# Treatment of Early Stage Osteonecrosis of the Femoral Head

By David R. Marker, BS, Thorsten M. Seyler, MD, Mike S. McGrath, MD, Ronald E. Delanois, MD, Slif D. Ulrich, MD, and Michael A. Mont, MD

## Introduction

Osteonecrosis is a devastating disease that primarily affects weight-bearing joints. The hip is the most commonly affected joint. Although hip osteonecrosis can affect patients of any age group, it typically presents in young patients between the ages of twenty and forty years[1]. The factors that affect the progression of this disease are still not fully understood, but radiographic lesion size, femoral head collapse (if present), and, occasionally, clinical presentation at the time of diagnosis have been shown to be predictive of the eventual clinical outcome[2,3]. After collapse, most patients will require a standard total hip arthroplasty[4,5]. However, because of the young age of many of these patients, a hip replacement cannot be expected to last the patient's lifetime and therefore, when feasible, attempts should be made to save the femoral head prior to collapse with use of less invasive treatment modalities. The efficacy of these procedures has been variable, with reported success rates ranging between 60% and 80% at the time of short-term and midterm follow-up[6-8]. Current treatments range from pharmacotherapies to surgical interventions that include core decompression, vascularized or nonvascularized bone-grafting, and osteotomy. Recently there have been attempts to enhance these surgical techniques with use of various growth and differentiation factors.

The primary purpose of this report is threefold: (1) to discuss the importance of early diagnosis and the standards for identifying and staging osteonecrosis; (2) to assess the efficacy of various treatment modalities and techniques by conducting an extensive literature review and comparing reported outcomes with those of patients treated at our institution; and (3) to provide a recommended treatment algorithm based on the assessment of these treatment options.

## The Diagnosis and Staging of Osteonecrosis

All patients who were treated at our institution for early stage osteonecrosis of the hip and included in the present study were diagnosed with use of the following criteria: (1) clinical presentation with throbbing, deep groin pain, and one or more associated risk factors; or (2) a previous diagnosis of osteonecrosis in another joint (Table I). Patients who met one of these clinical criteria underwent subsequent magnetic resonance imaging to confirm the clinical diagnosis. Although considered less specific and not used as one of the diagnostic criteria, a physical examination was also helpful in diagnosis because many patients had limited internal rotation of the hip in both extension and flexion. The most common presentation was that of groin and/or occasional buttock pain that was intermittent, described as deep and throbbing[9], and of gradual onset. The pain typically was associated with movement and weight-bearing activities, although some patients progressed to have pain at rest. In a minority of the cases, the pain appeared abruptly. There were also some patients who remained relatively asymptomatic despite radiographic evidence of advanced progression of the disease.

Magnetic resonance imaging is generally accepted as the standard for confirming a suspected clinical diagnosis of osteonecrosis, and, as previously noted, this modality was used to diagnose all patients included in the present study. The authors of a recent Japanese study developed a list of major and minor radiographic criteria for diagnosing osteonecrosis. Major criteria included femoral head collapse, evidence of a crescent sign and demarcating sclerosis on radiographs, and low-intensity bands on T1-weighted magnetic resonance images. Minor criteria included joint-space narrowing, radiographic evidence of mottled sclerosis and acetabular involvement, and homogeneous or inhomogeneous low intensity without the band pattern on T1-weighted magnetic resonance images[10]. Although bone scanning was previously advocated as a useful diagnostic tool[11-13], this imaging modality has subsequently been shown to have poor sensitivity. In a recent study by Mont et al., the sensitivity of magnetic resonance imaging was compared with that of bone scanning in sixty-one hips

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**TABLE I Diagnosis of Early Stage Osteonecrosis***

| Direct Risk Factors | Associated Risk Factors |
|---|---|
| Traumatic fracture and/or dislocation | Corticosteroid use |
| Sickle cell disease | Alcohol abuse |
| Radiation | Tobacco abuse |
| Chemotherapy | Systemic lupus erythematosus |
| Myeloproliferative disorders | Organ transplant |
| Thalassemia | Gastrointestinal disorder |
| Caisson disease | Pregnancy |
| | Genetic inheritance |
| | Coagulation deficiency |

*The diagnosis of osteonecrosis is made when the patient has deep groin pain plus one or more risk factors or when the patient is asymptomatic but has radiographic evidence of disease and a diagnosis of osteonecrosis in other joints. The diagnosis can be confirmed with use of magnetic resonance imaging.

with pathologically confirmed osteonecrotic lesions[14]. While all lesions were successfully identified with the use of magnetic resonance imaging, only thirty-seven (61%) were detected by bone scan. The lowest sensitivity for bone scans was found in hips with early stage osteonecrosis (22% of Ficat and Arlet[15,16] stage-I hips and 36% of small lesions).

