ELSEVIER
SAUNDERS

Orthop Clin N Am 38 (2007) 13–22

ORTHOPEDIC
CLINICS
OF NORTH AMERICA

# Avascular Necrosis of the Femoral Head: Role of Vascularized Bone Grafts

J. Mack Aldridge, III, MD*, James R. Urbaniak, MD

*Division of Orthopaedic Surgery, Duke University Medical Center, P.O. Box 3293, Durham, NC 27710, USA*

Since the first description of osteonecrosis (ON) of the femoral head at the turn of the twentieth century [1], much has been written about its etiology, pathophysiology, and treatment. Unfortunately, few definitive conclusions have been drawn regarding its development or treatment. With an prevalence of between 10,000 and 20,000 new cases per year [2], combined with its devastating clinical consequences and propensity to afflict younger patients, ON continues to serve as the subject of considerable debate and research. Thanks, in large part, to an explosion of clinical and bench work investigations during the past few decades, we have begun to unravel the complexities of this process. For example, it is now known that chronic and high-dose steroid administration, alcohol abuse, trauma to the hip, coagulopathies, and abnormal vascular anatomy frequently are associated with, and implicated in, the development of ON [3]. It also is well established that this condition, if left untreated, progresses to femoral head collapse with subsequent hip degeneration in most cases [4]. Because of this tendency to progress and the high percentage of young and active patients that is affected, the ideal solution for this condition, short of prevention, is one that relieves pain, preserves or restores the sphericity of the femoral head, and ultimately prevents deterioration of the hip. It is hoped that fulfilling these treatment criteria would forestall or prevent the need for a second surgery (ie, arthroplasty), an important objective particularly for younger patients. Despite recent technological advances in total hip arthroplasty (THA), which is an excellent option for the older patient who has an arthritic hip joint, the activity level and longevity of younger patients who have ON continue to challenge the capabilities of THA. Furthermore, it often is difficult for the arthroplasty surgeon to feel justified in proceeding with THA simply for osteonecrosis of femoral head (ONFH)-related pain in patients who are younger than 50 years of age, particularly for the patient with a preserved joint space and no acetabular involvement.

It is important to remember the context in which the concept for vascularized bone grafting was conceived. In the late 1960s and early 1970s, when so many of the biologic-preserving procedures were conceptualized, a durable and reliable artificial hip prosthesis largely evaded orthopedic surgeons. Today, technologically advanced metals and polymers that are demonstrating excellent wear characteristics have allowed reconstructive surgeons the freedom of implanting such components in much younger patients, who only years ago would not have been given that option.

There is no consensual agreement among surgeons as to a single reliable surgical procedure, which can consistently achieve the objectives of removing the painful necrotic bone, while preserving the native hip geometry and restoring pain-free full hip range of motion. Conceptually, the best operation is one that removes the necrotic bone from the femoral head and replaces it with viable and structurally sound bone, thus restoring vitality to the femoral head, preventing collapse of the articular surface, and delaying, if not preventing, THA.

* Corresponding author.
*E-mail address:* aldri004@mc.duke.edu (J.M. Aldridge).

0030-5898/07/$ - see front matter 
doi:10.1016/j.ocl.2006.10.012

*orthopedic.theclinics.com*

Several approaches to treatment for ON of the femoral head have been described, including weight restriction and observation, core decompression, various osteotomies, bone grafting (structural or nonstructural and vascularized or nonvascularized), and arthroplasty (hemiarthroplasty, resurfacing techniques, total hip replacements). No single technique has emerged as the gold standard for all patients, largely because of the high variability among each case (patient age, medical comorbidities, degree of pain, stage of ON, patient expectations). Bone grafting, regardless of the specific type, is an attractive treatment option. It combines the benefit of decompressing the femoral head with the added benefit of introducing an osteoconductive or osteoinductive material into the devitalized head. Furthermore, such grafting preserves the shape of the femoral head and articular cartilage, unlike the osteotomy and arthroplasty techniques described. Several variations of grafting have been described and include debridement of the necrotic lesion with traditional corticocancellous or cancellous grafts (autologous and allogenic); resurfacing of the femoral head with fresh osteochondral allografts; debridement and revascularization with muscle pedicle grafts; and debridement and grafting with vascularized bone segments (iliac, tensor fascia lata, fibula). This article focuses on the various options for restoring vascularity to the necrotic femoral head, and attempts to outline the patient selection, surgical technique, and results of the authors' preferred method, the free vascularized fibular graft (FVFG).

## Vascularized bone graft

In an effort to address directly the devascularized status of the femoral head, certain investigators have described the transfer of vascularized bone grafts into the necrotic portions of the femoral head. Such a procedure, in addition to replacing necrotic bone with healthy bone, also establishes a new source of circulating blood, which provides osteoinductive progenitor cells for the purposes of restoring a healthy subchondral plate. Local, pedicled bone grafts and free vascularized bone grafts have been described. The latter requires a successful microscopic-assisted anastomosis, and, therefore, is considered more technically demanding. The benefits and potential pitfalls of each method are addressed.

