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Mechanical factors in loosening of Christiansen and Charnley arthroplasties

A series of 96 Christiansen and 23 Charnley hip arthroplasties, mainly for osteoarthrosis, were followed for an average of 40 (15–93) months. Radiolucent zones at the cement bone interface and resorption of the calcar were more frequent in the Christiansen than in the Charnley hips. Medial and axial migration, and cement fracture often occurred concurrently, with a total frequency of 27/96 in the Christiansen and 4/23 in the Charnley subseries. Wide radiolucent zones in the acetabular cement bone interface were more frequent in the Christiansen hips. Six acetabular protrusions were observed in the Christiansen hips against none in the Charnley hips. The average Harris' hip scores were significantly higher for the Charnley than for the Christiansen hips. Reoperation for loosening was performed in two Charnley hips and 19 Christiansen hips.

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Many types of total hip prosthesis have seen the light of day during the last quarter century, and new designs continue to appear. When theoretically promising innovations have been made, short-term follow-ups are presented with great enthusiasm. However, some constructions have already been found to be less successful in relatively short follow-ups (Wilson & Scales 1970, Head 1981), while very few reports with over 10 years of follow-up have been published (Harrold 1982). Experimental studies may focus on factors which may not be the most essential for clinical results and the numerous prostheses can only rightly be evaluated on the basis of long-term clinical reports.

We studied a series of patients with total hip replacement, in whom Charnley and Christiansen prostheses were used, with similar indications, age structure and follow-up, thus allowing a joint analysis and a critical comparison.

Patients and methods

During 1974–1979, 96 Christiansen and 23 Charnley total hip replacements were performed on 99 patients and were followed up for 40 ± 16 (mean ± s.d.) (range 15–93) months. Thirty-six patients were male and 63 were female, with an age range from 34 to 85 (70 ± 7.9) years. Fifteen patients, who could have been included in the study, died during the observation period.

The indication for operation was mainly osteoarthrosis. Patients with revisions of a previous hip prosthesis were excluded, as were patients who developed a postoperative infection. There were no differences in the demographic or preoperative factors between the two subseries. The choice of the prosthesis depended wholly on the preference of the surgeon.

The Christiansen arthroplasty (Sundal et al. 1974) was performed by the anterolateral approach in 68 cases, and by the posterior approach in 28 cases.

The Charnley arthroplasty was performed by the transtrochanteric method (Charnley 1972) in 17 cases and through an anterolateral approach in six cases.

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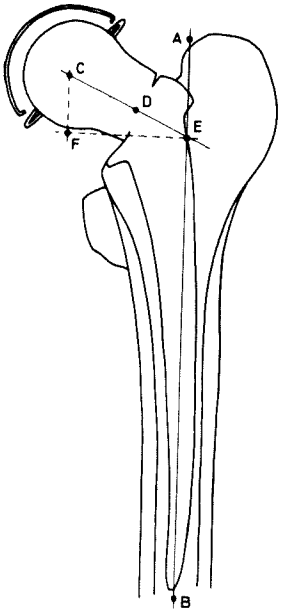

Figure 1. Christiansen total prosthesis. AB = Axis of the proximal femur. CD = Axis of the ball-neck. E = Intersection of the lines AB and CD. F = Projection of centre point C on a line perpendicular to AB. EF = Offset of the ball centre in relation to the femoral shaft.
In this case the offset of the prosthesis itself in relation to the prosthesis stem axis is smaller than EF.

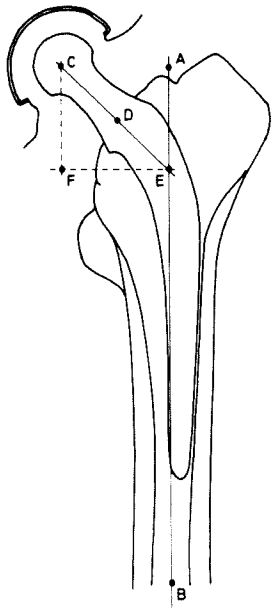

Figure 2. Charnley total prosthesis. Same symbols as Figure 1.
In this case, the offset of the prosthesis itself is greater than the offset of the ball centre in relation to the femoral shaft.

The femoral and acetabular components were cemented in place by manual pressure, using methylmethacrylate with added barium sulphate (Simplex). The acetabular cement was anchored by four 10 mm holes or dependings in the pelvis.

The clinical examination of the patients at the end of the follow-up period was performed by two of the authors (AA, OS), and included a history of pain and daily activities, and the clinical status (Harris 1969).

The presence and progression of any radiologic change was checked in sequential films. The x-ray films were analyzed by the radiologist (AB), together with one of the other authors.

