The Outcome of Charnley Total Hip Arthroplasty with Cement after a Minimum Twenty-Year Follow-up

The Results of One Surgeon*

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ABSTRACT: We evaluated the results of 330 total hip arthroplasties that were performed with use of the Charnley prosthesis and cement in 262 patients by the senior one of us between July 1970 and April 1972. All hips had been thoroughly assessed preoperatively to document the patient's functional level. All patients had been disabled because of pain in the hip or a fracture of the hip, and 212 patients (81 per cent) had used walking aids.

At a minimum of twenty years after the index operation, eighty-three patients (ninety-eight hips) were still living, 174 patients (224 hips) had died, and five patients (eight hips) had been lost to follow-up. The outcome of the arthroplasty was determined for all except the five latter patients. Thus, the outcome of 322 (98 per cent) of the 330 arthroplasties was known at the latest follow-up evaluation. Radiographs were available for sixty-three of the eighty-three patients (seventy-six [78 per cent] of the ninety-eight hips) who were alive for the entire follow-up period.

Of the ninety-eight hips in the living patients, eighty-three (85 per cent) caused no pain, fourteen (14 per cent) caused mild pain, and one (1 per cent) caused moderate pain. Fifty-two hips (53 per cent) were in patients who did not use walking aids, and only seven (7 per cent) were in patients who used support for walking because of the hip.

At the minimum twenty-year follow-up, thirty-two (10 per cent) of the 322 hips that had been followed had been revised: eight (2 per cent), because of loosening with infection; twenty-one (7 per cent), because of aseptic loosening; and three (1 per cent), because of dislocation. Of the ninety-eight hips of the patients who were still alive, fifteen (15 per cent) had been revised: three (3 per cent), because of loosening with infection; eleven (11 per cent), because of aseptic loosening; and one (1 per cent), because of dislocation. The rate of revision due to aseptic loosening of the acetabular component in all 322 hips was 6 per cent (eighteen hips), while in the ninety-eight hips of the patients who were alive at least twenty years after the arthroplasty, it was 10 per cent (ten hips). The rate of revision because of aseptic loosening of the femoral component in all 322 hips was 2 per cent (eight hips), while in the ninety-eight hips of the living patients, it was 3 per cent (three hips).

When the rates of radiographic loosening (definite or probable) and aseptic loosening confirmed at revision are combined, forty-three (13 per cent) of all 322 acetabular components and twenty-two (22 per cent) of the ninety-eight acetabular components in the patients who survived at least twenty years had loosened, while twenty (6 per cent) of all 322 femoral components and seven (7 per cent) of the ninety-eight femoral components had loosened.

Of the 322 hips for which the outcome was known after a minimum follow-up of twenty years, 291 (90 per cent) had retained the original implant until the patient died or until the most recent follow-up examination. Of the ninety-eight hips of patients who lived for at least twenty years, eighty-three (85 per cent) had retained the original prosthesis.

Analysis of the long-term results of any operative procedure is important for the establishment of the outcome of the procedure. This outcome then serves as a basis for comparison of the results of newer procedures and of non-operative treatment. Although total hip arthroplasty with cement has been performed for more than twenty years in the United States, there have been no reports, to our knowledge, on patients who have been followed for a minimum of twenty years. Because the rates of survival of the implants and the outcomes

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associated with the various designs and procedures for total hip arthroplasty have changed over time, the long-term follow-up of a series of patients is important to determine the durability and function of the implants over time.

In the current study, a series of patients in whom a Charnley total hip arthroplasty with cement had been performed by the senior one of us (R. C. J.) were followed for a minimum of twenty years. The purpose of the study was to establish the long-term durability of total hip replacement with cement, performed by one surgeon who had used a mechanically sound prosthetic design and a hand-packing technique for application of the cement. We believe that our data provide a basis for comparison of the outcomes of newer devices and techniques for total hip reconstruction, performed both with and without cement.

Materials and Methods

Between July 1970 and April 1972, 262 patients had 330 total hip replacements, performed by the senior one of us (R. C. J.), at the Iowa Methodist Medical Center in Des Moines, Iowa. There were 128 men (159 hips) and 134 women (171 hips) in the series. The average age of the patients at the time of the index arthroplasty was sixty-five years (range, twenty-nine to eighty-six years); for the eighty-three patients who were alive at least twenty years postoperatively, the average age at the time of the index arthroplasty was fifty-nine years. The preoperative diagnosis was osteoarthritis in 245 (74 per cent) of the 330 hips, rheumatoid arthritis in fifteen (5 per cent), degenerative osteoarthritis secondary to congenital dysplasia of the hip in twenty-one (6 per cent), traumatic osteoarthritis in twenty-five (8 per cent), slipped capital femoral epiphysis in seven (2 per cent), osteonecrosis in four (1 per cent), Legg-Calvé-Perthes disease in one (less than 1 per cent), ankylosing spondylitis in three (1 per cent), acromegaly in three (1 per cent), juvenile Otto pelvis in four (1 per cent), and osteoarthritis with infection in childhood in two (1 per cent). The arthroplasties were equally distributed between the left and right hips (165 each).