Imaging is important in the diagnosis of hip osteonecrosis as well as in predicting outcome (Table II), and standard radiographs are commonly used to stage the progression of disease. Although the most frequently used staging system is that of Ficat and Arlet[15,16], a number of other systems have been used, including those by the University of Pennsylvania (also known as Steinberg[17,18]), ARCO (Association Research Circulation Osseous[19-21]), and The Japanese Orthopaedic Association[22-24] (Table III). On the basis of the differences in some of the other most frequently used staging systems, it has been reported that there is no accepted way to relate one of these systems to another[25]. We do advocate collecting enough data to allow use of any of the most commonly used systems. In addition to these staging systems, the Kerboul angle and the arc of the affected necrotic area of the femoral head have been used to evaluate lesion size[26,27]. By summing the two angles measured on the anteroposterior and lateral radiographs, the combined necrotic angle is determined to define a small (<150°), medium (150° to 250°), or large (>250°) lesion. If the size is small (affecting <15% of the femoral head) and the patient is asymptomatic, the lesion may heal spontaneously[2]. Most systems have ascribed prognostic significance to staging of lesion size. Early stage or smaller lesion size leads to the best prognostic results with any treatment method.

## Materials and Methods

Ninety-three patients (126 hips) were treated at our institution. Eight patients (eight hips) underwent nonvascularized bone-grafting combined with a type-I collagen lyophilizate (Colloss E; Ossacur, Oberstenfeld, Germany); thirty-three patients (thirty-nine hips) underwent nonvascularized bone-grafting combined with recombinant human bone morphogenetic protein-7 (osteogenic protein-1 [OP-1]; Stryker Biotech, Hopkinton, Massachusetts); and fifty-two patients (seventy-nine hips) underwent a multiple small-diameter (3.2 to 3.4-mm) drilling technique. The type-I collagen lyophilizate used was an equine bone-derived collagen-based protein matrix that included considerable amounts of various growth factors, including vascular endothelial growth factor, transforming growth factor-β1, transforming growth factor-β2, insulin-like growth factor-I, bone morphogenetic protein-2, bone morphogenetic protein-3, and bone morphogenetic protein-7. The surgical outcomes for core decompression with small-diameter drilling[8] and nonvascularized bone-grafting combined with recombinant human bone morphogenetic protein[28] were previously reported and are included in the present study to provide a comprehensive overview of techniques used at our institution.

**TABLE II Femoral Head Characteristics Affecting Treatment Options and Outcomes**

| Radiographic Characteristic | Options and Outcomes |
|---|---|
| Acetabular involvement | Any sign of osteoarthritis will limit treatment options |
| Lesion collapse | Precollapse lesions are associated with the best prognosis |
| Large necrotic segment | Smaller lesions are associated with better results |
| Extent of head depression | Hips with <2 mm of depression are associated with more favorable outcomes |

**TABLE III Staging Systems Based on Imaging Findings**

| Ficat and Arlet[15,16] | | University of Pennsylvania[17,18]* | | Association Research Circulation Osseous[19-21] (ARCO) | | Japanese Orthopaedic Association[22-24] (Ohzono) | |
|---|---|---|---|---|---|---|---|
| Stage | Description | Stage | Description | Stage | Description | Stage | Description |
| I | Normal | 0 | Normal | 0 | None | 1 | Demarcation line† |
| II | Diffuse sclerotic or cystic lesions | I | Positive findings on bone scan or magnetic resonance imaging | 1 | Normal findings on radiography or computed tomography; positive findings with at least one other technique | 2 | Early flattening without demarcation line around necrotic area |
| III | Subchondral fracture | II | Diffuse sclerotic or cystic lesions | 2 | Sclerosis, osteolysis, focal porosis | 3 | Cystic lesions |
| IV | Femoral head collapse, osteoarthritis, acetabular changes | III | Step-off in contour of subchondral bone | 3 | Crescent sign and/or flattening of articular surface | | |
| | | IV | Flattening of femoral head | 4 | Osteoarthritis, acetabular changes | | |
| | | V | Joint-narrowing or acetabular changes | | | | |
| | | VI | Advanced degenerative changes | | | | |

*Further stratified as A, B, or C, depending on increasing severity. †Stratified by medial to lateral weight-bearing area.