The position of the femoral stem was classified as neutral when the long axis of the stem deviated less than 5° from the long axis of the proximal femoral stem. Otherwise, the position was graded as varus or valgus.

The medial offset of the prosthesis head was determined as the perpendicular distance from the centre of the ball to the mid-axis of the femoral shaft (Figures 1 and 2). The offsets of the three Christiansen prostheses on the x-ray films averaged 46, 52 and 58 mm, depending on the neck length. The offset of the Charnley prosthesis was on average 46 mm. A varus position of the stem resulted in an average 9 mm augmentation and a valgus position in an average 9 mm reduction of the total offset.

Cementing on the femoral component was considered adequate when the cement covered the tip of the stem and filled the whole proximal cancellous area to the cortical bone.

The coverage of the acetabular component under the pelvic roof was considered adequate when the lateral edge of the plastic cup was uncovered for less than 10 degrees of the circumference.

Medial migration of the stem was measured using two vertical reference lines in A-P films, the midline of the stem and the medial cortical line. The time of appearance and the progression of migration were recorded. Axial migration of the stem was measured using horizontal reference lines in A-P films through the junction of the prosthetic neck and stem and the tip of the smaller trochanter, and comparing subsequent films. Migration of the acetabular component (protrusion) occurred mediocranially (Figure 3) and was judged in subsequent films using the ileopectineal line as reference.

Among the other radiographic signs associated with loosening (Beckenbaugh & Ilstrup 1978), radiolucent lines in the cement bone interface (Figure 4), reactive cortical change (sclerosis or irregular resorption) and resorption of the calcar femorale were recorded. All radiolucent zones around the acetabular component appeared between the cement and bone. They were classified as lateral, central or

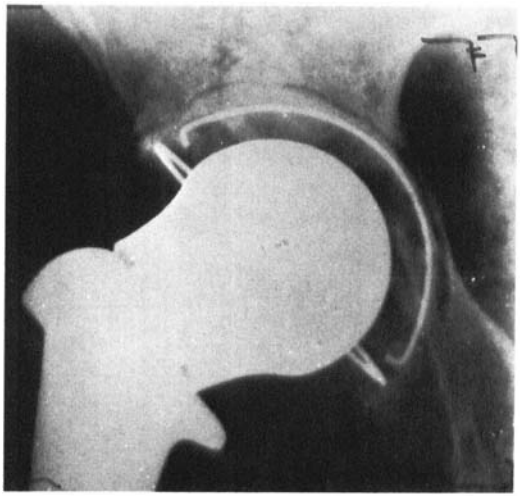

Figure 3. Christiansen total prosthesis 4 years 7 months after insertion. A 5 mm protrusion in relation to the original socket position is present.

medial or as a combination of these as seen in the A-P views. The width of the clearance was recorded.

Results

Factors related to the surgical technique

The stem was inserted in a varus position in 34 of 96 Christiansen hips, neutrally in 48 hips and in valgus in four cases, compared with 4, 10 and 9 Charnley prostheses, respectively ($P<0.001$). No stem fractures were experienced.

The amount of cement around the femoral component was fully adequate in 36 Christiansen hips and in 16 Charnley cases; the cementing was of sufficient length but not width in 48 and six hips; and the cementing was inadequate in length and width in 12 hips and one hip, respectively ($P < 0.01$).

Coverage of the socket under the pelvic roof was sufficient in 79 of the Christiansen hips and in 22 Charnley hips ($P < 0.10$). Six of the Christiansen sockets and two of the Charnley acetabular components had too steep a lateral outlet (>60°), which resulted in dislocation and early reoperation in three and one case, respectively.

Femoral stem loosening

Although no statistically significant differences were observed in the frequencies of femoral stem loosening between the groups at the end of follow-up, the frequencies of fracture of the cement and migration medially and axially (definite signs of loosening) were higher for the Christiansen than the Charnley hips (Table 1). A radiolucent zone in the cement-bone interface was present more often in the