A Charnley hip prosthesis was used in all patients. A stainless-steel polished stem with a 22.25-millimeter-diameter head (Chas. F. Thackery, Leeds, England, or Zimmer, Warsaw, Indiana) and an acetabular component, made of ultra-high molecular weight polyethylene, with an outer diameter of either forty or forty-four millimeters, were inserted with use of Simplex P cement (Northill Plastics, Great Britain, or Howmedica, Rutherford, New Jersey).

All operations were performed with use of a lateral approach through an osteotomy of the greater trochanter. Complete capsulectomy was done routinely. The acetabular component was placed as far medially and inferiorly as possible. All loose cancellous bone was removed from the proximal part of the femur, and the cement was hand-packed, in the doughy phase, into the acetabulum and the femoral canal independently. The trochanter was reattached as far laterally as possible. All of the operations were performed in a standard (1950-vintage) operating room. Neither systemic antibiotics nor a body-exhaust system was used.

Postoperatively, the involved extremity was placed in balanced suspension for four to seven days. The patients were subsequently taught to walk with crutches, which they did for six weeks after discharge. They used a cane for an additional two to six months, until they could walk well without support.

All patients had been thoroughly evaluated preoperatively, with documentation of pain, gait, activity level, range of motion of the hip, and ability to perform activities of daily living. Most patients were followed at regular intervals; the short-term and ten-year results for this series have been reported previously.15,16

Sixty-eight hips (21 per cent) had been operated on before the initial arthroplasty; eight of these hips had had more than one previous procedure. A cup arthroplasty had been performed in thirty-two hips; an endoprosthesis had been inserted without cement in twenty; an osteotomy had been performed in six; fixation of a fracture had been done in fifteen; and one hip each had had insertion of a Pemister bone graft for treatment of osteonecrosis, irrigation and débridement for treatment of infection in childhood, and a hip arthrodesis for treatment of osteoarthritis with infection.

Attempts were made to interview all 262 patients who had composed the initial series or to contact their families. The surviving patients were asked to return for clinical and radiographic evaluation. Those who were unable to return were asked to have radiographs made locally and then sent to us for evaluation. All of the living patients were either evaluated clinically or interviewed by telephone by us, with use of the standard system of terminology for the reporting of results that was described by Johnston et al.17 Members of the families of the patients who had died were interviewed to determine the function of the hip at the time of death. For 237 patients (292 hips), a complete functional assessment was possible, through either a personal interview or an interview with a family member; for the twenty remaining patients, only the status of the hip with regard to whether or not it had been revised was known.

At the time of the latest follow-up evaluation, eighty-three patients (ninety-eight hips) were still alive and 174 patients (224 hips) had died. Five patients (eight hips) had been lost to follow-up. Thus, the status of 322 (98 per cent) of the original 330 hips was known at the most recent follow-up examination. Of the eighty-three patients who were alive, sixty-three (seventy-six hips [78 per cent of the ninety-eight hips]) were evaluated clinically and with use of an anteroposterior radiograph of the pelvis that included the tip of the femoral stem, made...
a minimum of twenty years after the index arthroplasty. Twenty-five of these patients (twenty-nine hips) returned for examination and thirty-eight patients (forty-seven hips) sent radiographs that had been made elsewhere. The twenty remaining patients (twenty-two hips) refused to have follow-up radiographs made and were evaluated on the basis of a telephone interview only. For these twenty patients, the most recent radiographs had been made at a minimum of ten years for fourteen hips and at a minimum of five years for four hips. Of the 174 patients who were known to have died, the average interval from the index operation to death was eleven years and the average interval from the index operation to the time that the most recent radiographs were made was eight years.

Radiographic Evaluation

Observations and measurements were based on anteroposterior radiographs of the pelvis that had been made early postoperatively and at the latest follow-up evaluation for all patients. In addition, interval radiographs were used to determine the time that various radiographic changes had occurred. Correction for magnification was made with use of a template with measured concentric circles, and the known diameter of the femoral head of the implant was compared with that measured on the radiograph.

Loosening of the femoral component was classified according to the criteria of Harris et al. Definite loosening was defined as subsidence of the femoral component, fracture of the cement or stem, or the presence of a radiolucent line that had not been seen on the immediate postoperative radiograph at the interface between the stem of the prosthesis and the cement. (The third criterion was modified to apply to any lucency between the stem of the prosthesis and the cement of more than one millimeter.) Probable loosening was defined as the presence of a continuous lucency along the entire bone-cement interface. Possible loosening was defined as a radiolucent line at the bone-cement interface that encompassed more than 50 but less than 100 per cent of the circumference of the stem on at least one radiograph.

