Charnley Total Hip Arthroplasty with Use of Improved Cementing Techniques

A Minimum Twenty-Year Follow-up Study

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Background: In total hip arthroplasty, techniques for cementing the femoral component have changed over time. The purpose of the present study was to determine whether a cementing technique that includes use of a distal cement plug and retrograde filling of the femoral canal affects the fixation of the femoral component at a minimum of twenty years after the operation.

Methods: Between 1976 and 1978, the senior one of us (R.C.J.) performed 357 total hip arthroplasties with use of a Charnley flatback polished femoral stem and a contemporary cementing technique (insertion of a distal cement plug and retrograde filling of the femoral canal with cement) in 320 patients. The results after a minimum follow-up of twenty years were compared with those after 330 total hip arthroplasties performed, between 1970 and 1972, with the same femoral stem by the same surgeon with use of a hand-packing technique of cementing in 262 patients. The clinical and radiographic evaluation as well as the duration of follow-up were identical in the two groups.

Results: In the group managed with the contemporary cementing technique, six (1.8%) of the 336 hips that had not been lost to follow-up or revised because of infection or dislocation were revised because of aseptic loosening of the femoral component. Of the ninety-one hips in the eighty-two patients who were alive at a minimum of twenty years, five (5%) had a revision because of aseptic loosening of the femoral component. Only one hip was revised during the fifteen-to-twenty-year follow-up interval. (The revision was performed because of a fracture of the femoral component.) The rate of failure when radiographic signs of loosening were included was 4.8% (sixteen of 336 femoral components that had not been revised because of infection or dislocation) for the group managed with the contemporary cementing technique compared with 6.3% (twenty of 319 hips) in the group managed with the hand-packing technique; the difference was not significant (p = 0.40). Adequate filling of the femoral canal with cement was found to be associated with improved survival of the femoral component (p = 0.03).

Conclusions: While no significant difference between the two cementing techniques could be identified, the ability to deliver adequate cement around the femoral component was more predictable with the contemporary cementing technique. In addition, the prevalence of loosening of the femoral component was low with use of either technique, a tribute to the Charnley flatback polished femoral component design.

When total hip arthroplasty is performed with cementing of the femoral component, it is important to obtain adequate circumferential filling of the femoral canal and adequate interdigitation of the cement with bone. Although these goals can be achieved with hand-packing techniques, improved methods for delivery of the cement should enable most surgeons to provide an adequate mantle of cement more consistently and reproducibly.

We evaluated the results at a minimum of twenty years after total hip arthroplasty performed with use of the Charnley prosthesis and a so-called second-generation cementing technique (use of a distal cement plug and retrograde filling of the femoral canal with cement). This series was previously reported on after a minimum duration of follow-up of fifteen years. The goal of the present study was to determine whether the newer technique of cementing provided better long-term fixation than that achieved with a hand-packing technique in another series of arthroplasties performed by the same surgeon.

Materials and Methods

Between July 1976 and June 1978, the senior one of us (R.C.J.) performed 357 total hip replacements in 320 patients (135 men [152 hips] and 185 women [205 hips]) with use of a contemporary cementing technique. The average age
of the patients at the time of the index arthroplasty was sixty-nine years (range, twenty-four to eighty-eight years). Eighty-two patients were alive at least twenty years postoperatively, and their average age at the time of the index arthroplasty was fifty-nine years (range, twenty-four to eighty-five years). The results in this group were compared with those after 330 total hip replacements performed in 262 patients with use of a hand-packing technique of cementing. The surgery in those patients was performed, between July 1970 and April 1972, by the same surgeon, with use of the same prosthesis, and the patients had a comparable duration of follow-up. The average age at the time of the index arthroplasty in that group was sixty-five years (range, twenty-nine to eighty-six years). The operative techniques for the two groups have been previously described. With the so-called contemporary femoral cementing technique, the canal was prepared by removal of all loose cancellous bone and by meticulous drying. A cement plug was placed distally, and a cement gun was used to introduce cement in a retrograde manner. No seal was placed over the proximal opening of the femoral canal to better pressurize the cement. A Charnley hip prosthesis (Zimmer, Warsaw, Indiana), consisting of a stainless-steel polished flatback femoral stem with a 22.25-mm-diameter head and an ultra-high molecular weight polyethylene acetabular component (sterilized by gamma irradiation in air) with an outer diameter of either 40 or 44 mm, was used in all patients in both groups. Both components were inserted with Simplex-P cement (Howmedica, Rutherford, New Jersey).