All patients were assessed clinically and radiographically both preoperatively and at a mean follow-up time of thirty-three months (range, twelve to eighty-one months). Clinical assessment was based on pain, function, and range-of-motion scoring as determined with use of the Harris hip scoring system[29] and on whether the patient required additional surgical intervention following initial treatment. Radiographic staging of the disease was determined with use of the Ficat and Arlet staging system[15,16]. Hips at Ficat stage III or IV were a contraindication for core decompression or drilling, whereas only hips at Ficat stage IV were a contraindication for the nonvascularized bone-grafting techniques. Additionally, the extent of necrosis of the femoral head was assessed with use of anteroposterior and lateral radiographs and the Kerboul angle[27]. A minimum of two of three authors (T.M.S., S.D.U., M.A.M.) conducted the radiographic evaluations.

The results for the patients treated at our institution were compared with results reported in other studies in the current literature. An extensive literature review of the databases of the U.S. National Library of Medicine, the National Institutes of Health, and Embase was carried out. The initial search parameters used to identify potentially relevant articles were "necrosis and hip," and all articles were screened with use of a previously defined protocol[30]. All articles identified in this manner were subject to a review by two or more of the authors. Only reports that provided radiographic outcomes, provided clinical outcomes, and/or indicated whether patients required additional surgery following an initial treatment were included in our analysis. Additionally, reports that involved fewer than ten patients were excluded. The articles that met our inclusion criteria were then stratified by treatment modality: nonoperative, pharmacological therapy, core decompression, nonvascularized bone-grafting, vascularized bone-grafting, and osteotomy.

## Results

### *Nonoperative Treatment*

The nonoperative treatments reported in the literature include pharmacological therapy, extracorporeal shock-wave therapy, and electromagnetic stimulation (see Appendix). In addition, some authors reported using physical therapy or only monitoring disease progression at early stages without any intervention.

#### Pharmacological Agents

Pharmacological agents that have been used to treat osteonecrosis of the hip include lipid-lowering agents, anticoagulants, prostacyclin analogs, and bisphosphonates. The theoretical benefit of using cholesterol-lowering agents, such as statins, is based on the association of high levels of blood lipids and an increased risk of the development of osteonecrosis of the hip. Anticoagulants and prostacyclin analogs may work by inhibiting aggregation of platelets, thus enhancing blood flow to ischemic bone areas and potentially promoting revascularization. The use of bisphosphonates for osteonecrosis has been assessed because of the ability of bisphosphonates to decrease osteoclastic activity and permit bone formation via the osteoblastic process. The clinical failure rates for the various pharmacological therapies have ranged from 0% to 10%. In one of these studies, Pritchett reported that the prevalence of osteonecrosis was only 1% in patients who were receiving corticosteroid therapy and who received concurrent

**TABLE IV Outcomes of Multiple Small-Diameter Drilling Cohort***

| Data | Number of Hips | Clinical Failure *(%)* | P Value | Radiographic Failure *(%)* | P Value |
|---|---|---|---|---|---|
| Overall | 79 | 38 | | 35 | |
| Radiographic variables | | | | | |
| Ficat stage I | 54 | 28 | p = 0.013† | 28 | p = 0.066 |
| Ficat stage II | 25 | 60 | p = 0.013† | 52 | p = 0.066 |
| Lesion size | | | | | |
| Small | 57 | 30 | p = 0.032† | 26 | p = 0.014† |
| Large | 22 | 59 | p = 0.032† | 59 | p = 0.014† |
| Risk factors | | | | | |
| Corticosteroid use | 47 | 42 | | 40 | |
| Alcohol abuse | 19 | 63 | | 63 | |
| Tobacco abuse | 26 | 31 | | 31 | |
| Systemic lupus erythematosus | 20 | 39 | | 33 | |
| Sickle cell disease | 5 | 20 | | 20 | |
| Human immunodeficiency virus | 4 | 25 | | 25 | |

*Outcomes were previously reported[8]. †Values were significant.

statin therapy[31]. While the results of the pharmacological studies appear promising, the reported results were limited to only short-term to midterm follow-up.

### Shock-Wave Therapy

The mechanism for shock-wave treatment is not fully understood but may involve improved vascularity of the affected areas of the femoral head. Some studies[32,33] have reported outcomes similar to or better than those reported after surgical interventions; however, to our knowledge, no studies have reported long-term results with use of this treatment modality.

