Corrective Osteotomy for Osteonecrosis of the Femoral Head

THE RESULTS OF A LONG-TERM FOLLOW-UP STUDY*

BY MICHAEL A. MONT, M.D.†, ADRIAN C. FAIRBANK, M.D.†, KENNETH A. KRACKOW, M.D.‡, AND DAVID S. HUNGERFORD, M.D.†, BALTIMORE, MARYLAND

Investigation performed at the Orthopaedic Department, The Johns Hopkins University School of Medicine, and the Division of Arthritis Surgery, Department of Orthopaedic Surgery, Good Samaritan Hospital, Baltimore

ABSTRACT: We reviewed the long-term results of thirty-seven corrective osteotomies that had been performed for osteonecrosis of the femoral head that was stage II or III according to the classification of Ficat and Arlet. At a mean of 11.5 years (range, five to eighteen years) postoperatively, twenty-eight hips (76 per cent) had a good or excellent result according to the Harris hip-scoring system, and nine (24 per cent) had a fair or poor result and subsequently needed a total hip arthroplasty. Six of the nine failures were in the seventeen hips of patients who had received corticosteroids. Conversely, of the twenty hips of patients who had not received corticosteroids, seventeen (85 per cent) had a good or excellent result as determined by the Harris hip score at the latest follow-up evaluation. Five of the six hips that had had a combined necrotic angle of more than 200 degrees preoperatively had subsequent collapse of the femoral head. Of the thirty-one hips that had had a combined necrotic angle of less than 200 degrees preoperatively, twenty-seven (87 per cent) had a good or excellent clinical result.

There were five complications. Three non-unions and one cutout of the compression screw were successfully treated, and these hips had an excellent clinical result at the time of the latest follow-up. The fifth complication was osteomyelitis and led to a poor result.

The results of this study suggest that corrective intertrochanteric osteotomy is a successful treatment for Ficat and Arlet stage-II or III disease if the patient has a small or medium lesion (a combined necrotic angle of less than 200 degrees) and is not receiving continuous high doses of corticosteroids.

Osteonecrosis of the femoral head is a challenging clinical problem. Moreover, many patients are first seen after the femoral head has already collapsed, leaving the surgeon with few treatment alternatives other than total hip replacement. Osteonecrosis is reported to be the underlying process accounting for approximately 10 per cent of hip arthroplasties performed in the United States[8,18,22,28]. In a study of 2012 total hip arthroplasties[18], osteonecrosis was the diagnosis in 103 hips (5 per cent). The National Hospital Discharge Survey[28] revealed that osteonecrosis had accounted for 21,000 (10 per cent) of 209,000 hip arthroplasties in 1991. The disease usually occurs in young patients, with the mean age in most studies[17,27] being less than forty years, making the effects even more devastating. Salvage by hip replacement in these young patients is also associated with problems[6,30,33]. Many authors have reported high rates of failure with older techniques of cementing. Cornell et al.[7] reported that eleven (39 per cent) of twenty-eight femoral components had failed. Dorr et al.[10] studied the results of eighty-one total hip arthroplasties. At a mean of 9.2 years (range, five to 16.5 years) postoperatively, they found that ten (45 per cent) of twenty-two hips in patients who had osteonecrosis had failed. It is too early to tell whether modern techniques of cementing and the use of so-called first-generation prostheses without cement have led to an improvement in these results[4,32]. Consequently, there is a continuing search for procedures that preserve the femoral head, such as vascularized and non-vascularized bone-grafting[12,26,29,31,35,40,41,44] and osteotomy[2,3,9,11,14,15,19-21,23,24,29,31,36-39,42,43].

The rationale for the use of an osteotomy to treat osteonecrosis of the femoral head includes both vascular and neurological factors. Some authors have reported that the salutary effects of periarticular osteotomies on symptoms may be due to the reduction of venous hypertension and subsequent intramedullary pressure after such procedures[2,3]. However, most authors have emphasized the importance of the biomechanical effect of the removal of the necrotic or collapsing segment of the femoral head from the principal weight-bearing area of the hip, thus allowing the weight-bearing contact with the acetabulum to be borne by the articular cartilage of the femoral head, which is supported by healthy bone.

There are many reports in the European and Japanese literature concerning the use of various types of osteotomies for the salvage of hips with Ficat and Arlet stage-II or III disease[9,11,14,15,19-21,23,24,29,31,36-39,42,43]. In Japan, a well known technique is the transtrochanteric osteotomy as described by Sugioka et al.[37,38]. This technically

*No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article. No funds were received in support of this study.

†Good Samaritan Hospital, Professional Office Building, G-1, 5601 Loch Raven Boulevard, Baltimore, Maryland 21239. Please address requests for reprints to Dr. Mont.