We attempted to interview all living patients and the families of the patients who had died. The living patients either returned for clinical and radiographic follow-up or, if they were unable to return, were asked to send radiographs (made locally) to us for evaluation. All living patients were evaluated in person or were interviewed by telephone with use of a standard system of terminology for reporting results as described by one of us (R.C.J.) and colleagues. The evaluators were not blinded to the outcome results.

At a minimum of twenty years after the operation, eighty-two patients (ninety-one hips) were still alive, 234 patients (262 hips) had died, and four patients (four hips) had been lost to follow-up. Thus, the status of 353 hips (>98% of the original 357 hips) was known. Of the eighty-two patients (ninety-one hips) who were alive, forty-five (fifty-one hips [56%]) were evaluated both clinically and with an anteroposterior radiograph of the pelvis that included the tip of the femoral stem. Thirty-three of the patients (thirty-six hips) who were alive at least twenty years postoperatively, and their average age at the time of the index arthroplasty was sixty-nine years (range, twenty-four to eighty-eight years). Eighty-nine patients (ninety-one hips) who were alive, forty-five (fifty-one hips) were evaluated with use of a standard system of terminology for reporting results as described by one of us (R.C.J.) and colleagues. The evaluators were not blinded to the outcome results.

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The prevalence of radiographic loosening without infection was determined on the basis of 336 hips (all except those that had been revised because of infection or dislocation and the four hips that were lost to follow-up). The prevalence of revision at least twenty years after the index operation was calculated on the basis of the ninety-one hips in the eighty-two living patients. The prevalence of radiographic loosening without infection at least twenty years after the index operation was calculated on the basis of the fifty-one hips for which radiographs were made at the latest follow-up visit; those that had been revised because of dislocation or infection were excluded from this analysis. The clinical follow-up data at least twenty years after the index operation were evaluated on the basis of the ninety-one hips in the eighty-two living patients. Similar calculations were made for the cohort managed with the hand-packing technique of cementing. Clinical results in both series were evaluated with use of a standard system of terminology for reporting results.

Radiographic Evaluation

Radiographic evaluation of loosening of the acetabular and femoral components and osteolysis was the same for the patients who were managed with the contemporary cementing technique and those who were managed with the hand-packing technique. One of the two observers (J.J.C.) was the same for both groups. The wear measurements for both groups were performed by the same observer (J.P.O.). The methods for all of these observations have been previously reported. The technique for the cementing of the femoral component was graded according to the criteria defined by Schmalzried and Harris.

Statistical Analysis

The Kaplan-Meier method was used to evaluate survival of the implant with regard to revision or loosening, or both. Survivorship curves with corresponding confidence intervals were generated, with failure defined according to six end points: (1) revision for any reason; (2) revision because of aseptic loosening; (3) revision because of aseptic loosening of the acetabular component; (4) revision because of aseptic loosening of the femoral component; (5) loosening of the acetabular component, defined as definite or probable radiographic loosening or revision because of aseptic loosening; and (6) loosening of the femoral component, defined as definite or probable radiographic loosening or revision because of aseptic loosening.