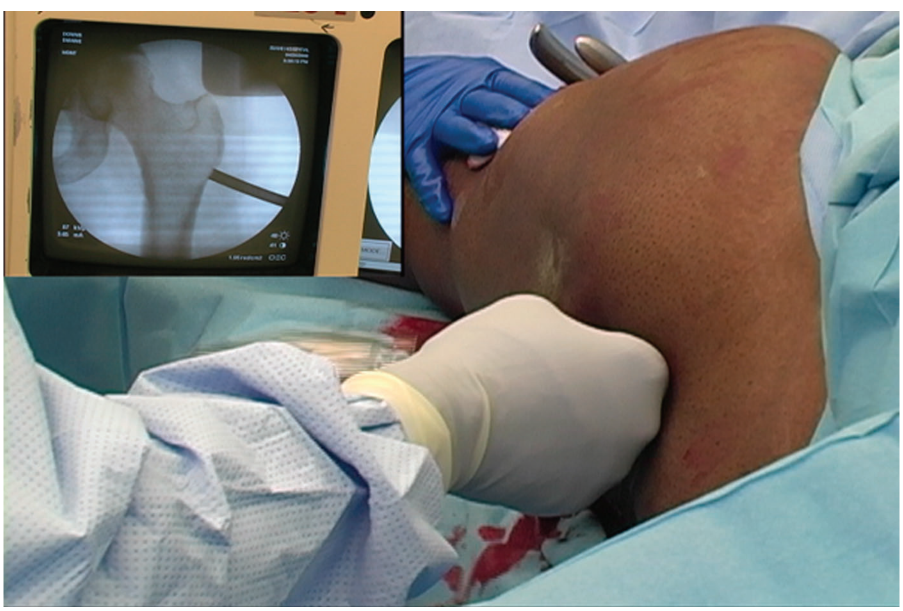

Fig. 1

The core decompression site is positioned just above the level of the lesser trochanter to reduce the risk of a stress fracture in the femur. After a small hole is placed in the midlateral cortex at the point where the bone begins to flare laterally, a small guidewire is inserted, under fluoroscopic guidance, through the hole in the center of the lesion in the femoral head. With use of a conical reamer or cannulated drill, the lateral femoral cortex is then opened to a diameter of 10 mm. Next, as shown in the inset, with use of continued fluoroscopic guidance, an 8-mm trephine is manually advanced.

**Electromagnetic or Electrical Stimulation**

Pulsed electromagnetic field therapy and electrical stimulation are used because they have the potential to promote osteogenic activity in the necrotic area[34]. Massari et al. reported that pulsed electromagnetic field therapy in patients with Ficat stage-II or III osteonecrosis of the hip was superior to core decompression[35]. In contrast, electrical stimulation used as an adjunctive therapy to core decompression and grafting has not shown any significant benefit when compared with similar treatments without electrical treatment[36,37].

**Natural Progression**

The reported clinical failure rates in studies that assessed untreated patients ranged from 38% to 100% and were generally higher than the rates in studies that reported on the use of interventional treatment modalities. In contrast to some of the high clinical failure rates in studies that assessed natural disease progression in symptomatic patients, in a study by Min et al., only 32% of asymptomatic patients progressed to collapse, with 38% becoming symptomatic at a mean follow-up time of eight years[3].

***Core Decompression with or without Adjunctive Biological Agents***

Core decompression was one of the first surgical treatments proposed for early stage osteonecrosis[38,39]. The core track may promote the formation of healthy bone by reducing bone-marrow pressure as well as inducing neovascularization. There are two reported methods of core decompression: large-diameter trephines and small-diameter drills. The most common method, the 8 to 10-mm trephine, is completed under fluoroscopy (Fig. 1) with the core track either being left open or filled in with bone graft[40]. Recent studies of core decompression combined with various biological treatments have reported clinical failure rates as low as 0% to 18% at the time of short-term and midterm follow-up (see Appendix).

**Small-Diameter Technique**

Because of some of the reported complications (e.g., articular cartilage damage and subchondral fractures) that have been associated with the large-diameter technique, Kim et al. developed the multiple small-diameter core decompression technique[41] (Fig. 2). In their initial cohort of patients treated with this technique, they reported a lower rate of collapse (14.3%) as compared with the rate reported with the traditional trephine method[41]. Similar results were found in the cohort of patients at our institution who were managed with this small-diameter drilling technique[8] (Table IV).

**Tantalum Implants**

The use of a tantalum implant has been reported in two studies[42,43]. Tantalum is a light metal that has a high yield to stress. In these studies, porous tantalum rods were used to potentially allow bone growth to occur while providing support. While the short-term results in these studies compared favorably to other core decompression techniques (see Appendix), longer follow-up is needed to more fully assess the efficacy of this procedure.