Subsidence of the femoral component was determined with use of the method of Loudon and Charnley. A vertical line, drawn through two measured mid-points on the distal (straight) part of the stem, defined the central axis of the stem. Lines were then drawn perpendicular to this line, at the distal tip of the stem and at the point where the trochanteric wire passed through the lateral cortex of the femur. The distance between these two lines was measured on the initial postoperative radiograph and on the radiograph that was made at the latest follow-up evaluation. Subsidence was defined as a difference in measurement (taking into account magnification) of more than five millimeters when the two radiographs were compared, fracture of the cement, or the presence of a superolateral lucency of more than one millimeter at the cement-prosthesis interface.

Migration of the acetabular component was evaluated with use of the criteria of Massin et al. On each radiograph, the vertical distance between the center of the cup and the line joining the two teardrops was measured. The horizontal distance between the center of the cup and a vertical line through the teardrop also was measured. If these distances varied more than five millimeters between the radiograph that had been made immediately postoperatively and that made at the latest follow-up evaluation, or if any new crack was detected in the cement mantle around the prosthesis, the acetabular component was considered to have migrated. Definite loosening of the acetabular component was defined as migration of the component or the presence of any new fracture in the cement mantle; probable loosening, as a circumferential lucency around 100 per cent of the component at the bone-cement interface; and possible loosening, as a radiolucent around 50 to 99 per cent of the component at the bone-cement interface.

The wear rate of the acetabular component was determined with use of the technique described by Livermore et al. The linear wear rate was determined by measurement of the width of the acetabular cup along a line connecting the center of the femoral head to the acetabular cup-cement interface at its shortest distance. This measurement was made on the latest follow-up radiograph and then compared with the width, measured at the same location, on the initial postoperative radiograph. The radiographic measurements were made with use of a caliper, to an accuracy of 0.025 millimeter. The difference between the measured values determined the distance of linear migration of the femoral head, taking into account the differences in magnification between the two radiographs.

Any bone loss in the periacetabular region that appeared cystic was recorded, as was any localized loss of the endosteal cortex of the femur. The position of the stem (varus, valgus, or neutral) was measured on each radiograph, by extension of the previously described line along the central axis of the stem distally and by determination of whether this line was parallel (neutral), divergent (valgus), or convergent (varus) in relation to a line drawn along the endosteal lateral cortex distally. Heterotopic bone, when present, was graded according to the classification of Brooker et al.

The clinical and radiographic findings were analyzed with use of a chi-square test with the Yates correction when both variables were categorical and with use of a one-way analysis of variance and a two-tailed Student t test when one variable was continuous. Multivariate regression analysis also was performed. Kaplan-Meier survivorship curves, with corresponding confidence intervals, were calculated with failure defined according to these six end-points: revision or resection of all or
part of the original prosthesis; aseptic loosening of either or both components necessitating revision; aseptic loosening of the acetabular component necessitating revision; aseptic loosening of the femoral component necessitating revision; radiographic evidence of definite or probable loosening, or aseptic loosening of the acetabular component necessitating revision; and radiographic evidence of definite or probable loosening, or aseptic loosening of the femoral component necessitating revision. 

Radiolucent lines between the cement and bone, as seen on the anteroposterior radiograph, were recorded on the basis of the three acetabular zones described by DeLee and Charnley and the seven femoral zones delineated by Gruen et al. 

**Results**

**Clinical Results**

At the minimum twenty-year follow-up evaluation, the average age of the eighty-three patients who were still alive was eighty years (range, fifty-six to ninety-eight years). For the 174 patients who had died, the average age at the time of death had been seventy-nine years (range, thirty to 104 years). Twenty-four patients had died in the first five years after the index arthroplasty; forty-six, between five and ten years; sixty, between ten and fifteen years; and forty-four, between fifteen and twenty years.

A deep infection had developed in eight (2 per cent) of the 322 hips for which the outcome was known at the latest follow-up evaluation and in three (3 per cent) of the ninety-eight hips in the patients who were still alive. Fourteen (4 per cent) of the 322 hips and five (5 per cent) of the ninety-eight hips had dislocated at the time of the latest follow-up. The trochanteric wire had been removed because of trochanteric bursitis in twenty-one (7 per cent) of the 322 hips and in eight (8 per cent) of the ninety-eight hips.

Before the index arthroplasty, ten (3 per cent) of the total group of 330 hips had not been painful; three (1 per cent) had caused mild pain; fifty-three (16 per cent), moderate pain; and 264 (80 per cent), severe pain. All patients had excellent relief of the pain after the total hip replacement, and this was maintained during the course of follow-up. Of the ninety-eight hips in the patients who were still alive at least twenty years after the index arthroplasty, eighty-four (86 per cent) caused no pain and fourteen (14 per cent) caused only slight, occasional pain. Only one patient had moderate pain, which caused her to modify her activities. No patient had severe pain that caused major limitation in activities of daily living. With regard to the 322 hips for which the outcome was known, no pain was reported for 274 (85 per cent); mild pain, for forty-six (14 per cent); and severe pain, for two (1 per cent).