‡Buffalo General Hospital, 100 High Street, Buffalo, New York 14203.

TABLE I
STAGING OF OSTEONECROSIS OF THE FEMORAL HEAD[13]

Stage	Radiographic Appearance
I	Normal
II	Cystic or osteosclerotic lesions, or both; normal contour of femoral head; no subchondral fracture
III	Crescent sign or subchondral collapse
IV	Narrowing of joint space, secondary acetabular changes (cysts, marginal osteophytes, and destruction of cartilage)

demanding operative procedure has been associated with variable rates of success[9,24,29,36-39]. Varus and valgus osteotomies have also been associated with variable rates of failure after short-term follow-up of approximately five years[14,15,19-21,25,29,31,42-43].

The purpose of the present report is to describe the long-term results of corrective intertrochanteric osteotomy for the treatment of Ficat and Arlet[13] stage-II or III osteonecrosis.

Materials and Methods

Between January 1975 and December 1988, thirty-four patients had a corrective intertrochanteric osteotomy for the treatment of a painful hip associated with Ficat and Arlet[13] stage-II or III radiographic changes of osteonecrosis (Table I). To be included in the study, a patient had to have been followed for a minimum of five years postoperatively. Two patients died, at nine and sixteen months, from causes unrelated to the operation. Of the remaining thirty-two patients, five had a bilateral procedure; thus, a total of thirty-seven procedures were performed. All patients were entered into the study prospectively and were followed yearly both clinically and radiographically; the mean duration of follow-up was 11.5 years (range, five to eighteen years), with the most recent evaluation taking place within the three months before this writing. No patient was lost to follow-up. There were eighteen male patients (twenty-one hips) and fourteen female patients (sixteen hips); the mean age at the time of the operation was thirty-two years (range, sixteen to forty-four years).

The indications for the osteotomy included strict clinical as well as radiographic criteria. All patients were less than forty-five years old; had severe pain in the groin on weight-bearing, with a variable degree of pain at rest; and had a range of motion of at least 90 degrees of flexion, with no hip-flexion contracture of more than 15 degrees, and at least 20 degrees of abduction as assessed with the patient under general anesthesia at the time of the operation. In addition, psychosocial factors were critical. The procedure was not performed in patients who were thought to be incapable of participating in the rehabilitation program or of accepting the prolonged period of disability postoperatively.

The preoperative radiographs were evaluated carefully to determine whether the criteria for the operation were met. These included a concentric femoral head with no worse than stage-II or III osteonecrosis[13]; an arc of at least 20 degrees, on the lateral aspect of the femoral head, that was free of any underlying necrotic bone[20]; and a normal joint space with no acetabular involvement. Six hips were classified as stage II preoperatively and thirty-one, as stage III.

The underlying causes predisposing to the development of osteonecrosis included the use of corticosteroids for the treatment of other conditions in sixteen patients (50 per cent) with seventeen involved hips. Of these sixteen patients, seven (eight hips) had systemic lupus erythematosus, five had inflammatory bowel disease, and four had another illness (asthma, optic neuritis, Hodgkin disease, and glomerulonephritis). All of these patients had been maintained on the equivalent of more than twenty milligrams of prednisone per kilogram of body weight a day for a minimum of three months both before and after the osteotomy. An additional seven patients (22 per cent) had a history of an alcohol intake of more than 400 milliliters a week. No associated risk factors were found for the remaining nine patients (28 per cent).

The diagnosis of osteonecrosis was made on the basis of the clinical history and the appearance on anteroposterior, frog-leg lateral, and lateral radiographs. A biopsy of a specimen obtained from a previous core decompression had provided histological proof of osteonecrosis in six hips with stage-II disease and nine hips with stage-III disease[13]. The time from the core decompression to the osteotomy ranged from six months to five years (mean, twenty-three months). The other twenty-two hips with stage-III disease had not had a previous biopsy (or any other operative intervention) but had pathognomonic radiographic changes, including an anterolateral sequestrum and a crescent sign, with a variable degree of collapse of the femoral head. No patient had radiographic evidence of acetabular involvement, such as cysts or marginal osteophytes, and all had evidence of at least two millimeters of circumferentially intact joint space on the anteroposterior and lateral radiographs. The stages of the lesions in the thirty-seven hips in this study correspond to stages II, III, and IV of the rating scale of Steinberg et al.[34] and to stages II-A, II-B, II-C, III-A, III-B, and III-C of the classification of the Association Research Circulation Osseous[1].