***Bone-Grafting***

**Nonvascularized Graft**

Nonvascularized bone-grafting is more invasive than core decompression and has typically been used in hips with a femoral head collapse of <2 mm or in hips in which core decom-

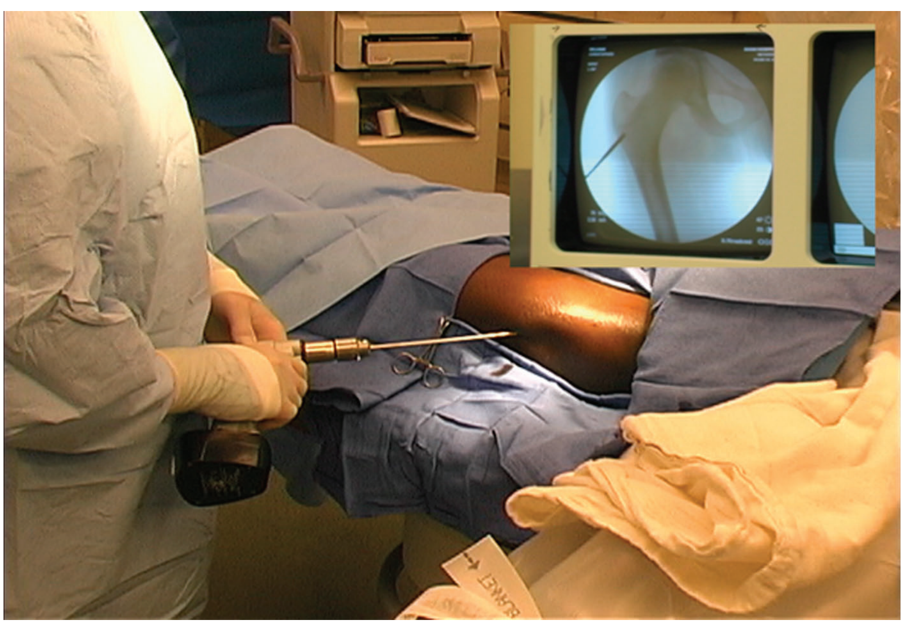

Fig. 2

The multiple small-diameter core decompression technique utilizes a 3.2 to 3.4-mm drill. The procedure is performed under fluoroscopic guidance as an outpatient procedure[40].

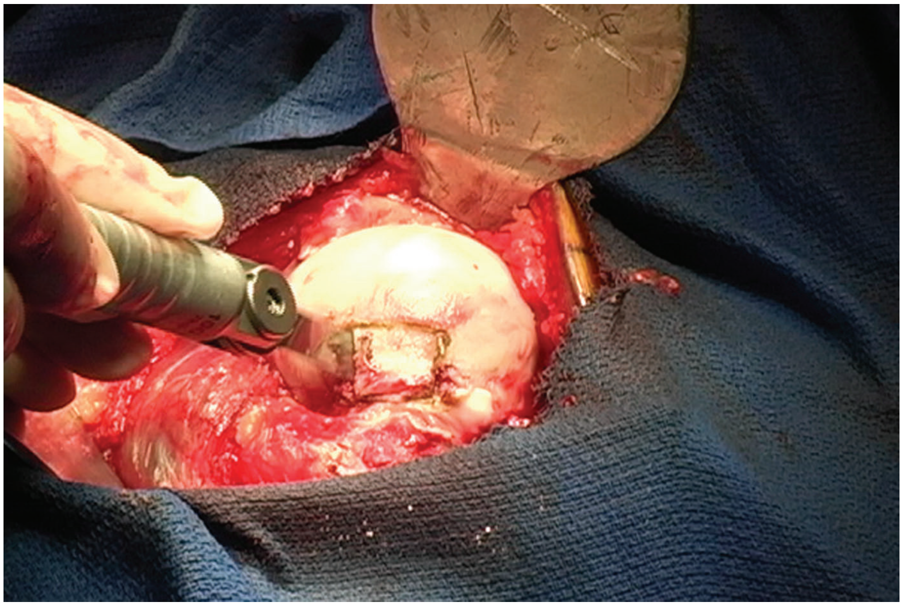

Fig. 3-A

**Figs. 3-A through 3-E** The light-bulb technique. **Fig. 3-A** After the femoral head is exposed, an oscillating saw is used to create a cortical window at the junction of the articular cartilage and femoral neck.