Preoperatively, none of the 262 patients in the entire series had performed strenuous manual labor, thirty-one (12 per cent) had engaged in moderately strenuous labor, 181 (69 per cent) had done light labor, and fifty (19 per cent) had been only minimally active. Of the eighty-three patients who were alive at least twenty years after the index arthroplasty, forty-one (49 per cent) performed at least light labor on a regular basis and only four were bedridden at the time of follow-up. Of the 237 patients for whom there was a functional assessment, 109 (46 per cent) were able to perform at least light labor on a regular basis and only nineteen (8 per cent) were bedridden at the time of death or of the latest follow-up evaluation (Table 1).

Before the index arthroplasty, fifty (19 per cent) of the 262 patients had been able to walk without support, 123 (47 per cent) had used a cane, and eighty-nine (34 per cent) had used crutches. Of the 255 patients who were evaluated one to two years postoperatively, 196 (77 per cent) were able to walk without support, fifty-four (21 per cent) used a cane, and five (2 per cent) used crutches. There was some increase with regard to the use of support for walking by the time of the minimum twenty-year follow-up evaluation. Of the eighty-three patients who were still alive, forty-three (52 per cent) were able to walk without aids, sixteen (19 per cent) used a cane part-time, and twenty (24 per cent) used aids full-time. Four patients (5 per cent) were unable to walk. Of the forty patients who used walking aids or could not walk, only seven (18 per cent) could not walk without support, or at all, because of the involved hip: the remaining thirty-three (82 per cent) had the problem with regard to walking because of involvement of another joint or because of systemic illness. Of the 237 patients from whom a complete clinical history was obtained at the time of the latest follow-up, 106 (45 per cent) used no support for walking, thirty-eight (16 per cent) used a cane part-time, seventy-five (32 per cent) used walking aids full-time, and eighteen (8 per cent) were unable to walk.

Of the eighty-three patients who were still alive at the latest follow-up evaluation, fifty (60 per cent) were able to walk without limitations; four (5 per cent) could walk for thirty to sixty minutes; eleven (13 per cent), for ten to thirty minutes; eleven (13 per cent), for two to ten

<table>
<thead>
<tr>
<th>Activity Level</th>
<th>All Patients* (N = 237) (Per cent)</th>
<th>Patients Alive at Least 20 Yrs. after Index Op. (N = 83) (Per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strenuous manual labor</td>
<td>1 (2)</td>
<td>2</td>
</tr>
<tr>
<td>Moderately strenuous manual labor</td>
<td>6 (12)</td>
<td>12</td>
</tr>
<tr>
<td>Light manual labor</td>
<td>39 (35)</td>
<td>35</td>
</tr>
<tr>
<td>Semi-sedentary</td>
<td>33 (35)</td>
<td>35</td>
</tr>
<tr>
<td>Sedentary</td>
<td>14 (12)</td>
<td>12</td>
</tr>
<tr>
<td>Bedridden</td>
<td>8 (5)</td>
<td>5</td>
</tr>
</tbody>
</table>

*At the time of death or of the latest follow-up.
THE OUTCOME OF CHARNLEY TOTAL HIP ARTHROPLASTY WITH CEMENT

Figs. 1-A through 1-F: Graphs showing survivorship curves (solid line), with 95 per cent confidence levels (dotted lines), for six different end-points.

Fig. 1-A: The probability of retention of the original prosthesis, with revision or resection of all or part of the prosthesis as the end-point.

The probability of retention of the original prosthesis, with aseptic loosening of one or both components confirmed at revision as the end-point.
The probability of retention of the original prosthesis, with aseptic loosening of the acetabular component confirmed at revision as the end-point.

The probability of retention of the original prosthesis, with aseptic loosening of the femoral component confirmed at revision as the end-point.
The probability of retention of the original prosthesis. The end-point was radiographic evidence of definite or probable loosening of the acetabular component, or aseptic loosening confirmed at revision.

The probability of retention of the original prosthesis. The end-point was radiographic evidence of definite or probable loosening of the femoral component, or aseptic loosening confirmed at revision.
minutes; three (4 per cent), for less than two minutes; and four (5 per cent) were unable to walk at all. Of the 237 patients for whom a complete history was obtained, 125 (53 per cent) were able to walk without limitations; nine (4 per cent), for thirty to sixty minutes; thirty-six (15 per cent), for ten to thirty minutes; thirty-one (13 per cent), for two to ten minutes; eighteen (8 per cent), for less than two minutes; and eighteen (8 per cent) were unable to walk at all.

Of the eighty-three patients who survived at least twenty years, seventy (84 per cent) were able to maintain their own home, five (6 per cent) lived in their own home with assistance, and eight (10 per cent) needed someone to care for them full-time.

In the group that survived at least twenty years, the result of the total arthroplasty in ninety-four (96 per cent) of the ninety-eight hips was considered satisfactory by the patient. One patient who had had a bilateral total hip arthroplasty was dissatisfied because of recurrent bilateral dislocations that had begun ten years postoperatively. Another patient who had had the procedure bilaterally was completed satisfied with the result in one hip but dissatisfied with the result in the other hip because the hip caused constant, moderate pain. The third patient was dissatisfied because of a limb-length inequality of two centimeters. Of the 292 hips for which all clinical information was available, satisfaction with the result of the arthroplasty was reported for 283 (97 per cent).