The clinical and radiographic results were analyzed with use of the two-tailed Fisher exact test for categorical variables. The Wilcoxon rank-sum test was used to compare rates of wear according to categorical variables, as these rates are not normally distributed. The Spearman correlation coefficient was used to analyze the association between patient age and component wear as well as that between weight and wear. The log-rank test was used to compare the survivorship curves of the group managed with the contemporary cementing technique with those of the group managed with the hand-packing technique.
Results

In the group managed with the contemporary cementing technique, the average age of the eighty-two patients who were still alive at least twenty years postoperatively was eighty-two years (range, forty-five to 106 years) at the time of follow-up. For the 234 patients who had died, the average age at the time of death was eighty-two years (range, fifty-five to 108 years). Forty-nine patients had died in the first five years after the index arthroplasty; fifty-nine, between five and ten years after the arthroplasty; eighty-one, between ten and fifteen years; and forty-five, between fifteen and twenty years.

Revision of the Original Prosthesis

Of the 353 hips that had not been lost to follow-up, thirty-nine (11.0%) had had a revision and two (<1%) had had a Girdlestone resection arthroplasty during the follow-up period. Twenty-two hips (6.2%) had been revised because of aseptic loosening of the femoral or acetabular component, or both (two hips); seven (2.0%), because of loosening with infection; and ten (2.8%), because of dislocation. The two resection arthroplasties were performed because of loosening with infection; both were done in patients who died before the time of the latest follow-up evaluation. Of the ninety-one hips in the eighty-two patients who were alive at a minimum of twenty years, twenty-one (23%) had been revised: fifteen (16%), because of aseptic loosening of the femoral or acetabular component, or both (two hips); one (1%), because of loosening with infection; and five (5%), because of dislocation. Only one hip was revised in the interval between the fifteen and twenty-year follow-up evaluations. That revision was performed because of a fracture of the femoral component.

Of the nine infections, eight developed early (less than 10 years) after the index arthroplasty, and one developed between fifteen and twenty years. One (1%) had been revised because of loosening with infection; two (2%) had been revised because of loosening with dislocation; and six (6%) had been revised because of aseptic loosening.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>Combined Prevalence of Aseptic Loosening Twenty Years After Total Hip Arthroplasty</th>
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<tbody>
<tr>
<td>Acetabular component</td>
<td>18 (5.4%)</td>
</tr>
<tr>
<td>Revision</td>
<td>14 (12%)</td>
</tr>
<tr>
<td>Radiographic evidence</td>
<td>25 (7.4%)</td>
</tr>
<tr>
<td>Total</td>
<td>43 (12.8%)</td>
</tr>
<tr>
<td>Femoral component</td>
<td>6 (1.8%)</td>
</tr>
<tr>
<td>Revision</td>
<td>3 (3%)</td>
</tr>
<tr>
<td>Radiographic evidence</td>
<td>10 (3.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>16 (4.8%)</td>
</tr>
</tbody>
</table>

*Excluding those that had been revised because of infection or dislocation and those that were lost to follow-up.

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>Most Recent Outcomes Twenty Years After Total Hip Arthroplasty</th>
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<tbody>
<tr>
<td>Outcome</td>
<td>Hips Managed with Contemporary Cementing Technique</td>
</tr>
<tr>
<td>Original prosthesis retained</td>
<td>312 (88%)</td>
</tr>
<tr>
<td>Revision*</td>
<td>31 (6, 17, 8) (8.7%)</td>
</tr>
<tr>
<td>One</td>
<td>7 (0, 5, 2) (2.0%)</td>
</tr>
<tr>
<td>Two</td>
<td>1 (1, 0, 0) (&lt;1.0%)</td>
</tr>
<tr>
<td>Three</td>
<td>2 (2, 0, 0) (&lt;1.0%)</td>
</tr>
<tr>
<td>Girdlestone resection arthroplasty*</td>
<td>2 (2, 0, 0) (&lt;1.0%)</td>
</tr>
</tbody>
</table>

*The reasons for the revision are in parentheses (the number of hips with loosening associated with infection, the number with aseptic loosening, and the number with dislocation, respectively).
five years postoperatively) and one developed ten years after the index procedure. Six of the nine hips were successfully treated with a revision. One hip needed a second revision but was stable at the fifteen-year follow-up evaluation and until the death of the patient, according to a relative. All reimplantations were performed as a one-stage procedure. The remaining two hips had a Girdlestone resection arthroplasty.