Operative Planning and Technique

All patients had a corrective osteotomy that was performed by the two senior ones of us (D. S. H. and K. A. K.) with use of either a fixed-angle AO blade-plate (twenty-nine hips) or a sliding compression screw with a side-plate (eight hips) for fixation. Through a lateral approach to the proximal part of the femur, the fascia lata and vastus lateralis muscle were split close to the intermuscular septum. In the twenty procedures in which a flexion component was added to the osteotomy, an anterior capsulotomy was performed to allow extension of the hip. The hip joint was not exposed in the remaining seventeen procedures. No patient had advancement of the greater trochanter. The operations were done with the patient supine and with the extremity draped free on a radiolucent table. Intraoperative radiographs were used to confirm the seating of the chisel and the final reduction of the osteotomy; fluoroscopy was not employed.

The osteotomy was done with a combination of power saws and hand-held osteotomes, starting at the lateral cortex adjacent to the proximal border of the lesser trochanter and using the insertion of the conjoined tendon as a landmark. The purpose of the osteotomy was to remove the osteonecrotic area of the femoral head from the zone of maximum pressure against the acetabulum during weight-bearing and to replace it with unaffected, radiographically sound bone in the posterolateral part of the femoral head. The femoral head was moved into abduction and the femoral shaft was brought into adduction and flexion, thus bringing the necrotic area anteriorly, inferiorly, and medially. The amount of varus correction that was desired was determined on the preoperative anteroposterior radiographs and ranged from 20 to 42 degrees (mean, 28 degrees). It was decided to add a flexion component (mean, 21 degrees; range, 12 to 31 degrees) to the osteotomy in twenty hips and to add an extension component (mean, 18 degrees; range, 12 to 24 degrees) in six hips on the basis of the preoperative anteroposterior and lateral radiographs. The purpose of adding either an extension or a flexion component was to move the necrotic segment from the anterior (or posterior) margin of the acetabulum.

Postoperatively, the patients were allowed to walk with two crutches, using toe-touch weight-bearing (a maximum of ten kilograms) for two months. They then used one crutch until union of the osteotomy was visible radiographically, usually four to six months after the operation.

Clinical Evaluation

The most recent follow-up evaluation was done either clinically (twenty-eight patients) or by telephone with both the patient and his or her current orthopaedic surgeon (four patients). All hips were evaluated preoperatively and at the time of the latest follow-up with the Harris hip-scoring system[16]. According to this system, 90 to 100 points indicates an excellent result; 80 to 89 points, a good result; 70 to 79 points, a fair result; and less than 70 points, a poor result. For the purpose of evaluating the over-all result, all patients who had a Harris hip score of less than 80 points or in whom a subsequent hip replacement had been necessary were considered to have had a failure. Clinical success was defined as a Harris hip score of 80 points or more, no need for walking aids, and a range of flexion of 70 degrees.

Radiographic Evaluation

The prospective evaluation of all preoperative radiographs included staging according to the system of Ficat and Arlet[13] as well as measurement of the necrotic angle as described by Kerboul et al.[20]. With the latter method, outlines of the osteonecrotic lesion are made on the anteroposterior and lateral radiographs and the arc of the surface involved by the necrosis is measured with a goniometer on each radiograph. These two angles are then added together to derive the combined necrotic angle.

The most recent radiographic evaluation was performed by two of us (M. A. M. and A. C. F.) and included staging with the system of Ficat and Arlet[13], measurements of the combined necrotic angle[20], and characterization of any evidence of progression of collapse of the femoral head. The degree of collapse or restoration of the height of the femoral head as well as any evidence of narrowing of the joint space were measured on the most recent anteroposterior radiographs and were compared with the measurements on the preoperative radiographs.

Results

Twenty-eight (76 per cent) of the thirty-seven hips had a good or excellent result, with an improvement in the Harris hip score from a mean of 38 points (range, 10 to 52 points) preoperatively to a mean of 89 points (range, 80 to 100 points) at the time of the latest follow-up. Twenty hips (54 per cent) in eighteen patients were rated as excellent. All of these patients participated in high-stress sports, including tennis and jogging, with minimum problems with the hip. Of the twenty hips in the sixteen patients who had not received corticosteroids, seventeen (85 per cent) had a hip score of 80 points or more (range, 80 to 100 points) at the time of the latest follow-up. Of the seventeen hips in the sixteen patients who had received corticosteroids, eleven had a hip score of more than 80 points (range, 84 to 98 points). Thirteen of the fifteen hips that had had a previous core decompression had a satisfactory result (Figs. 1-A, 1-B, and 1-C).

Nine hips (24 per cent) had a failure and a total hip replacement was performed. Four of these hips had had a satisfactory result for five years or more (mean, six years; range, five to 7.5 years) before failing.

