with subsidence. We considered that while a clear zone and cement tip fracture were phenomena which accompanied prosthetic subsid-

ence, calcar resorption and cortical atrophy of the femur were catabolic changes in the femoral cortex which led to subsidence. The stem-filling ratio and distal packing of cement were factors of operative technique, while calcar resorption and atrophy of the femoral cortex were biological factors.

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