## Local pedicle bone graft

Before the advent of microvascular surgery, surgeons who wanted to restore circulation to the femoral head were limited in doing so with only local pedicle bone grafts. The presumed superiority of vascularized pedicular bone grafts over nonvascularized bone graft was outlined nicely in 1984 [5]. Before this, in 1973, Meyers and colleagues [6] reported on 150 cases of displaced subcapital and transcervical fractures of the femoral neck that were treated with a quadratus muscle–pedicle–bone graft. They reported an impressive 95% union rate with only a 5% incidence of late segmental collapse. Later in 1978, Meyers [7] first reported on the application of this same muscle–pedicle bone graft for the treatment of femoral head ON in 23 patients. With follow-up available between 6 months and 2 years, good results were found in all 8 patients who had Ficat stages I or II disease, but in only 5 of 15 patients who had Ficat stages III or IV disease.

Lee and Rehmatullah [8] reported their findings with a muscle–pedicle–bone graft and cancellous bone graft for the "silent hip" in idiopathic ON of the femoral head. They reported a 70% success rate with their technique, noting—similar to Meyers' earlier observations—better success in patients who had Ficat stages I or II disease. The apparent lack of efficacy in treating Ficat stages III or higher disease limited this particular technique from widespread application.

In 1991, Baksi [9] reported his results at 3 to 12 years follow-up (mean, 7 years) in treating 61 patients (68 osteonecrotic femoral heads) with a variety of muscle–pedicle–bone grafts. Of the several types of muscle–pedicle–bone grafts used, the tensor fascia lata anteriorly and the quadratus femoris posteriorly were preferred. The technique in all cases consisted of a hip arthrotomy, multiple drillings of the necrotic lesion, and muscle–pedicle–bone grafting. For cases with advanced collapse, a cheilectomy of the superolateral portion of the femoral head and an adductor tenotomy were added; 83% of the patients obtained good or excellent results at follow-up. The investigator noted that patients who had traumatic or idiopathic ON tended to have better results, whereas those who had cortisone-induced ON had inferior results. Lastly, most of the patients in this study had advanced disease, with 82% of the cases demonstrating some degree of collapse.

In 1993, Iwato and colleagues [10] reported satisfactory outcome in 17 of 23 hips (74%) that were treated with deep circumflex iliac artery pedicled iliac crest bone graft. Most patients demonstrated no femoral head collapse preoperatively, but more than 50% had progressed to radiographic collapse at a mean follow-up of 3 years. It is difficult to predict the efficacy of this technique in addressing stage III or IV disease.

More recently, in 2002, Stein and colleagues [11] reported on their use of a vascularized muscle pedicle flap for the treatment of ON of the femoral head in 37 patients. Their composite flap of iliac crest and anterior half of the tensor fascia lata is based on the longitudinal artery perfusing the tensor fascia lata. There is no direct vascular pedicle to the bone. Instead, successful perfusion of the bone graft relies on indirect flow from the accompanying muscle. In their series, 86% had complete resolution of pain, none had a fixed flexion deformity, and 89% walked without a limp. The investigators did not comment on the absence or presence of these parameters preoperatively, nor did they quantify their follow-up period. In addition, the results are not stratified according to age, size of lesion, or stage of disease. Their results are encouraging; however, the lack of follow-up and lack of quantified data make interpretation of this technique and its subsequent application difficult. Finally, this technique relies on the metaplastic capabilities of muscle, which introduces another variable into the osteoneogenic process.

In support of this muscular metaplasia, in 1996, Forgon and Montsko [12] reported their experimental observations that in the devitalized femoral heads of rabbits, revascularization was quicker with the use of muscle–pedicle–bone grafts than with muscle–pedicle–bone grafts. The extent of revascularization was not quantified, but was graded rather subjectively. Also, healing was complete for both techniques by 12 weeks. The lack of structural support in using only a muscle pedicle graft and the lack of clinical trials to support its efficacy warrant judicious consideration of such a technique.

## Free vascularized bone graft

In the late 1970s, simultaneously, but separately, Judet and Gilbert, Brunelli, and Urbaniak began using the FVFG for the treatment of avascular necrosis of the femoral head. The development of the high-powered microscope provided surgeons the freedom to use nonpedicled grafts, which set the stage for this new technique. The fibula, with its corticocancellous bone stock, generous vascular pedicle (one artery and two accompanying veins), and low donor site morbidity, has emerged as the workhorse for free vascularized bone graft transfer. Largely because of the technically demanding nature of the case, experience with the FVFG has been limited to few centers around the world. Although each center uses the fibula as the vascularized bone graft, the technique relating to the fibular harvest and introduction into the femur varies in certain ways that are worthy of mention.