Radiographic Results

Radiographs were made, at the minimum twenty-year follow-up evaluation, for seventy-six (78 per cent) of the ninety-eight hips in the patients who were still alive. For the other twenty-two hips, radiographs had been made at least ten years (fourteen hips) or five years (four hips) after the arthroplasty, or early postoperatively (four hips). The mean interval between the index arthroplasty and the time that the most recent radiographs were made was nineteen years for the patients who were alive at least twenty years postoperatively. No radiographs that had been made at a reasonably long follow-up interval (minimum, five years) were available for thirty-three of the 330 hips in the entire series. The mean interval between the index arthroplasty and the time that the most recent radiographs were made was eleven years.

Acetabular wear was measured in the seventy-six hips that had been followed radiographically for at least twenty years. The mean amount of linear wear was 0.074 millimeter (range, 0.00 to 0.213 millimeter) per year. As determined with a Student t test, the rate of acetabular wear correlated with the prevalence of revision done because of aseptic loosening (p = 0.006) and with lysis

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Fig. 2-A

Figs. 2-A, 2-B, and 2-C: Radiographs of a man who had bilateral Charnley total hip arthroplasty because of primary osteoarthrosis when he was sixty-three years old. He performed strenuous manual labor for five years after the operation.
Fig. 2-A: Early postoperative radiograph.
Fig. 2-B: Radiograph of the right hip, made three years postoperatively, shows lucency superolaterally, at the interface between the femoral component and the cement.

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of the femur in zone 7° (p = 0.009), and it approached a significant correlation with loosening of the acetabular component (p = 0.107). There was no correlation between acetabular wear and loosening of the femoral component (p = 0.681).

Of the ninety-four hips in the patients who had survived for at least twenty years and who had been followed radiographically for at least five years, fifty-one (54 per cent) had femoral osteolysis in zone 7° (the calcar area). Femoral osteolysis was uncommon (three hips [3 per cent]) in zones 1 through 6. There was no correlation between femoral osteolysis and aseptic loosening that led to revision (chi-square test with Yates correction, p = 0.765). Osteolysis of the acetabulum was also uncommon (three hips [3 per cent]); however, it did correlate with aseptic loosening that led to revision (chi-square test with Yates correction, p = 0.012). The prevalence of radiolucent lines (of any thickness) at the prosthesis-cement interface in zone 1 of the femoral component was 38 per cent (thirty-six of ninety-four hips).

As mentioned, radiographic loosening was determined according to the modified criteria of Harris et al.¹¹, which included revision of a component because of aseptic loosening. In the ninety-four hips in the patients who had survived at least twenty years after the index arthroplasty and had been followed radiographically for at least five years, there was definite radiographic loosening of seventeen acetabular components (18 per cent) and seven femoral components (7 per cent); probable loosening of four acetabular components (4 per cent) and seven femoral components (7 per cent); and possible loosening of three acetabular components (3 per cent) and one femoral component (1 per cent). Considering all 297 hips that had long-term radiographic follow-up, definite loosening had occurred in twenty-five (8 per cent) of the acetabular components and sixteen (5 per cent) of the femoral components; probable loosening, in twelve (4 per cent) of the acetabular components and one (less than 1 per cent) of the femoral components; and possible loosening, in forty-five (15 per cent) of the acetabular components and four (1 per cent) of the femoral components.

The combined prevalence of definite or probable radiographic loosening of the femoral component, according to the modified criteria of Harris et al., and of aseptic loosening of the femoral component necessitating revision was 7 per cent (twenty of the 297 hips that had had adequate radiographic follow-up) and 7 per cent (seven of ninety-four hips in the patients who were alive at least twenty years after the index arthroplasty and had had adequate radiographic follow-up). The combined prevalence of definite or probable radiographic loosening of the acetabular component, as defined by Harris et al., and of aseptic loosening of the acetabular component necessitating revision was 14 per cent (forty-three) for the larger group of hips and 23 per cent (twenty-two) of the hips in patients who were alive at least twenty years after the index arthroplasty (Table II).

**Fig. 2-C**

At the latest follow-up visit (at least twenty years postoperatively), the radiolucency was seen to have progressed. The prosthesis was considered loose according to radiographic criteria. The patient walked without limitations, had no pain or limp, and did not use assistive devices. Flexion of the hip ranged from 0 to 130 degrees, with 40 degrees of internal rotation, 40 degrees of external rotation, 40 degrees of abduction, and 30 degrees of adduction.