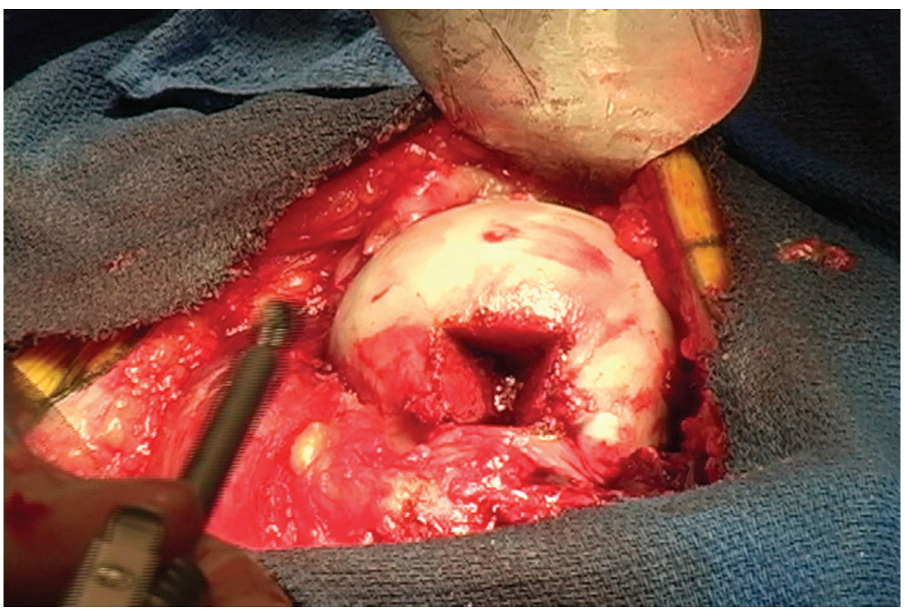

Fig. 3-B

Osteotomes are used to elevate the cortical window, a high-speed burr is introduced into the femoral head, and the necrotic bone is removed.

pression has been unsuccessful. The surgical techniques for the three commonly used approaches, the Phemister, trapdoor, and light-bulb techniques, were recently reported by Seyler et al.[28]. The light-bulb technique was used for the patients in the present study who were treated with nonvascularized bone-grafting combined with type-I collagen lyophilizate (Figs. 3-A through 3-E).

Overall, six of the eight patients treated with nonvascularized bone-grafting combined with a type-I collagen lyophilizate reported a decrease in pain and had no radiographic progression of disease. The two patients in whom treatment failed had femoral head collapse at six and seven months, respectively. The results of this small cohort were similar to the results of other nonvascularized bone-grafting procedures that made use of recombinant human bone morphogenetic protein both at our institution (Table V) and elsewhere (see Appendix).

### Vascularized Graft

The concept of using a vascularized bone graft was developed after studies of nonvascularized bone grafts suggested that

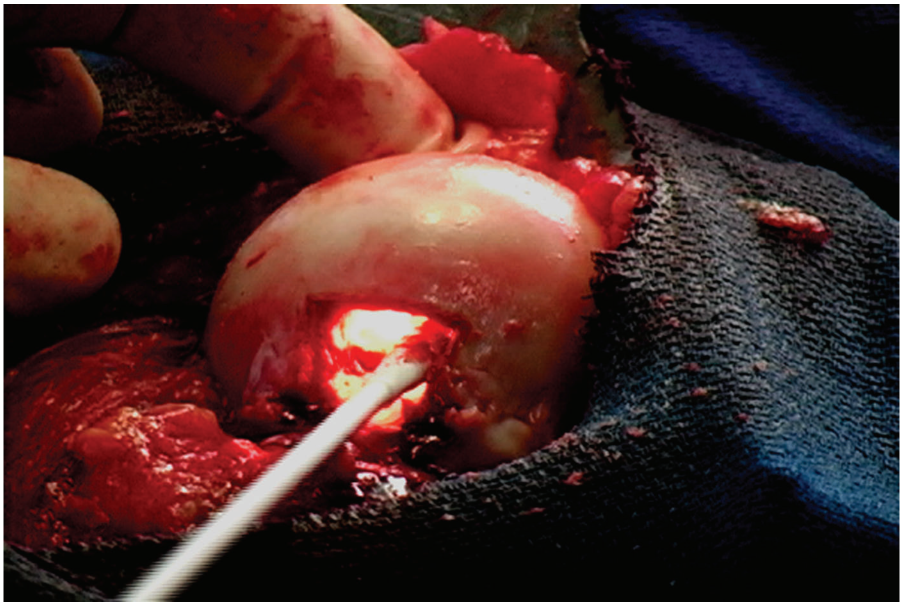

Fig. 3-C

A light is introduced into the femoral head to ensure that all of the necrotic bone has been removed.

Fig. 3-D

The type-I collagen lyophilizate (Colloss E) is then mixed with cancellous bone, which provides structural stability and maintains the contour of the femoral head. Each sterile unit of the lyophilizate contained 20 mg of type-I collagen-based protein matrix.

there was not adequate vascularization following the procedure. This procedure is technically difficult, time-intensive, and requires two teams: one team prepares the femur while the other team harvests bone from the fibula or ilium.