Radiographic Results

Twenty-seven (87 per cent) of the thirty-one hips that had had a combined necrotic angle of less than 200 degrees met the criteria for clinical success. Conversely, five of the six hips that had had a combined necrotic angle of more than 200 degrees had a failure. Five of the six hips that had been Ficat and Arlet[13] stage II preop-

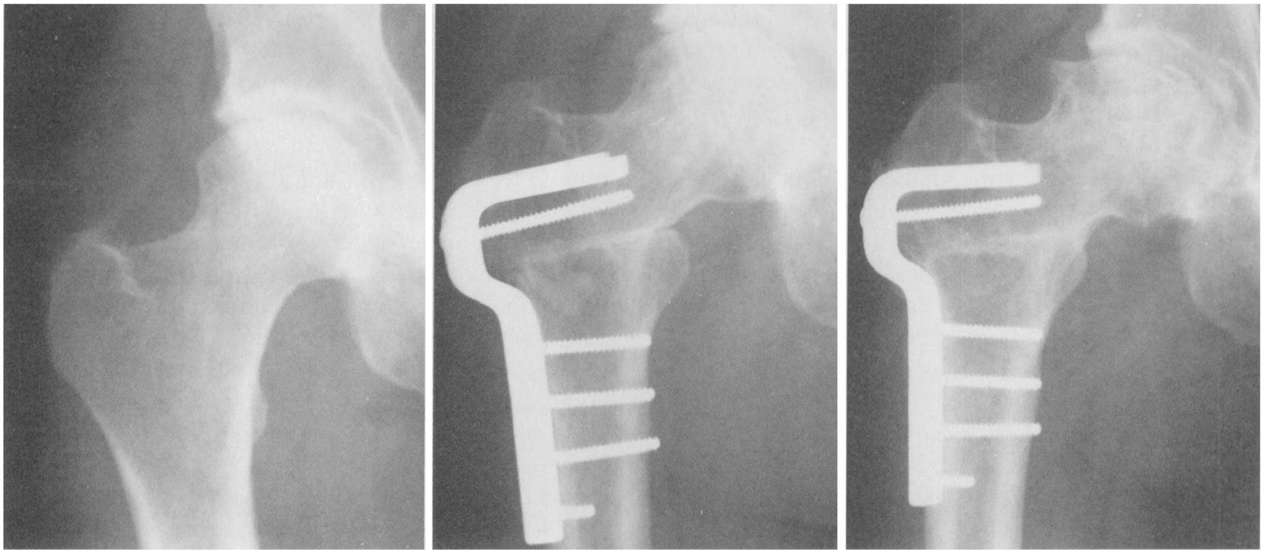

FIG. 1-A FIG. 1-B FIG. 1-C

Figs. 1-A, 1-B, and 1-C: Anteroposterior radiographs of the right hip of a thirty-year-old woman who had stage-III osteonecrosis of the femoral head[13].

Fig. 1-A: Before the osteotomy, there is minimum evidence of collapse of the femoral head.

Fig. 1-B: Two months after the corrective osteotomy with insertion of a blade-plate.

Fig. 1-C: Eleven years postoperatively, despite some evidence of additional collapse, the patient had done well, with a Harris hip score of 92 points.

eratively and twenty-three (74 per cent) of the thirty-one that had been stage III met the criteria for clinical success. All of the hips that had been stage II had had a necrotic angle of less than 200 degrees.

Six of the nine failed hips that were treated with a total hip replacement had had progression to stage-IV disease[13], with extensive collapse of the femoral head, narrowing of the joint space, and acetabular changes (cysts or osteophytes, or both). In the remaining three hips, the femoral head had remained unchanged, with no progression of collapse or narrowing of the joint space. No reason was evident for the persistent, severe pain that necessitated total joint replacement. Eighteen of the twenty-eight hips that had a good or excellent Harris hip score at the time of the latest follow-up had no evidence of progression of collapse of the femoral head or narrowing of the joint space. Eight hips had between one and three millimeters of collapse of the femoral head but nevertheless had a satisfactory clinical rating. Six of these hips had between one and three millimeters of narrowing of the joint space.

Complications

There were five complications directly related to the operation. Osteomyelitis developed in one male patient, who had Hodgkin disease and was receiving high doses of steroids and other antimetabolites, and this led to a poor result. (He had been operated on before the introduction of prophylactic antibiotics.) In another patient, the compression screw cut out, necessitating replacement with a blade-plate device. This patient did not bear weight for six months and, at the time of the latest follow-up, had a good result. The remaining three patients had a non-union of the osteotomy site. One had healing after the blade-plate was replaced with a compression screw, and the other two were managed with autologous bone graft, with subsequent union. All five patients had an excellent result at the time of the latest follow-up. There were no medical complications.