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**TABLE II**

**COMBINED PREVALENCE OF ASEPTIC LOOSENING**

<table>
<thead>
<tr>
<th>Determinant of Loosening</th>
<th>All Hips* (N = 319)</th>
<th>Hips in Patients Alive at Least 20 Yrs. after Index Op. (N = 94)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetabular component</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revision</td>
<td>18 (6%)</td>
<td>10 (11%)</td>
</tr>
<tr>
<td>Radiographic criteria</td>
<td>25 (8%)</td>
<td>12 (13%)</td>
</tr>
<tr>
<td>Total</td>
<td>43 (13%)</td>
<td>22 (23%)</td>
</tr>
<tr>
<td>Femoral component</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revision</td>
<td>8 (3%)</td>
<td>3 (3%)</td>
</tr>
<tr>
<td>Radiographic criteria</td>
<td>12 (4%)</td>
<td>4 (4%)</td>
</tr>
<tr>
<td>Total</td>
<td>20 (6%)</td>
<td>7 (7%)</td>
</tr>
</tbody>
</table>

*At the time of death or of the latest follow-up. Eight of the original 330 hips were lost to follow-up and three were revised for dislocation, leaving 319 hips.
Heterotopic ossification was present in 121 (41 per cent) of the 297 hips. According to the criteria of Brooker et al., the ossification was grade 1 in seventy-five hips (25 per cent), grade 2 in twenty-three (8 per cent), grade 3 in twenty (7 per cent), and grade 4 in three (1 per cent).

Revision of the Original Prosthesis

Of the initial group of 322 hips, thirty-one (10 per cent) had had a revision or resection arthroplasty at the time of the latest follow-up. The revision or Girdlestone procedure had been performed because of aseptic loosening in twenty-one hips (7 per cent), loosening with infection in eight hips (2 per cent), and dislocation in three hips (1 per cent). (One patient had had a revision of only the acetabular component because of recurrent dislocations, two years after the index operation. Only the femoral component was revised, because of a fracture of the stem, at a second revision four years later. Only two fractures of the stem occurred in the entire series. For statistical purposes, the data for this patient were entered as one revision in the categories of both aseptic loosening and revision for dislocation. This accounts for the total number of thirty-one rather than thirty-two revisions.) Of the ninety-eight hips in the patients who survived at least twenty years after the index operation, eleven (11 per cent) had had a revision because of aseptic loosening; three (3 per cent), because of loosening with infection; and one (1 per cent), because of dislocation — a total rate of revision of 15 per cent (Table III).

All eight infections occurred early (less than five years) postoperatively, except for one that occurred approximately seven years after the index procedure and one that developed at twelve years. The average interval between the index arthroplasty and the revision that was done because of aseptic loosening was fourteen years (range, ten to twenty-one years) for the acetabular components and fourteen years (range, seven to eighteen years) for the femoral components.

Of the eight hips that had loosening with infection, six eventually were treated with a Girdlestone procedure. The two remaining hips were subsequently revised three times. The prevalence of loosening with infection did not correlate with that of previous operations on the affected hip (p = 0.414) or with the type of the previous operation (p = 0.281), according to a chi-square test with Yates correction.

The radiographs and operative notes were reviewed for each hip that had been revised because of aseptic loosening, to determine whether the cause of failure had been loosening of the acetabular or the femoral component, or both. Of the 322 hips for which the outcome was known at the latest follow-up evaluation, thirteen (4 per cent) had been revised because of aseptic loosening of the acetabular component; three (1 per cent), because of aseptic loosening of the femoral component; and five (2 per cent), because of loosening of both components.

<p>| TABLE III |</p>
<table>
<thead>
<tr>
<th>REASONS FOR REVISION</th>
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<tbody>
<tr>
<td>Reason</td>
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<tr>
<td>Loosening with infection</td>
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<tr>
<td>Aseptic loosening</td>
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<tr>
<td>Dislocation</td>
</tr>
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<td>Total</td>
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</table>

*At the time of death or of the latest follow-up.

Of the ninety-eight hips in the patients who were still alive at least twenty years after the initial arthroplasty, eight (8 per cent) had been revised because of aseptic loosening of the acetabular component; one (1 per cent), because of aseptic loosening of the femoral component; and two (2 per cent), because of loosening of both components. Aseptic loosening that had led to revision correlated with male sex (p = 0.023), an age of less than fifty years at the time of the initial arthroplasty (p = 0.0005), and the patient's reported level of activity (p = 0.02), according to a chi-square test with Yates correction. Although the prevalence of aseptic loosening that had led to revision was higher in patients who had had a previous operation on the affected hip (9 compared with 6 per cent), this was not significant (p = 0.437, chi-square test with Yates correction). The rate of aseptic loosening (definite or probable) of the femoral component was higher in patients who had had previous insertion of an endoprosthesis without cement (p < 0.001): it occurred in five of twenty hips in which an endoprosthesis had been converted to a Charnley total hip arthroplasty. At the time of the conversion of the femoral endoprosthesis, no attempt had been made to remove the entire fibrous membrane and neocortex, although we currently do this routinely.

Survivorship Analysis

The Kaplan-Meier method was used to calculate the probability of retention of the original prosthesis from the time of the initial Charnley total hip arthroplasty to one of these six end-points: (1) revision or resection of all or part of the original prosthesis; (2) aseptic loosening of one or both components necessitating revision; (3) aseptic loosening of the acetabular component necessitating revision; (4) aseptic loosening of the femoral component necessitating revision; (5) radiographic evidence of definite or probable loosening, or aseptic loosening of the acetabular component necessitating revision; and (6) radiographic evidence of definite or probable loosening, or aseptic loosening of the femoral component necessitating revision. Survivorship curves, with 95 per cent confidence intervals, were calculated (Figs. 1-A through 1-F).