Judet and Gilbert [13] reported on their results using the FVFG at an average follow-up of 18 years. They described access to the femoral head through an anterior arthrotomy with evacuation of the necrotic bone, and replenishing the void with cancellous bone through an elevated trapdoor in the overlying cartilage and subchondral bone. The contralateral, rather than ipsilateral, fibula is harvested. Overall, 52% of their 60 patients had satisfactory results. The investigators noted a high incidence of hip stiffness, presumably due to the hip capsulotomy. Good results were obtained in 80% of patients who were operated on at 40 years of age or younger and in patients who had Marcus and colleagues' [14] stage II and III disease.

Brunelli and Brunelli [15] reported on their experience with an extra-articular bone grafting technique that is similar to the authors' technique in treating 61 patients who were followed up at a mean of 10 years. They noted 74% clinical survivorship, with 16 of 45 cases progressing to hip arthrosis. Of these 16, 8 required THA at an average of 9 years after grafting. Yoo and colleagues [16] published the results of the Korean experience with FVFG. Their series consisted of 121 patients, with 91% good or excellent results in 81 hips. Follow-up was possible at a minimum of 3 years (range, 3–10 years).

Zhang and colleagues [17] reported this year on the Chinese experience with FVFG. They reported on 48 patients (56 hips) with an average age of 37.7 years and an average follow-up of 16 months. Etiologies included trauma, steroids, alcohol, and idiopathy. Patients who had Steinberg grade II ON had better Harris hip scores at last follow-up than did patients who had Steinberg stage III or IV disease. The preoperative Harris hip scores for patients who had Steinberg grade II, III, or IV ON were 78.5, 69.3, and 58.4, respectively. At the most recent follow-up, the Harris hip scores improved to 94.4, 85.7, and 76.4, respectively. Dr. Zhang's technique requires an anterior arthrotomy, with the creation of an anterior cortical trough in the femoral neck. This allows for a shorter fibular pedicle and consequently, less dissection in the leg. The stress riser that is imparted by the trough in the femoral neck as well as the likelihood for hip stiffness and potential insult to the vascular supply following an arthrotomy should be considered when calculating the overall benefit of this particular technique.

In 2005, Dr. Shaffer of Cleveland, Ohio reported his series of 101 hips that was treated with vascularized fibular grafting with a minimum 5-year follow-up [18]. Sixty-one percent of the hips had not been converted to THA at the 5-year mark, and 42% survived until the 8-year postoperative mark. The average Harris hip score for the cohort improved from 58 $\pm$ 13 preoperatively to 80 $\pm$ 15 at the 5-year mark. Of the 81 patients who were living at the time of final review, 46 stated that they would undergo the procedure again. The study group consisted of varying degrees of femoral head involvement, with most patients having preoperative collapse. These investigators concluded that vascularized fibular grafting may provide a chance for normal hip function in the intermediate or long term in carefully selected patients. Their technique varied from the authors' technique in that they had a single operative team, which increases the operative time, and, more specifically, the time between graft harvest and re-establishment of fibular perfusion. Secondly, their harvested pedicle was shorter, and, thus required more extensive donor vessel dissection. They commented that the 6-month postoperative radiographs showed incorporation of all fibulas, and concluded that such added vessel mobilization did not affect their outcomes adversely.

A recent comparative study between nonvascularized and vascularized fibular grafts for large ON lesions of the femoral head demonstrated superiority of the vascularized graft specifically in postcollapse lesions of the femoral head [19]. Forty-six hips were matched according to size of lesion, etiology, and stage and were evaluated prospectively at 4 years. The investigators concluded that the hips that were treated with vascularized fibular grafting did better clinically and radiographically than did those comparatively matched hips that were treated with nonvascularized fibular grafts. In point of fact, at the 4-year follow-up period, the hips that were treated with vascularized fibular grafts showed better postoperative Harris hip scores (70% versus 35% improvement), statistically less radiographic progression and collapse, and statistically less mean dome depression. The investigators further concluded that the results of vascularized grafting were best when the procedure was used to treat precollapse lesions. All vascularized fibular grafts were transplanted with a cutaneous buoy flap for postoperative surveillance. The vitality of these buoy flaps, the investigators contend, is proof that all of the transplanted fibulas remained perfused and viable. Use of the buoy flap as a sentinel for the fibula's vitality was published first in 1983 by Yoshimura and colleagues [20]. There is no uniform agreement among surgeons who perform this and similar operations that such a skin paddle is required.

The senior author (JRU), early in his experience with the FVFG procedure, obtained routine postoperative arteriograms to evaluate the patency of the anastomosis. Convinced of the reproducibility in perfusing and maintaining patency within the transplanted fibular vessels, we have not used a buoy flap or any other immediate postoperative vessel monitoring. Although the utility of the buoy flap is unquestioned, its large donor site morbidity—a real concern for some of the younger, more cosmetically conscious patients—tempers our enthusiasm for incorporating this technique into our practice.