Discussion

The importance of delaying total joint replacement in young, often bilaterally affected patients who have osteonecrosis must not be underestimated. Total joint arthroplasty done for osteonecrosis of the femoral head has been reported to be less successful than total hip replacement in other patients[27]. Even with the improvements in total hip replacement, it is very desirable to delay or avoid the need for such a procedure in these patients, as many will live for more than fifty years after the operation.

The use of osteotomy for the treatment of osteonecrosis has not gained widespread acceptance, probably because disparate outcomes have been reported[14,15,19-21,27,31,42,43]. It is difficult to compare results as studies have included patients with varied etiological factors, radiographic stages of the disease, indications, types of osteotomy that are indicated, and other technical factors. To confound evaluation of the results further, radiographic osteonecrosis has not been found to be directly related to the function of the hip[23].

The first major rotational osteotomies were performed by Wagner and Zeiler[42] in the 1960's. They used a double osteotomy with a maximum of 180 degrees of rotation of the necrotic segment. However, the results were no better than those of a more modest angular displacement. Of seventy-one patients who had eighty-three rotational osteotomies over a period of ten years, those who had a small combined necrotic angle had the best results. Unsatisfactory results were attributed to an excessively large necrotic area and advanced preoperative osteoarthrotic changes[42]. Sugioka et al.[37,38] reported that 236 (86 per cent) of 274 hips had a successful result at a mean of eleven years after a rotational osteotomy. Other Japanese surgeons have also reported some success with this technically demanding procedure. Masuda et al.[24] reported satisfactory results in thirty-six (69 per cent) of fifty-two hips that had been followed for a mean of five years (range, one to ten years). Sugano et al.[36] reported a similar rate of success at six years in twenty-three (56 per cent) of forty-one hips. However, these rates of success have not been duplicated in the United States[9,11,39]; in one study, there were fifteen failures in eighteen hips at a mean of five years[9].

In Europe, various, less dramatic types of osteotomies have been done, also with a variable rate of success. In 1965, Merle d'Aubigné et al.[25] reported good or excellent results, in terms of relief of pain, in fifty-nine (79 per cent) of seventy-five hips with stage-II or III disease[13] that had been treated with a varus or varus rotational osteotomy; the duration of follow-up ranged from one to six years. In a subsequent report of an overlapping group of patients from the same institution[20], twenty-eight (60 per cent) of forty-seven hips were described as remaining painless after five years. Maistrelli et al.[21] reported a successful clinical result in seventy-five (71 per cent) of 106 hips in ninety-eight patients at two years postoperatively. At a mean of eight years (range, four to fifteen years), sixty-one (58 per cent) of the 106 hips had a good or excellent result and only twenty-four (23 per cent) needed a total hip replacement or an arthrodesis. From our institution, Jacobs et al.[19] reported the results of intertrochanteric osteotomy of the hip in sixteen patients (twenty-two hips) who had stage-II or III disease. At a mean of slightly more than five years, sixteen hips (73 per cent) had a good or excellent result.

In all of the reports just cited, it was stressed that the size of the lesion is a critical factor in the rate of success of osteotomy. Kerboul et al.[20] emphasized the importance of preoperative identification of hips in which it is possible to move the necrotic area away from the point of maximum pressure with the acetabulum. Of the twenty-six hips in which this could not be done, only seven (27 per cent) had a satisfactory clinical result. In three other studies, it was independently observed that the results of intertrochanteric osteotomy were related to the size of the lesion[19,29,42]. This finding is in concordance with the results of the present study, in which five of six hips with the largest lesions (a combined necrotic angle of more than 200 degrees) failed, while twenty-seven (87 per cent) of thirty-one with smaller lesions had a successful result. In the current report, as in all previous reports on osteotomy, size was based only on the interpretation of plain radiographs, which has its limitations with regard to delineating the true extent of the osteonecrotic lesion. In the future, the use of magnetic resonance imaging or computerized tomography scans will undoubtedly allow a more accurate evaluation of the size and location of the lesion.

In a recent prospective study of a carefully defined population of young patients who were not receiving corticosteroids, Scher and Jakim[31] found that a valgus-extension osteotomy, combined with curettage and bone-grafting of the osteonecrotic segment, led to a good or excellent clinical result in thirty-six (80 per cent) of forty-five hips at a mean of sixty-five months (range, thirty-six to 126 months) postoperatively. They also found that a more favorable prognosis was associated with a smaller combined necrotic angle. However, they expressed reservations concerning this method of estimation of size from plain radiographs because of observer variations, difficulty in defining the boundaries of the lesion, and variations in projection.