The probability of retention of the prosthesis at the latest follow-up evaluation was 80 ± 8 per cent (mean and standard deviation). The probability of retention of...
The prosthesis at the latest follow-up visit was 84 ± 8 per cent with aseptic loosening necessitating revision as the end-point, 86 ± 8 per cent with aseptic loosening of the acetabular component necessitating revision as the end-point, and 95 ± 3 per cent with aseptic loosening of the femoral component necessitating revision as the end-point. With radiographic evidence of definite or probable loosening, or aseptic loosening necessitating revision as the end-point, as the end-point, the probability was 83 ± 14 per cent for the femoral component and 43 ± 20 per cent for the acetabular component. Because of the nature of a retrospective review, patients were not examined and radiographs were not made annually; therefore, the actual rate of deterioration of the interfaces, associated with loosening of a component on radiographic analysis, was probably not as steep as depicted. However, the confidence intervals demonstrate the potential for such error. Also, the confidence intervals increase suddenly after twenty years because of the few hips followed at twenty-one and twenty-two years.

The implant was retained in 291 (90 per cent) of the 322 hips for which the outcome was known and in eighty-three (85 per cent) of the ninety-eight hips in the patients who were still alive at least twenty years after the index procedure (Table IV). Other than one patient who had a resection arthroplasty for a dislocation, only patients in whom an infection of the hip had developed had a resection arthroplasty as the most recent outcome. Other than the two hips that had an infection, only two hips had a second or third revision as the most recent outcome in this closely followed group of patients.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Hips for Which the Outcome Was Known at Latest Follow-up Visit (N = 322)</th>
<th>Hips in Patients Alive at Least 20 Yrs. after Index Op. (N = 98)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original prosthesis</td>
<td>291 (90%)</td>
<td>83 (85%)</td>
</tr>
<tr>
<td>Retained</td>
<td>20 (6%) (0.18, 2*)</td>
<td>9 (9%) (0.9, 0*)</td>
</tr>
<tr>
<td>1 revision</td>
<td>2 (1%) (0.2, 0*)</td>
<td>2 (2%) (0.2, 0*)</td>
</tr>
<tr>
<td>2 revisions</td>
<td>2 (1%) (0.2, 0*)</td>
<td>2 (2%) (2.0, 0*)</td>
</tr>
<tr>
<td>3 revisions</td>
<td>2 (1%) (0.2, 0*)</td>
<td>2 (2%) (2.0, 0*)</td>
</tr>
<tr>
<td>Resect. arthroplasty</td>
<td>7 (2%) (6.0, 1*)</td>
<td>2 (2%) (1.0, 1*)</td>
</tr>
</tbody>
</table>

*The reasons for the revisions are in parentheses (the number of hips with loosening associated with infection, the number with aseptic loosening, the number with dislocation).
Discussion

Rarely has the outcome at a minimum of twenty years been reported for a large series of patients who had a specific operation. Fortunately, with the development and extensive use of total hip replacement, a number of investigators, early on, began to critically evaluate their results applying the methodology used to determine the functional outcomes of previous hip procedures, most notably cup arthroplasty\textsuperscript{1,5,15,19,31,32}.

The senior one of us (R. C. J.) began the preoperative assessment and follow-up of the patients in the current series at the start of his practice in Des Moines,
Iowa, in July 1970; he previously reported the short-term and minimum ten-year results for these patients. We evaluated the durability, after at least twenty years of follow-up, of a single design (the Charnley prosthesis) for total hip arthroplasty. All of the operations had been performed by one of us (R. C. J.) with use of a single approach to the hip (transtrochanteric); with use of the same type of cement (Simplex P), implanted with a hand-packing technique; and without use of antibiotic prophylaxis. The Charnley total hip prostheses performed well over the long term. Of the 322 hips for which the outcome was known, only twenty-one (7 per cent) were revised because of aseptic loosening, while of the ninety-eight hips in the patients who were still alive at least twenty years after the index arthroplasty, eleven (11 per cent) were revised for that reason. In addition, 290 (90 per cent) of the 322 implants and eighty-three (85 per cent) of the ninety-eight implants were still in place, and only two patients needed a third hip replacement because of aseptic loosening (Table IV).

The excellent clinical results had also been maintained; eighty-four (86 per cent) of the ninety-eight hips caused no pain and fourteen (14 per cent), only occasional, mild pain. Although this population of patients was relatively old (average, eighty years; range, fifty-six to ninety-eight years) at the most recent follow-up evaluation, nearly one-half of them were able to perform at least light labor. Only seven patients used assistive devices because of the hip. More importantly, seventy patients (84 per cent) maintained their own home, five (6 per cent) lived at home with assistance, and only eight (10 per cent) needed someone to care for them full-time.