## The Duke experience

ON of the femoral head, in any patient, is a troubling diagnosis, but it is intensified when the patient is young and active. The authors believe that the FVFG ideally is indicated for the younger, active patient who has precollapse femoral head ON. The average age of the authors' patients is 33 years. THA in such a young active individual is not an ideal solution given the current implant design and wear characteristics, although these have improved dramatically over the past decade. There are no absolute exclusion criteria with regard to age for FVFG; however, as patients approach 50 years of age, the authors consider more heavily the relative benefits of THA, taking into account the percentage of femoral head involvement, presence of collapse, and the degree of hip motion. With the occasional exception of patients who have early stage I ON, the authors believe that core decompression alone inadequately addresses the pathology. They reason that if consideration is given to decompress the femoral head, why not insert bone into the void for osteoconductive properties and support? To continue that line of thought, why not insert a vascularized corticocancellous bone to provide support and osteoconductive and osteoinductive properties? Such thinking led us to use the FVFG routinely in treating ON of the femoral head. Prospective and retrospective studies have demonstrated higher success rates (ie, lower rates of conversion to total hip replacement) with vascularized bone grafting over core decompression for treatment of ON of the femoral head [21,22]. Our published data demonstrated near equal rates of success between core decompression and vascularized bone grafting for Ficat stage I disease, but exposed a significant disparity between success rates for Ficat stages II and III disease. Our survival rates at 50 months for hips with Ficat stage II and III disease that were treated with vascularized bone grafting were 89% (111 hips) and 81% (500 hips), respectively. The survival rates for hips with Ficat stage II and III disease that were treated with core decompression were 65% (48 hips) and 21% (47 hips), respectively [22].

The senior author (JRU) has performed more than 2600 FVFGs to the femoral head for treatment of symptomatic ON during the period from 1979 to 2006. Certain trends have emerged from this experience. With regard to progression, our observation has been that for an asymptomatic opposite hip with no evidence of ON, the likelihood for developing symptomatic ON is 7.8%. If, at presentation, the uninvolved asymptomatic hip demonstrates findings that are consistent with stage I (abnormal MRI) ON, there is a 28% chance of disease progression and the development of symptoms in that hip. For an asymptomatic opposite hip with radiographic findings that are indicative of stage II or III disease, there is an 82% chance of radiographic or clinical progression [23]. The authors investigated which factors affected progression and found that the Marcus and Enneking stage, percent of head involvement at presentation, and etiology were most predictive of progression.

For our series, at the most recent review, there was an 88% success rate [24] associated with vascularized fibular grafting if there was no collapse of the femoral head (either stage I or II). The success rate decreased to 78% if there was any degree of subchondral fracture or collapse (stage III or IV). The success rate for patients with an articular step-off of between 1 and 3 mm decreased even lower to 68.9% at the 5-year mark. Typically, patients with idiopathic or alcohol-related ON had worse outcomes. Subjectively, patients did equally well; 81% of patients were satisfied with their decision to have FVFG and 86% of patients reported a decrease in their need for pain medicine.

We offer the procedure to symptomatic patients who are younger than 50 years of age and have stage II, III, or IV disease (Fig. 1). Patients who are younger than 20 years of age and have stage V ON with preserved hip motion also are candidates for the procedure. There has been particular controversy regarding the management of stage I ON. We offer patients who have symptomatic stage I ON the vascularized fibular grafting technique more often than core decompression. In our hands, core decompression is effective only for patients who are younger than 50 years of age, with a stage I or stage II central lesion of dense bone (not cystic) involving less that 25% of the femoral head. If performed outside of these parameters, we believe that core decompression may exacerbate the already compromised vascular status of the femoral head, and ultimately hasten progression of the condition. We recommend total hip replacement for patients who are older than 50 years of age with any degree of symptomatic ON or patients who are older than 40 years who have advanced stage IV disease or greater than 50% involvement of the femoral head and limited hip motion. We do not operate on patients with asymptomatic hips, but rather follow them closely and offer free vascularized fibular grafting when they develop symptoms or demonstrate radiographic progression of the condition.