In the current study, there was a lower rate of success in the group that was receiving corticosteroids (eleven of the seventeen hips had a hip score of more than 80 points). As a confounding variable, the osteonecrotic lesions in this group were larger; four hips had a combined necrotic angle of more than 200 degrees, compared with two such hips in the group that was not receiving corticosteroids.

Because of the radiographic progression that we observed in eight hips despite an early clinical success, we expect that some of these hips will deteriorate with longer follow-up. Nevertheless, the fact that the symptoms did not increase or an arthroplasty was not needed until a mean of eleven years after the operation in this group of patients suggests that the natural progression of the disease process has been delayed.

One concern about osteotomy as an interim procedure has been that it might be difficult to convert to a hip arthroplasty should one become necessary. In a study of 105 arthroplasties in ninety-three patients, the final outcome was not affected by such previous operations, although the rate of intraoperative complications was 17 per cent (eighteen of 105). The problems included difficulty in removing the screws or plate, reaming the femur, or broaching the femoral shaft; broken screws; and fracture of the shaft, calcar, and greater trochanter. These technical difficulties appear to be manageable, but they need to be recognized by the surgeon.

Another option for patients who have osteonecrosis of the femoral head is vascularized fibular grafting, as recently described by Urbaniak et al.[41] for 103 consecutive symptomatic hips with stage-II or III disease[13]. However, this treatment necessitates much technical expertise as well as a long operative time (three hours and thirty minutes for the surgeons who performed the most procedures[41]). The rate of morbidity is probably similar to or greater than that associated with osteotomy, with vascular fibular grafting requiring sacrifice of part of the fibula and restriction of weight-bearing for a prolonged (six-month) period. We believe that a rational approach would be to perform an osteotomy or a nonvascularized bone-grafting procedure in patients who have a small lesion (a combined necrotic angle of less than 200 degrees) and to reserve the use of vascularized fibular grafting for patients who have a larger lesion.

On the basis of the results of this long-term follow-up study, corrective intertrochanteric osteotomy appears to be a successful treatment for selected patients who have stage-II or III osteonecrosis of the femoral head[13]. There was long-term preservation of the femoral head in twenty-eight (76 per cent) of the thirty-seven hips. We are specifically encouraged by the rate of success in patients who were not taking corticosteroids. Our criteria for the selection of patients include: (1) an age of less than forty-five years and a painful hip; (2) an early post-collapse (stage-III) or late pre-collapse (stage-II) hip, with no narrowing of the joint space or acetabular involvement; (3) a 20-degree arc of the lateral aspect of the femoral head that is free of necrosis (otherwise, a valgus osteotomy may be considered); (4) a small-to-medium lesion (less than 200 degrees of involvement of the head); and (5) no continued use of high doses of corticosteroids.