As demonstrated in other long-term studies, aseptic loosening of the acetabular component appears to be the major problem associated with total hip arthroplasty after ten years. In the current study, the rate of aseptic loosening of the acetabular component, regardless of whether the end-point was defined as aseptic loosening confirmed at revision or as radiographic evidence of failure, was approximately three times greater for the hips in patients who survived at least twenty years after the index arthroplasty and two times greater for all hips for which the outcome was known, compared with the rate of aseptic loosening of the femoral component (Table II). The first revision of an acetabular component because of aseptic loosening occurred nine and one-half years after the index arthroplasty. The pattern of loosening of the acetabular component, as demonstrated by the survivorship analysis (Fig. 1-C), should deter the orthopaedic surgeon from being overly enthusiastic about the encouraging results of the use of newer acetabular components and techniques for fixation of the component when the duration of follow-up is less than ten years. On the other hand, more durable fixation of the acetabular component is probably the most important area for continued investigation and refinement to ensure the durability of total hip arthroplasties after fifteen to twenty years.

Radiograph made twenty-one years after the index arthroplasty, showing no changes at the interface between the bone and cement or between the prosthesis and cement. The patient was interviewed by telephone. He stated that the hip was not painful, that he could walk without limitations or a limp, and that he used a cane only because of poor vision.
Aseptic loosening of the femoral component necessitating revision occurred in only eight (2 per cent) of the 322 hips for which the outcome was known and in only three (3 per cent) of the ninety-eight hips in patients who were alive at least twenty years after the index procedure. Even by today’s standards, the design of the Charnley prosthesis can be considered mechanically sound: no sharp edges are seen on cross section, and the rounded medial surface allows the even distribution of load from metal to cement. Although the prostheses used in our patients were made of stainless steel, the lower rate of fractures of the stem compared with those reported in other studies in which the same type of prosthesis was used can probably be attributed to the generous mantles of cement, especially proximally, that were obtained in our patients. A lucency between the prosthesis and the cement was present superolaterally in 38 per cent of the hips of the patients who survived at least twenty years, but few of these lucent lines progressed to more than one millimeter in width (Figs. 2-A, 2-B, and 2-C). There also were very few radiolucent lines at the bone-cement interface. This finding of so-called stem-debonding12,16, which refers to a lucent line between the prosthesis and the cement, is probably inherent with use of a polished stem. In reality, a bond can never occur between cement and a polished stem17. The prosthesis had to move within the cement in the patients who had debonding, but the implant continued to function well for at least twenty years, with no other evidence of loosening, such as grossly visible cracks in the cement distally, as seen on radiographs. Only long-term studies can determine whether better bonding between the cement and the prosthesis will decrease the prevalence of loosening of the femoral component. It may be argued that our results relative to the femoral component cannot be reproduced by all orthopaedic surgeons who use techniques involving hand-packing of cement; however, the newer systems for the delivery of cement — which includes filling of the femoral canal and surrounding of the entire prosthesis with cement and which is possible in most patients — should at least ensure the reproducibility of the mantles of cement that were obtained in our study11,12,28.

Relatively few cystic areas of bone lysis surrounding the prosthesis, documented as osteolysis in the orthopaedic literature22, were observed in the current study; such areas were noted around three acetabular components (3 per cent) and three femoral components (3 per cent) at the minimum twenty-year follow-up. Linear acetabular wear, as measured on radiographs, averaged 0.074 millimeter a year in the patients who were followed for at least twenty years. The low prevalence of lysis may be related to the relatively small amount of volumetric wear that has been reported with use of the twenty-two-millimeter head of the femoral prosthesis22 and the more-than-adequate thickness of the polyethylene (minimum, nine millimeters) of the acetabular component. There was a correlation between wear and bone loss in zone 7 of the femoral component and between wear and revision done because of aseptic loosening, and there was a trend (but not a significant correlation) between wear and bone loss and loosening of the acetabular component, implicating polyethylene as a major factor in the process of loosening (Figs. 3-A and 3-B).

Loosening because of infection was a major problem in our patients; it occurred in eight (2 per cent) of the 322 hips for which the outcome was known and in three (3 per cent) of the ninety-eight hips in patients who were alive at least twenty years after the index arthroplasty. Loosening with infection accounted for all of the third revisions and for all of the resection arthroplasties other than the one done in an inactive patient who had had late, recurrent dislocations. The use of a more rapid air-exchange system and of body-exhaust suits in the operating room, the administration of antibiotic prophylaxis, and the knowledge gained over the years with regard to both the diagnosis and the treatment of infection have dramatically decreased the prevalence of this complication14,20,24,30,34.

In summary, our data demonstrate the outcomes and durability achieved with use of first-generation techniques for insertion of cement in conjunction with a mechanically sound design (the Charnley prosthesis) for total hip arthroplasty, at a minimum twenty-year follow-up. Our study revealed marked improvement in, and long-term maintenance of, function for patients who have had a total hip arthroplasty (Figs. 4-A, 4-B, and 4-C). These findings should provide a basis for the comparison of improvements in outcome and durability that will be achieved with newer designs and techniques of total hip arthroplasty.

References