The technique for performing this procedure was reported recently [25]. Certain points and potential pitfalls are worthy of recapitulation. The preoperative work-up consists of a thorough physical examination that focuses on the hip motion and establishment of distal leg blood flow. The dorsalis pedis and posterior tibial arteries must be palpated or auscultated with a Doppler probe. If either is undetectable, then an arteriogram is obtained. This has been a rare occurrence in our experience (<0.2%). General anesthesia is used, and is augmented with an epidural for vasodilatation of the anastomosed vessels and for postoperative pain management. The surgery is performed with the patient in the lateral decubitus position. The hip incision is curvilinear, apex anterior, with the proximal one

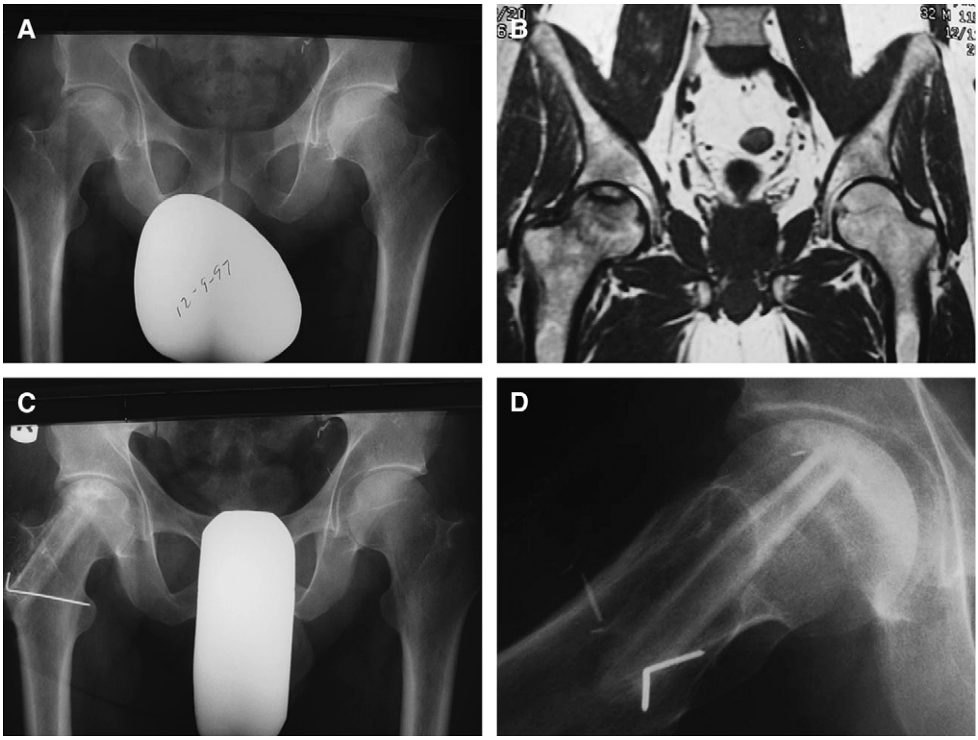


Fig. 1. (*A*) Anteroposterior (AP) radiograph of the pelvis of a 32-year-old man with steroid-related femoral head osteonecrosis. Demonstrated is the characteristic lesion in the anterolateral portion of the femoral head. Note the rim of increased density indicative of necrotic bone. The femoral head remains round without evidence of collapse and the joint space is well preserved. (*B*) T1-weighted coronal MRI of the same patient showing the pathognomonic serpiginous border between viable and nonviable bone in the upper weight-bearing portion of the right femoral head. (*C*) AP pelvis radiograph of the same patient 8 years following FVFG. Notice preservation of the femoral head sphericity, no appreciable joint space narrowing, and good fibular graft incorporation. (*D*) Lateral radiograph of the same patient 8 years after the FVFG procedure. Mild flattening of the femoral head is seen, but no articular collapse and absence of a crescent sign is noted.

third cephalad to the vastus ridge. With the help of a specially designed "four-quadrant" retractor, the interval between the tensor fascia lata and the gluteus medius is exposed. The vastus lateralis is reflected from its origin extending distally 6 to 8 cm, which exposes the posterolateral aspect of the proximal femur. The interval between the rectus femoris and vastus intermedius is exposed. It is here that the ascending branch of the lateral femoral circumflex artery and its two accompanying veins course at a 45° cephalad direction toward the hip (Fig. 2). These three vessels are dissected carefully from the surrounding soft tissues and reflected down. Complete release of the origin of the vastus intermedius fibers allows for an unencumbered path for the vessels as they are rotated toward the lateral aspect of the femur for the

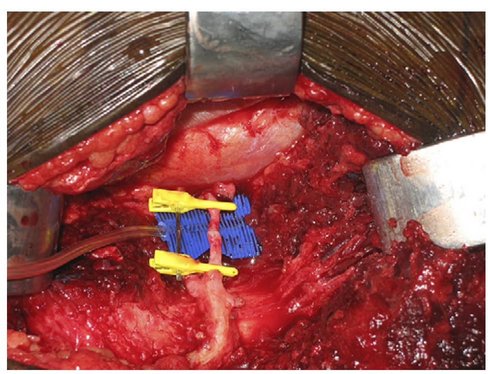

Fig. 2. Ascending branch of the lateral femoral circumflex artery (reflected from its natural course between the rectus femoris and the tensor fascia lata) before anastomosis with the peroneal artery.

anastomosis. The necrotic bone within the femoral head is accessed by way of a core that is created at the lateral aspect of the greater trochanter (Fig. 3).