There have been similar outcomes for both the iliac and fibular grafts, with reported failure rates ranging from 0% to 58% for iliac grafts compared with 0% to 88% for fibular grafts (see Appendix). Yen et al. compared both techniques and reported similar clinical outcomes when comparing graft location but a longer operative time for the use of fibular grafts (seven hours) as compared with the use of iliac grafts (four hours)[44].

*Osteotomy*

An osteotomy alters the angle of the femoral neck so that necrotic tissue is relocated away from the weight-bearing segment, thus redistributing the forces to healthy bone. The procedure has been indicated for young patients who do not take corticosteroid medications, who have at least 90° of hip

**TABLE V Comparison of Nonvascularized Techniques with Regard to Outcome***

| | OP-1 | | Type-I Collagen Lyophilizate | |
|---|---|---|---|---|
| | Number of Hips | Prevalence of Collapse *(%)* | Number of Hips | Prevalence of Collapse *(%)* |
| Lesion size | | | | |
| Small | 7 | 13 | 0 | NA |
| Medium | 23 | 17 | 5 | 20 |
| Large | 9 | 78 | 3 | 33 |
| Location of lesion† | | | | |
| A | 8 | 13 | 1 | 0 |
| B | 12 | 42 | 2 | 50 |
| C1 | 12 | 17 | 3 | 0 |
| C2 | 7 | 71 | 2 | 50 |
| Ficat and Arlet stage | | | | |
| Stage I | 0 | NA | 0 | NA |
| Stage II | 22 | 18 | 5 | 20 |
| Stage III | 17 | 53 | 3 | 33 |
| Stage IV | 0 | NA | 0 | NA |

*Outcomes for patients treated with OP-1 were previously reported[28]. NA = not applicable. †Type-A lesions occupy the medial one-third or less of the weight-bearing portion; Type-B lesions occupy the medial two-thirds or less of the weight-bearing portion; Type-C lesions occupy more than the medial two-thirds of the weight-bearing portion; Subtypes C1 and C2 further stratify the C-type lesions: Type-C2 lesions extend laterally to the acetabular edge, whereas Type-C1 lesions do not.

flexion, and who have a lesion that occupies <30% of the femoral head. Two types of procedures have been described: the transtrochanteric rotational osteotomy (anterior or posterior) and the intertrochanteric angular osteotomy (flexion, extension, valgus, and varus as well as various combinations of the same). The transtrochanteric rotational osteotomy has been largely successful in Asian countries, with reported survival rates of up to 90% at five years and 73% at ten years, but survival rates have been 40% or lower in Europe. Compared with the rotational osteotomy, the intertrochanteric angular osteotomy has been more successful in Europe and the United States, with success rates ranging from 72% to 87% at follow-up times of four to ten years, as shown in a table in the Appendix. The greater success of the rotational osteotomy in Asian

Fig. 3-E
The type-I collagen lyophilizate and cancellous bone mix is packed into the femoral head with use of a layered approach.

countries may be due to an anatomic difference in the Asian population; specifically, the posterior capsule of the hip in Asians may be more lax and may allow for better rotation of the anterior portion of the femoral neck[45]. Complications are common because the procedure is technically demanding. Poor fixation with screws may cause an increased varus deformity, delayed union, and even secondary collapse of the femoral head. Fixation with a plate and screws has been associated with fewer complications. The position of the lesion may also influence the outcome. Lesions of the posterior part of the femoral head are associated with fewer complications and less collapse as compared with lesions of the anterior part of the femoral head. Finally, revision to a total hip arthroplasty may be more difficult following an osteotomy because the subsequent alignment of the femoral metaphysis may make stem placement difficult.

## Conclusions and Recommended Treatment Algorithm

The outcomes of patients treated at our institution as well as other reported outcomes in the literature suggest that core decompression and nonvascularized bone-grafting techniques are viable options to avert the need for additional surgery in patients with early stage osteonecrosis of the hip. These results are consistent with current practice, as core decompression was recently reported to be the most commonly offered intervention for symptomatic precollapse (University of Pennsylvania stage-IB and IIB) osteonecrosis by members of the American Association of Hip and Knee Surgeons[46]. Other treatment modalities, such as pharmaceuticals and vascularized bone-grafting, also may delay the need for more invasive procedures, such as total hip arthroplasty. However, due to the reported efficacy of the use of total hip arthroplasty in patients with osteonecrosis, it has recently been questioned whether these invasive procedures are appropriate, given the potential difficulty of later conversion to a hip replacement[47].