References

1. **ARCO (Association Research Circulation Osseous):** Committee on Terminology and Classification. *ARCO News,* 4: 41-46, 1992.
2. **Arnoldi, C. C.:** Vascular aspects of degenerative joint disorders. A synthesis. *Acta Orthop. Scandinavica,* Supplementum 261, 1994.
3. **Arnoldi, C. C.; Lemperg, R.;** and **Linderholm, H.:** Immediate effect of osteotomy on the intramedullary pressure in the femoral head and neck in patients with degenerative osteoarthritis. *Acta Orthop. Scandinavica,* 42: 454-455, 1971.
4. **Barrack, R. L.; Mulroy, R. D., Jr.;** and **Harris, W. H.:** Improved cementing techniques and femoral component loosening in young patients with hip arthroplasty. A 12-year radiographic review. *J. Bone and Joint Surg.,* 74-B(3): 385-389, 1992.
5. **Benke, G. J.; Baker, A. S.;** and **Dounis, E.:** Total hip replacement after upper femoral osteotomy. A clinical review. *J. Bone and Joint Surg.,* 64-B(5): 570-571, 1982.
6. **Chandler, H. P.; Reineck, F. T.; Wixson, R. L.;** and **McCarthy, J. C.:** Total hip replacement in patients younger than thirty years old. A five-year follow-up study. *J. Bone and Joint Surg.,* 63-A: 1426-1434, Dec. 1981.
7. **Cornell, C. N.; Salvati, E. A.;** and **Pellicci, P. M.:** Long-term follow-up of total hip replacement in patients with osteonecrosis. *Orthop. Clin. North America,* 16: 757-769, 1985.
8. **Coventry, M. B.; Beckenbaugh, R. D.; Nolan, D. R.;** and **Ilstrup, D. M.:** 2,012 total hip arthroplasties: a study of postoperative course and early complications. *J. Bone and Joint Surg.,* 56-A: 273-284, March 1974.
9. **Dean, M. T.,** and **Cabanela, M. E.:** Transtrochanteric anterior rotational osteotomy for avascular necrosis of the femoral head. Long-term results. *J. Bone and Joint Surg.,* 75-B(4): 597-601, 1993.
10. **Dorr, L. D.; Luckett, M.;** and **Conaty, J. P.:** Total hip arthroplasties in patients younger than 45 years. A nine- to ten-year follow-up study. *Clin. Orthop.,* 260: 215-219, 1990.
11. **Eyb, R.,** and **Kotz, R.:** The transtrochanteric anterior rotational osteotomy of Sugioka. Early and late results in idiopathic aseptic femoral head necrosis. *Arch. Orthop. and Trauma Surg.,* 106: 161-167, 1987.
12. **Fairbank, A. C.; Bhatia, D.; Jinnah, R. H.;** and **Hungerford, D. S.:** Long-term results of core decompression for ischaemic necrosis of the femoral head. *J. Bone and Joint Surg.,* 77-B(1): 42-49, 1995.
13. **Ficat, R. P.,** and **Arlet, J.:** Functional investigation of bone under normal conditions. In *Ischemia and Necroses of Bone,* pp. 29-52. Edited by D. S. Hungerford. Baltimore, Williams and Wilkins, 1980.
14. **Ganz, R.,** and **Büchler, U.:** Overview of attempts to revitalize the dead head in aseptic necrosis of the femoral head — osteotomy and revascularization. In *The Hip. Proceedings of the Eleventh Open Scientific Meeting of The Hip Society,* pp. 296-305. St. Louis, C. V. Mosby, 1983.
15. **Gottschalk, F.:** Indications and results of intertrochanteric osteotomy in osteonecrosis of the femoral head. *Clin. Orthop.,* 249: 219-222, 1989.
16. **Harris, W. H.:** Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J. Bone and Joint Surg.,* 51-A: 737-755, June 1969.
17. **Hungerford, D. S.:** Treatment of ischemic necrosis of the femoral head. In *Surgery of the Musculoskeletal System,* edited by C. McC. Evarts. Vol. 3, pp. 5-29. New York, Churchill Livingstone, 1983.
18. **Jacobs, B.:** Epidemiology of traumatic and nontraumatic osteonecrosis. *Clin. Orthop.,* 130: 51-67, 1978.
19. **Jacobs, M. A.; Hungerford, D. S.;** and **Krackow, K. A.:** Intertrochanteric osteotomy for avascular necrosis of the femoral head. *J. Bone and Joint Surg.,* 71-B(2): 200-204, 1989.
20. **Kerboul, M.; Thomine, J.; Postel, M.;** and **Merle D'Aubigné, R.:** The conservative surgical treatment of idiopathic aseptic necrosis of the femoral head. *J. Bone and Joint Surg.,* 56-B(2): 291-296, 1974.
21. **Maistrelli, G.; Fusco, U.; Avai, A.;** and **Bombelli, R.:** Osteonecrosis of the hip treated by intertrochanteric osteotomy. A four- to 15-year follow-up. *J. Bone and Joint Surg.,* 70-B(5): 761-766, 1988.
22. **Mankin, H. J.:** Nontraumatic necrosis of bone (osteonecrosis). *New England J. Med.,* 326: 1473-1479, 1992.
23. **Marti, R. K.; Schüller, H. M.;** and **Raaymakers, E. L. F. B.:** Intertrochanteric osteotomy for non-union of the femoral neck. *J. Bone and Joint Surg.,* 71-B(5): 782-787, 1989.
24. **Masuda, T.; Matsuno, T.; Hasegawa, I.; Kanno, T.; Ichioka, Y.;** and **Kaneda, K.:** Results of transtrochanteric rotational osteotomy for nontraumatic osteonecrosis of the femoral head. *Clin. Orthop.,* 228: 69-74, 1988.
25. **Merle d'Aubigné, R.; Postel, M.; Mazabraud, A.; Massias, P.;** and **Gueguen, J.:** Idiopathic necrosis of the femoral head in adults. *J. Bone and Joint Surg.,* 47-B(4): 612-633, 1965.
26. **Meyers, M. H.:** The treatment of osteonecrosis of the hip with fresh osteochondral allografts and with the muscle pedicle graft technique. *Clin. Orthop.,* 130: 202-209, 1978.