The fibula is harvested simultaneously during the hip approach (Fig. 4). A straight lateral 15-cm longitudinal incision is made coincident with the natural sulcus between the lateral and posterior compartments of the leg. The incision is begun approximately 10 cm distal to the fibular head and ends 10 cm proximal to the lateral malleolus. The fascia of the lateral compartment is incised

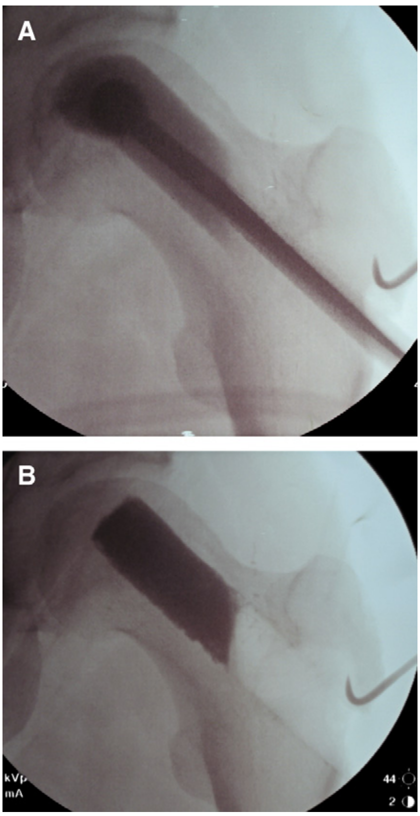


Fig. 3. (*A*) Contrast dye study of a femoral head undergoing removal of necrotic bone. A custom-made spherical reamer is used to remove as much of the necrotic lesion within the femoral head as is structurally prudent. Access to the necrotic lesion is from the lateral femur and contained within the bone. (*B*) Contrast dye study of the same femoral head after the necrotic lesion has been partially excavated and the resultant void was filled with autogenous bone graft (harvested from the greater trochanter). Note the squaring off or tapering of the core, indicating that the excavated area (previously seen as the bulbous area) has been filled adequately with cancellous bone graft.

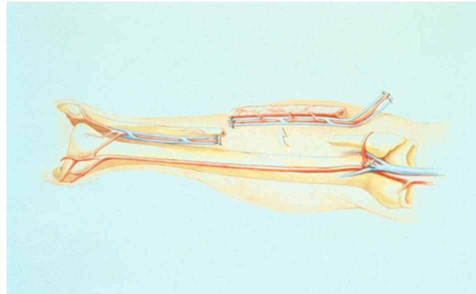

Fig. 4. Illustration showing the harvest of the fibula. The nutrient vessels enter the fibula predictably within the middle third of the bone. (*From* Lieberman JR, Berry DJ, Mont MA, et al. Osteonecrosis of the hip: management in the twenty-first century. Instructional Course Lectures 2003;52:343; with permission.)

in line with the skin incision, which exposes the peroneal muscles. The peroneals are reflected anteriorly off the lateral aspect of the fibula, until the anterior intermuscular septum is visualized. To preserve the periosteum, which the authors believe contributes greatly to the success of the vascularized graft, they recommend retaining a thin ($<1$ mm) layer of muscle, which ensures its protection.

The anterior intermuscular septum is divided, exposing the anterior musculature, which also is reflected off the fibula. The interosseous membrane is visualized easily and the adjacent anterior musculature and accompanying deep peroneal nerve and anterior tibial artery are gently swept off the interosseous membrane away from the fibula. With the use of a specially designed right-angle beaver blade, the interosseous membrane is divided close to its fibular attachment along the entire length of the proposed fibular graft. The posterior intermuscular septum is divided, which exposes the posterior muscles (the soleus proximally and the flexor hallucis longus distally).

The distal and proximal pedicles of the peroneal vessels are identified to ensure their protection during the fibular osteotomy. An oscillating saw is used to cut the fibula. The fibular cuts are made 15 cm apart, to ensure an adequate pedicle length. When performing the proximal osteotomy, it is important to identify and protect the superficial peroneal nerve, which is exposed proximally on the deep surface of the peroneus longus muscle.

Once the fibula has been cut proximally and distally, the distal peroneal vessels are identified again, isolated, and divided with the use of hemostatic clips. The now free distal pedicle is attached to the distal aspect of the fibula with a hemoclip to ensure that the peroneal vessels and any nutrient branches to the bone are not avulsed from the fibula during the remainder of the harvest. The fibula and adjoining peroneal vessels are dissected from the surrounding flexor hallucis longus, posterior tibialis, and soleus muscles. The fibula is elevated until it is tethered only by the proximal vascular pedicle. Once 4 to 5 cm of pedicle length is dissected, the pedicle is ligated with two large hemostatic clips and divided just distal to its origin from the posterior tibial vessels. The tourniquet is deflated and the fibular graft is passed to the back table for implant preparation. Once the exact length of fibula required has been determined from preparation of the proximal femur, this length is measured and marked on the fibular graft. The graft is inserted into the femoral head and the anastomosis is performed (Fig. 5). The leg wound is closed a short time later during the vascular anastomosis at the hip. The deep fascial layers of the leg are not reapproximated to prevent the development of a compartment syndrome.