Of the 336 hips for which the outcome was known at the latest follow-up evaluation and that had not been revised because of dislocation or infection, sixteen (4.8%) had been revised because of aseptic loosening of the acetabular component; four (1.2%), because of aseptic loosening of the femoral component (three had a fracture of the stem); and two (<1%), because of loosening of both components. Of the eighty-five hips in the patients who were still alive at least twenty years after the initial arthroplasty and had not had a revision because of infection or dislocation, ten (12%) had been revised because of aseptic loosening of the acetabular component; three (4%), because of aseptic loosening of the femoral component; and two (2%), because of loosening of both components. The outcomes in both the group managed with the contemporary cementing technique and the group managed with the hand-packing technique are compared in Tables I and II.

Other Complications
Twenty-five (7.1%) of the entire series of 353 hips and nine (10%) of the ninety-one hips in the living patients (including those that had had a revision because of dislocation) had dislocated at the time of the latest follow-up evaluation. The trochanteric wires had been removed because of bursitis in twelve (3.4%) of the 353 hips and in six (7%) of the ninety-one hips.

Satisfaction
Of the ninety-one hips in the patients who survived at least twenty years after the total hip arthroplasty, eighty-seven (96%) were considered by the patient to have better function; eighty-five (93%), to be less painful; and eighty-five (93%), to have a satisfactory result. Three patients were dissatisfied because of recurrent dislocation after a revision performed because of dislocation, and one was dissatisfied because of a 3-cm limb-length discrepancy after a revision performed because of aseptic loosening. Additionally, one patient was displeased that a revision had been needed because of aseptic loosening even though, after the revision, the patient was doing well. One patient’s family could not give a reason for the dissatisfaction.

Radiographic Results
Radiographs were made at least twenty years after the index arthroplasty for fifty-one (56%) of the ninety-one hips in the patients who were still alive (Fig. 1). Seventy-four (81%) of the hips in the living patients had a radiograph made at least fifteen years after the arthroplasty. In the entire series of 353 hips, fifty-one (14.4%) had a radiograph made at least twenty years postoperatively and 116 (33%) had a radiograph made at least fifteen years postoperatively. The average interval between the index arthroplasty and the most recent radiograph was nine years in the entire series of 353 hips and 16.8 years for the ninety-one hips in the living patients. A comparison of the radiographic results with those in the group managed with the hand-packing technique is provided in Table I.

Grade of the Cementing Technique
The immediate postoperative radiographs of the hips were used to grade the cementing technique according to the criteria of Schmalzried and Harris. Of the ninety-one hips in the patients who were alive at least twenty years after the index arthroplasty, nineteen (21%) had a grade-A cement mantle; thirty-eight

Fig. 1
Radiograph of a sixty-five-year-old woman, a retired schoolteacher, who had a Charnley total hip arthroplasty performed with a contemporary cementing technique when she was forty-four years old because of osteoarthritis resulting from congenital dislocation of the hip. At the time of follow-up, she had no pain, walked without aids or a limp, and performed light labor.
Wear and Osteolysis

Wear of the acetabular component was measured in the fifty-one hips that had been followed radiographically for at least twenty years. The average amount of linear wear was 0.094 mm/yr (range, 0.00 to 0.396 mm) a year. The calculated volumetric wear was 36.5 mm³ (range, 0.00 to 155.5 mm³) a year. Revision because of aseptic loosening of the acetabular component was associated with linear wear (p = 0.044), according to the Wilcoxon rank-sum test; the average rate of wear was 0.155 mm/yr for the revised components compared with 0.078 mm a year for the stable components. With use of the Spearman correlation coefficient, we could not detect a significant difference between the rate of wear and the patient’s weight (p = 0.22) or height (p = 0.46) or the grade of cementing technique (p = 0.73).