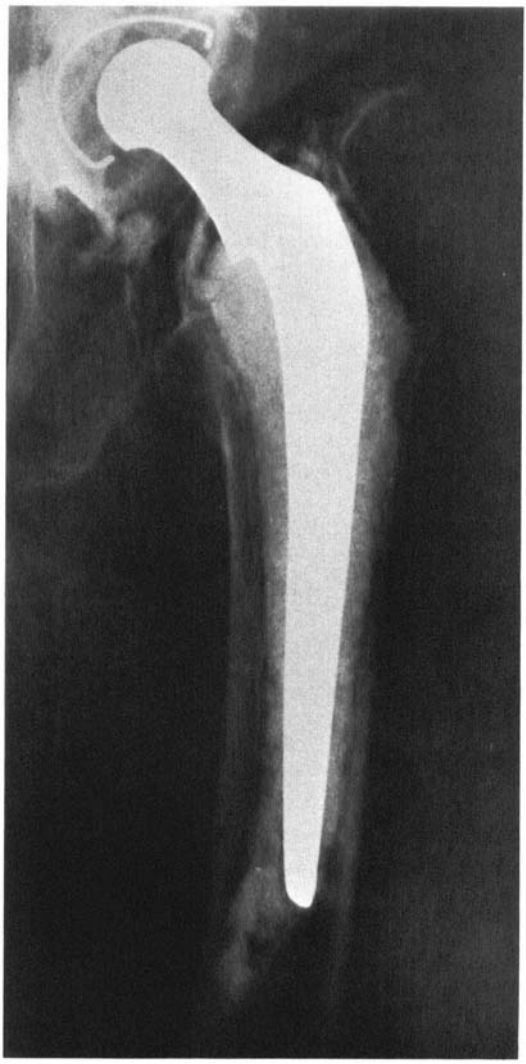

Figure 4. Charnley total hip replacement in a 7 year 9 month follow-up. An upper lateral and a medial radiolucent zone is present in the cement bone interface. The distance between the sclerotic bone line and the edge of the cement shadow was used to measure the width of the radiolucent zone.

Christiansen than in the Charnley subseries.

Some of the radiographic changes (suggestive signs) occurred with such a high frequency that they could not directly indicate clinically important loosening. Thus, radiolucent zones were present in a double frequency compared with all modes of loosening combined (Table 1). Resorption of the calcar femorale occurred with a very high frequency in the Christiansen hips where it was more common than in the Charnley hips. Cortical reactions were sporadic. The "suggestive" changes had significant associations with the "definite" loosening criteria in the series as a whole: resorption of the calcar-axial migration ($P < 0.05$), and the radiolucent zones in the cement-bone interface migration ($P < 0.001$). The definite criteria – cement fracture, medial and axial migration – showed highly significant mutual associations ($P < 0.001$).

Among the factors related to the surgical technique, the position of the stem and the adequacy of the cementing were associated with the radiographic signs of loosening. Thus, a varus position was associated with calcar resorption ($P < 0.001$) and lateral radiolucency in the cement bone interface ($P < 0.05$). An inadequate amount of cement was associated with cement fracture ($P < 0.02$), cortical bone reactions ($P < 0.05$), varus migration ($P < 0.05$), and most strongly with axial migration ($P < 0.001$).

The length of the prosthesis neck had significance for loosening, the prostheses with a long neck having a higher tendency to medial ($P < 0.01$) and axial migration ($P < 0.05$). In fact, no varus migrations occurred in Christiansen prostheses with a short or medium neck.

In the Christiansen hips, the offset of the ball centre (Figure 1) was directly associated with fracture of the cement ($P < 0.05$) and medial migration ($P < 0.05$).

Table 1. Number of hips with radiological loosening signs in the Christiansen (n = 96) and Charnley (n = 23) total hip replacements

Radiographic signs	Christiansen	Charnley	Significance level[1] of difference
Femoral component			
Fracture of cement	18	4	n.s.
Medial migration	12	1	n.s.
Axial migration	15	1	n.s.
Total of the modes of loosening[2]	28	5	n.s.
Radiolucent zones at cement bone interface	62	9	0.05
Broad radiolucencies (>3 mm)	14	1	n.s.
Calcar resorption	83	8	0.001
Cortical reactions	8	1	n.s.
Acetabular component			
Protrusion	6	0	n.s.
Radiolucent zones at cement bone interface[3]	73	11	0.01
Broad radiolucencies (>1.5 mm)	51	1	0.001

1. X^2 test, levels of significance used: n.s. = non-significant.
2. Various combinations of cement fracture and migrations were present.
3. Radiolucent zones present in the primary postoperative radiographs (23 per cent) had no relation to the appearance of later radiolucencies and are not included in these figures.

Acetabular component loosening

A cranio-medial protrusion of the acetabular component, was present in six Christiansen cases (combined with tilting in three cases), no protrusions or tiltings of the socket being observed in the Charnley subseries (n.s.). The frequency of post-primary progressive radiolucencies in the cement-bone interface was 73/96 in the Christiansen and 11/23 in the Charnley group ($P < 0.01$) (Table 1). Broad radiolucencies (> 1.5 mm) occurred more often in the Christiansen hips ($P < 0.001$). A significant association was found between broad radiolucent lines and protrusion ($P < 0.01$).