27. **Mont, M. A.,** and **Hungerford, D. S.:** Current concepts review. Non-traumatic avascular necrosis of the femoral head. *J. Bone and Joint Surg.,* 77-A: 459-474, March 1995.
28. **National Center for Health Statistics:** *1990 and 1991 National Hospital Discharge Survey.* Rosemont, Illinois, The American Academy of Orthopaedic Surgeons, Department of Research and Scientific Affairs, 1994.
29. **Saito, S.; Ohzono, K.;** and **Ono, K.:** Joint-preserving operations for idiopathic avascular necrosis of the femoral head. Results of core decompression, grafting and osteotomy. *J. Bone and Joint Surg.,* 70-B(1): 78-84, 1988.
30. **Saito, S.; Saito, M.; Nishina, T.; Ohzono, K.;** and **Ono, K.:** Long-term results of total hip arthroplasty for osteonecrosis of the femoral head. A comparison with osteoarthritis. *Clin. Orthop.,* 244: 198-207, 1989.
31. **Scher, M. A.,** and **Jakim, I.:** Intertrochanteric osteotomy and autogenous bone-grafting for avascular necrosis of the femoral head. *J. Bone and Joint Surg.,* 75-A: 1119-1133, Aug. 1993.
32. **Solacoff, D.; Mont, M. A.;** and **Krackow, K. A.:** Uncemented total hip arthroplasty in patients less than 45 years with avascular necrosis. *Orthop. Trans.,* 17: 1085, 1993-1994.
33. **Stauffer, R. N.:** Ten-year follow-up study of total hip replacement. With particular reference to roentgenographic loosening of the components. *J. Bone and Joint Surg.,* 64-A: 983-990, Sept. 1982.
34. **Steinberg, M. E.; Hayken, G. D.;** and **Steinberg, D. R.:** A quantitative system for staging avascular necrosis. *J. Bone and Joint Surg.,* 77-B(1): 34-41, 1995.
35. **Steinberg, M. E.; Bands, R. E.; Parry, S.; Hoffman, E.; Chan, T.;** and **Hartman, K. M.:** Does lesion size affect outcome in avascular necrosis? *Orthop. Trans.,* 16: 706-707, 1992-1993.
36. **Sugano, N.; Takaoka, K.; Ohzono, K.; Matsui, M.; Saito, M.;** and **Saito, S.:** Rotational osteotomy for non-traumatic avascular necrosis of the femoral head. *J. Bone and Joint Surg.,* 74-B(5): 734-739, 1992.
37. **Sugioka, Y.; Hotokebuchi, T.;** and **Tsutsui, H.:** Transtrochanteric anterior rotational osteotomy for idiopathic and steroid-induced necrosis of the femoral head. Indications and long-term results. *Clin. Orthop.,* 277: 111-120, 1992.
38. **Sugioka, Y.; Katsuki, I.;** and **Hotokebuchi, T.:** Transtrochanteric rotational osteotomy of the femoral head for the treatment of osteonecrosis. Follow-up statistics. *Clin. Orthop.,* 169: 115-126, 1982.
39. **Tooke, S. M. T.; Amstutz, H. C.;** and **Hedley, A. K.:** Results of transtrochanteric rotational osteotomy for femoral head osteonecrosis. *Clin. Orthop.,* 224: 150-157, 1987.
40. **Urbaniak, J. R.** [editor]: Aseptic necrosis of the femoral head treated by vascularized fibular graft. In *Microsurgery for Major Limb Reconstruction,* pp. 178-184. St. Louis, C. V. Mosby, 1987.
41. **Urbaniak, J. R.; Coogan, P. G.; Gunneson, E. B.;** and **Nunley, J. A.:** Treatment of osteonecrosis of the femoral head with free vascularized fibular grafting. A long-term follow-up study of one hundred and three hips. *J. Bone and Joint Surg.,* 77-A: 681-694, May 1995.
42. **Wagner, H.,** and **Zeiler, G.:** Idiopathic necrosis of the femoral head. Results of intertrochanteric osteotomy and joint resurfacing. In *Progress in Orthopedic Surgery.* Vol. 5, *Segmental Idiopathic Necrosis of the Femoral Head,* pp. 87-116. Edited by U. H. Weil. New York, Springer, 1981.
43. **Willert, H. G.; Büchhorn, G.;** and **Zichner, L.:** Results of flexion osteotomy on segmental femoral head necrosis in adults. In *Progress in Orthopedic Surgery.* Vol. 5, *Segmental Idiopathic Necrosis of the Femoral Head,* pp. 63-80. Edited by U. H. Weil. New York, Springer, 1981.
44. **Yoo, M. C.; Chung, D. W.;** and **Hahn, C. S.:** Free vascularized fibula grafting for the treatment of osteonecrosis of the femoral head. *Clin. Orthop.,* 277: 128-138, 1992.