Of the eighty-five hips in the patients who survived at least twenty years and had not had a revision because of infection or dislocation, twenty-eight (33%) had osteolysis in femoral zone VII, six (7%) had osteolysis in one or more of the other six femoral zones, and five (6%) had osteolysis on the acetabular side alone. The prevalence of radiolucent lines (of any thickness) at the prosthesis-cement interface in femoral zone 1 (so-called debonding of the femoral component) was 22% (nineteen of eighty-five hips).

Radiographic Signs of Loosening

Of the ninety-one hips in the patients who survived at least twenty years, eighty-five were not revised because of deep infection or dislocation. Fifty-one (56%) of the ninety-one hips had at least twenty years of radiographic follow-up, and seventy-four (81%) had a minimum of fifteen years of radio-
graphic follow-up. Of the eighty-five hips, ten (12%) had loosening of the acetabular component (definite in six and probable in four) and four (5%) had definite loosening of the femoral component. Six hips (7%) had possible loosening of the acetabular component, and no hip had possible loosening of the femoral component. Of the original cohort of 336 hips that had not had a revision because of infection or dislocation, twenty-five (7.4%) had loosening of the acetabular component (definite in sixteen and probable in nine) and ten (3.0%) had loosening of the femoral component (definite in nine and probable in one). Forty-eight acetabular components (14.3%) and one femoral component (<1%) were possibly loose.

The combined prevalence of definite or probable radiographic signs of loosening of the acetabular component and of aseptic loosening of the acetabular component necessitating revision was 12.8% (forty-three of 336 hips) overall, 24% (twenty-two) of the ninety-one hips in the eighty-two living patients, 29% (fifteen) of the fifty-one hips that had at least twenty years of radiographic follow-up, and 22% (twenty-six) of the 116 hips that had at least fifteen years of radiographic follow-up (Table I).

Loosening of both the acetabular and the femoral component was not associated with the patient’s age at the time of replacement, according to the log-rank test (p = 0.81 and 0.28, respectively). Revision performed because of aseptic loosening of the acetabular component was strongly associated with patient age (p = 0.0001). In addition, a significant relationship was found between age and revision performed because of aseptic loosening of the femoral component (p = 0.03).

With the numbers available, no association was found between loosening of the acetabular or the femoral component and gender (p = 0.11) or diagnosis.

The average weight was 185 lb (84 kg) for the patients who had aseptic loosening of the femoral component compared with 160 lb (73 kg) for those who had a stable hip replacement. However, with the numbers available, the difference was not significant (p = 0.06).
Survivorship Analysis

At the latest follow-up evaluation, 312 (88%) of the 353 original prostheses were functioning or had been in place when the patient died. Of the ninety-one hips in the eighty-two patients who were alive at least twenty years after the arthroplasty, seventy (77%) were still functioning with the index prosthesis in place (Table II).

Kaplan-Meier survivorship analyses (with 95% confidence intervals) were performed to compare the survival rates of the Charnley total hip replacements inserted with a contemporary cementing technique and those inserted with a hand-packing technique of cementing, as reported by two of us (R.C.J. and J.J.C.) and colleagues, after a minimum duration of follow-up of twenty years. With revision for any reason as the end point, the probability (and 95% confidence interval) of survival of the prosthesis was 82% ± 4% and 86% ± 8%, respectively (p = 0.037, log-rank test) (Fig. 2-A). With revision because of aseptic loosening as the end point, the probability of survival was 88% ± 4% and 88% ± 8%, respectively (p = 0.339, log-rank test) (Fig. 2-B). With revision because of aseptic loosening of the femoral component as the end point, the probability of survival was 98% ± 5% and 96% ± 3%, respectively (p = 0.290, log-rank test) (Fig. 2-C). With revision because of aseptic loosening of the acetabular component as the end point, the probability of survival was 90% ± 4% and 92% ± 8%, respectively (p = 0.127, log-rank test) (Fig. 2-D).