One of the limitations of our literature analysis was that the majority of the reports reviewed were Level-III or IV studies. There is a need for more Level-I studies to better understand the efficacy of the various nonoperative and surgical techniques that have been reported to be used in the treatment of early stage osteonecrosis of the femoral head. Furthermore, because there is a lack of standardized clinical and radiographic evaluation criteria, any attempt to perform a meta-analysis is limited, and valid comparisons are difficult to achieve. Despite these limitations, the literature suggests that,

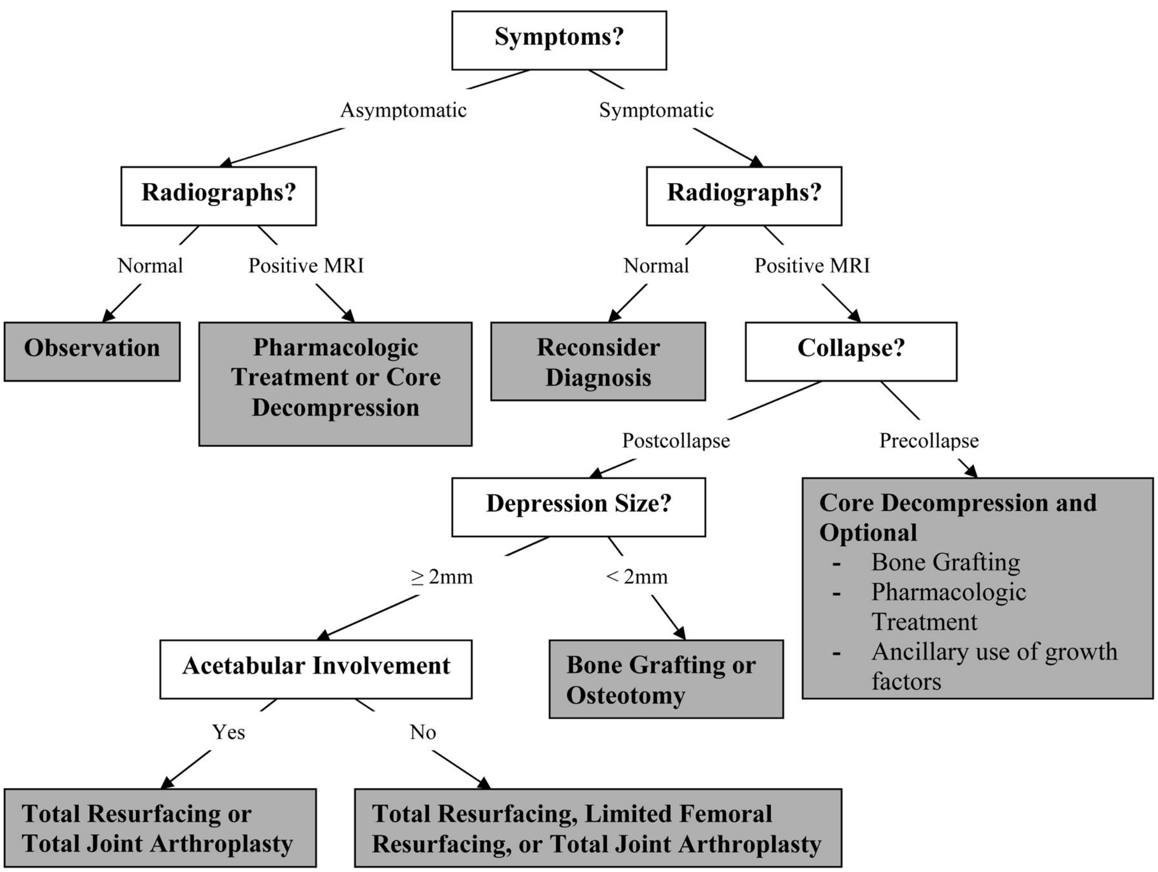


Fig. 4

The treatment for osteonecrosis of the hip should be determined on the basis of both the clinical and the radiographic assessment. MRI = magnetic resonance imaging. (Reprinted, with permission, from: Seyler TM, Marker D, Mont MA. Osteonecrosis. In: Klippel JH, Stone JH, Crofford LJ, White PH, editors. Primer on the rheumatic diseases. 13th ed. New York: Springer; 2008. p 571.)

in general, the various techniques are comparable.

There are a number of patient-specific factors that must be considered when determining a treatment plan for patients with osteonecrosis, including age and life expectancy, health, comorbidities, and activity level. Young or active patients who receive a total hip prosthesis are likely to require a revision at some point in their life. These patients should be considered as candidates for procedures such as core decompression or bone-grafting, which will delay the need for total hip arthroplasty. However, these procedures are only appropriate in patients whose hips are in the early stage of disease (Fig. 4).

## Appendix

eA Tables listing the details and results of the studies cited in this review can be found on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD/DVD (call our subscription department, at 781-449-9780, to order the CD or DVD). ■

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