For patients who have precollapse lesions, great care should be taken while excavating the necrotic bone to limit reamer/drill encroachment to less than 4 mm from the subchondral plate, to prevent unwanted subchondral collapse. In contrast, for patients who have established flattening or mild collapse, drilling up to within 2 to 3 mm of the subchondral surface is recommended to allow the surgeon an opportunity to restore some of the head's sphericity with advancement of an impactor, and, ultimately, the bone graft.

Fig. 5. The surgeons stand while anastomosing the femoral (ascending branch of lateral circumflex) and peroneal vessels. The patient is in the lateral position.

**Pearls and pitfalls**

The senior author (JRU) has modified and refined the FVFG procedure over the past 25 years. Such an extensive experience has led to several conclusions regarding critical points to avoid or adhere to for maximizing the success of the procedure. Several important considerations warrant mention. First, as in any microsurgical procedure, respectful handling of the vessels and a tension-free anastomosis is paramount to reestablishing and maintaining adequate blood flow. Ensuring adequate pedicle length during the fibular harvest is an important prerequisite for a tension-free vessel repair. We have found that a minimum 4-cm pedicle suffices for a tension-free repair. Another detail, which is overlooked easily, is monitoring for small leaks from perforators off the main peroneal vessels before inserting the fibula into the femur. Such inspection can be performed by irrigating the pedicle vessels with heparin by way of a blunt-tip syringe and watching for any leaks. Typically, we address any small leaks with microvessel clips or 6-0 monofilament suture. Lastly, securing the pedicle to the end of the fibula to be inserted into the head of the femur prevents unwanted stripping of the pedicle from the fibula as it passes through the core in the proximal femur. Intraoperative fluoroscopy can confirm preservation of the pedicle by highlighting the vessel clip placed on the end of the fibula. Visualization of this clip in the subchondral area confirms that the pedicle has been preserved longitudinally. Circumferential preservation of the pedicle is best ensured with a capacious femoral core, which allows unencumbered passage of the fibula up to the target area of the femoral head (Fig. 6). Conversely, overaggressive drilling of the proximal femur makes a core that is too large for the fibula and may lead to an increased risk for fracture and poorer incorporation of the graft. Before removing the microscope from the operative field after completion of the arterial anastomosis, we inspect and document backflow from the fibular endosteal vessels (Fig. 7), which can be seen readily as the fibula extends to the lateral margin of the trochanter.

**Complications**

Our experience with infections has been limited, largely attributable to the establishment of additional bleeding without placement of any sizable foreign materials. Five patients out of

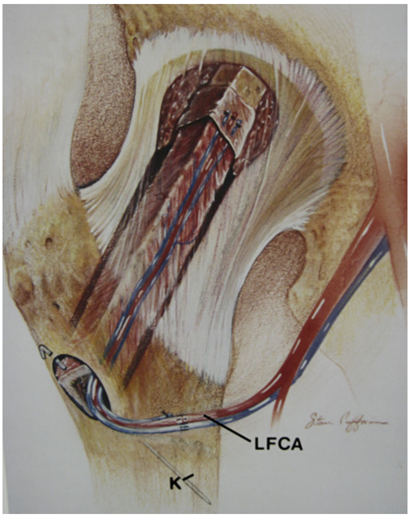


Fig. 6. Illustration showing the placement of the fibula within the femoral head. Note the capacious space to allow for pedicle blood flow. Also demonstrated is the bulbous area of removed necrotic bone that is filled with cancellous graft from the trochanter. K, Kircshner wire; LFCA, lateral femoral circumflex artery. (*From* Lieberman JR, Berry DJ, Mont MA, et al. Osteonecrosis of the hip: management in the twenty-first century. Instructional Course Lectures 2003;52;343; with permission.)

2600 required surgical washouts of the hip incision and roughly twice that number of patients had superficial cellulitis, which responded to oral antibiotics. More frequently encountered is a contracture of the great toe. This has occurred in the our series in roughly 3% of cases. We performed z-lengthenings of the flexor hallucis longus in those patients whose contracture was profound enough to impede normal gait or cause painful pressure on the tip of the toe.

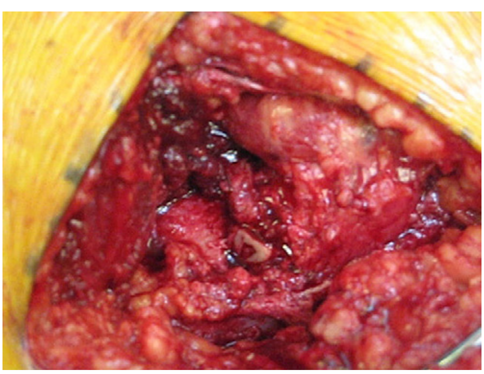

Fig. 7. The exposed end of the fibula along the lateral aspect of the femur can be visualized for bleeding once the anastomosis has been completed.