Clinical results

The clinical results in the two subseries are given in Table 2. The total Harris' hip score for Christiansen hips was 74 ± 18 and for Charnley hips 88 ± 11 ($P < 0.001$).

Time dependence was demonstrated for pain, which was more often present ($P < 0.01$) in patients with the Christiansen prosthesis when the observation time exceeded 60

Table 2. Clinical results after Christiansen and Charnley total hip replacement as expressed by Harris' (1969) hip score values

	Score values[1]		
	Christiansen hips	Charnley hips	P[2]
Daily activities	7.49±3.35	8.91±3.08	n.s.
Limp	6.89±3.24	9.14±2.85	0.005
Use of walking aid	6.82±3.40	8.92±2.97	0.005
Walking distance	7.37±3.13	8.78±3.03	0.05
Pain	36.00±8.97	39.83±7.29	0.05
Range of motion	4.46±0.83	4.79±0.41	0.01
Deformity	3.88±0.70	3.83±0.82	n.s.
Harris hip score	74.4±18.1	87.5±11.4	0.001

1. Mean ± standard deviation.
2. Probability level in two-tailed *t*-test. n.s. = non-significant ($P \geq 0.05$).

months; otherwise, the type of prosthesis was the only variable which affected the Harris' score.

Nineteen late reoperations for loosening were performed in the Christiansen and two in the Charnley subseries.

Discussion

When comparing the long-term clinical results of Christiansen and Charnley total hip replacement, we observed great differences in favour of the latter. Although the numbers of patients in our Christiansen and Charnley subseries were different, we found the two groups equal concerning the indications for replacement, the ages of patients and the length of follow-up. Certain differences in the surgical technical result were apparently due to differences in the design of the prosthesis and the operation technique. Thus, insertion of the stem in a varus position was more common in the Christiansen than in the Charnley group. Varus position has previously been found to predispose to loosening (Beckenbaugh & Ilstrup 1978, Willert et al. 1980).

The cementing results of the Christiansen stems were also less favourable. Other authors have reported an association between inadequate cementing and stem loosening (Beckenbaugh & Ilstrup 1978, Carlsson & Gentz 1980, Willert et al. 1980). We observed that, to give maximal protection against loosening, the cement mantle has not only to cover the total length of the prosthetic stem but also to extend from cortical wall to cortical wall of the medullary canal.

An increased offset due to a long neck of the femoral component apparently has an adverse effect. In fact, the Christiansen prostheses with a long neck had a greater tendency toward medial migration than the heads with medium or short necks in our series. Similar observations have been made by Willert et al. (1980) concerning different designs of Müller total hip prostheses. When calculating a total offset as a sum of the structural offset of the Christiansen prosthesis and the offset resulting from the position of the stem, we could substantiate this theory further, demonstrating increased frequency of cement fractures and medial migration with increased total offset due to long neck and varus position.

The frequencies of all modes of distinct loosening – cement fracture, stem migration and socket protusion – were greater in the Christiansen subseries. Radiolucent zones, indicative of a fibrous, reactive tissue layer between the bone and cement, were significantly more frequently present in the Christiansen total hips around both the femoral and acetabular component.

In addition to the separate femoral and acetabular factors explaining component loosening, we noticed in a recent analysis several acetabulo-femoral interactions of the loosening factors (Alho et al., unpublished data). Such observations lead to the conclusion that the prosthesis design plays an important role in loosening. Christiansen introduced the trunnion-bearing joint to unload the acetabulo-femoral ball joint itself and to reduce friction in the system. However, when revising loosened prostheses, we often found the trunnion joint jammed, which indicates that the major part of the movement does, after all, occur in the ball joint with a diameter of 37 mm. The finding by Wilson & Scales (1970) of the development of frictional torque values of such magnitude as to disrupt the bonds at the cement-bone interface is relevant in this connection.

Documentation of the multitude of problems associated with the use of the Christiansen hip prosthesis system is increasing (Nue Møller 1983, Sudmann et al. 1983). Obviously, this is one of the designs that should not be used.

We conclude that both surgical factors and factors related to the prosthesis design explain the better results in the Charnley hips. It is possible that by refining the surgical technique, the results of Christiansen total hip replacement could have been improved.

However, we feel that the design of the Charnley arthroplasty is more favourable. The stem, which is slenderer but still strong enough, allows a sufficient cement mantle around it on all sides. Also, the offset of the ball joint centre in relation to the stem is smaller in the Charnley stem, corresponding to the shortest neck of the Christiansen femoral head component. The low frictional torque of the small head may be a central factor in reducing the loosening stresses.

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