Discussion

By eliminating the variables of multiple surgeons and multiple prostheses, we attempted to determine whether the cementing technique affects the durability of the total hip replacement construct after twenty years of follow-up. In the present study, the results of total hip replacements performed by a single surgeon with use of a contemporary cementing technique were evaluated at a minimum of twenty years postoperatively. These results were then compared with those of total hip replacements performed with the same prosthesis (a Charnley polished flatback femoral component) by the same surgeon with a hand-packing technique of cementing and followed for a comparable duration. The methodologies used for the clinical and radiographic evaluations were identical in the two series, and one of the two observers who reviewed the radiographs was the same for both study groups, which helped to minimize the interobserver errors associated with radiographic evaluations.

With aseptic radiographic loosening of the femoral component as the end point, the probability of survival was 87% ± 10% and 92% ± 14%, respectively (p = 0.044, log-rank test) (Fig. 2-E). With aseptic radiographic loosening of the acetabular component as the end point, the probability of survival was 58% ± 4% and 84% ± 14%, respectively (p < 0.0001, log-rank test) (Fig. 2-F).
The findings in the present study corroborate those in previous studies that showed Charnley total hip arthroplasty with cement to be an extremely effective treatment for debilitating arthritis of the hip \(^2,3,4,5,6\). In the current study, the original prosthesis was in situ at the time of death or at the latest follow-up evaluation in 312 (88%) of the 353 hips. In addition, of the ninety-one hips in the eighty-two patients who survived at least twenty years after the index operation, eighty-five (93%) were rated as satisfactory by the patient, eighty-eight (88%) were not painful or only mildly so, and eighty-seven (96%) had better function than they had had before the surgery.

The rate of revision because of aseptic loosening of the femoral component was 1.8% (six) of the 336 hips managed with the contemporary cementing technique compared with 3% (eight) of the 319 hips managed with the hand-packing technique (Table I). Radiographic signs of loosening were found in 4.8% (sixteen) of the 336 hips managed with the contemporary cementing technique compared with 6.3% (twenty) of the 319 hips managed with the hand-packing technique; the difference was not significant (p = 0.40). Both groups had a low prevalence of failure, which is probably a testament to the prosthesis and the consistent surgical technique. The low prevalence of revision because of loosening of the femoral component in the group managed with the hand-packing technique of cementing also probably accounts for our inability to demonstrate a significant improvement in the group managed with the contemporary cementing technique.

At a minimum, no deleterious effects were associated with the use of a distal cement plug and a cement-gun delivery system. Even Charnley was concerned about this possibility \(^5\). He believed that a certain degree of elasticity was necessary in the prosthetic bone-construct and that better filling of the distal part of the femoral canal with cement through pressurization might lock in the prosthesis too tightly and impede so-called controlled subsidence, leading to stress-shielding of the proximal part of the femur with concomitant resorption of bone. The present study supports the finding that benign subsidence can still occur with contemporary cementing techniques, as nineteen (22%) of the eighty-five hips in the patients who survived for at least twenty years demonstrated so-called debonding (radiolucency at the cement-prosthesis interface in Gruen zone 1). Our findings corroborate those reported by Berry et al. \(^7\), who observed that debonding of a Charnley polished femoral component does not necessarily negate durable long-term performance. The present study also corroborates the observation, by other surgeons who used other prostheses, that the results achieved with improved cementing techniques are durable \(^6,7,8,9,10\). Finally, our study demonstrated that the results can be significantly improved in terms of durable fixation of the femoral component when the canal is adequately filled with cement and an adequate circumferential cement mantle is provided (p = 0.03) and that these goals can be more predictably accomplished with use of a distal cement plug and a cement-gun delivery system.

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