Subtrochanteric femur fracture is a devastating complication that, despite warnings and avoidance education, continues to occur at a rate of 1 per 100 patients. The rate was higher than this until we stopped harvesting from the greater and lesser trochanters. Since limiting the harvest of cancellous graft to only the greater trochanter, our incidence of subtrochanteric fractures has decreased to 1%. Most of these occur at the 6- to 8-week postoperative mark when patients begin to feel better and place excessive weight on the leg with a torsional force applied (eg, standing with weight on the leg and turning to look). In the past, these fractures were treated with a 95° side plate and screws with sacrifice of the fibular vessels; however, we recently have used the new proximal femoral locking plate from Synthes (Paoli, Pennsylvania). It is possible to use this plate, adequately securing the femoral fracture fragments while avoiding and preserving the fibular vessels, which is an exciting advancement in fracture fixation for this particular problem.

Irritation of the superficial lateral cutaneous branch of the peroneal nerve occurs to some degree in fewer than 10% of patients; in most of these patients, it resolves completely by the 6-month postoperative visit. We have had no permanent motor nerve injuries to the foot/ankle.

## Summary

Vascularized bone grafting to the femoral head has been described for several decades by surgeons from multiple countries. Although the particulars of the procedure vary among the different surgeons, the objectives are common: removing necrotic bone from the femoral head in a way that does not destabilize the subchondral plate and replacing this excavated area with structurally sound bone replete with an autogenous and re-established blood source.

At our institution, with the principles of microsurgery followed closely and patient selection scrutinized, we have observed a 5-year 80% success rate among patients from all stages. We define success as a significant improvement in the Harris hip score and no conversion to THA.

## References

[1] Paget J. Mortification lecture on surgical pathology. Lecture XIX:301–32-, 1860. Twynham GE: A case of Caisson disease. Br Ved J 1888;1:190–1.

[2] Mankin HJ. Nontraumatic necrosis of bone (osteonecrosis). N Engl J Med 1992;326:1473–9.

[3] Vail TP, Covington DB. The incidence of osteonecrosis. In: Urbaniak JR, Paul JP, editors. Osteonecrosis: etiology, diagnosis, and treatment. Rosemont (IL): American Academy of Orthopaedic Surgeons; 1997. p. 43–9.

[4] Merle d' Aubigne M, Postel M, Mazabraud A, et al. Idiopathic necrosis of the femoral head in adults. J Bone Joint Surg 1965;47B:612–33.

[5] Chacha PB. Vascularized pedicular bone grafts. Int Orthop 1984;8(2):117–38.

[6] Meyers MH, Harvey JP Jr, Moore TM. Treatment of displaced subcapital and transcervical fractures of the femoral neck by muscle-pedicle-bone graft and internal fixation. A preliminary report on one hundred and fifty cases. J Bone Joint Surg Am 1973;55(2):257–74.

[7] Meyers MH. The treatment of osteonecrosis of the hip with fresh osteochondral allografts and with the muscle pedicle graft technique. Clin Orthop 1978;Jan-Feb(130):202–9.

[8] Lee CK, Rehmatullah N. Muscle-pedicle bone graft and cancellous bone graft for the ''silent hip'' of idiopathic ischemic necrosis of the femoral head in adults. Clin Orthop 1981;Jul-Aug(158):185–94.

[9] Baksi DP. Treatment of osteonecrosis of the femoral head by drilling and muscle-pedicle bone grafting. J Bone Joint Surg Br 1991;73(2):241–5.

[10] Iwato H, Torii S, Hasegqwa Y, et al. Indications and results of vascularized pedicle iliac bone graft in avascular necrosis of the femoral head. Clin Orthop 1993;295:281–8.

[11] Stein H, Volpin G, Horer D. Vascularized muscle pedicle flap for osteonecrosis of the femoral head. Orthopedics 2002;25(5):485–8.

[12] Forgon M, Montsko P. Muscle-pedicle grafts or muscle-pedicle-bone grafts in the treatment of avascular necrotic femoral heads. Arch Orthop Trauma Surg 1996;115(3–4):223–6.

[13] Judet H, Gilbert A. Long-term results of free vascularized fibular grafting for femoral head necrosis. Clin Orthop 2001;May(386):114–9.

[14] Marcus ND, Enneking WF, Masam RA. The silent hip in idiopathic aseptic necrosis: treatment by bone-grafting. J Bone Joint Surg 1973;55A:1351–66.

[15] Brunelli G, Brunelli G. Free microvascular fibular transfer for idiopathic femoral head necrosis: long-term follow-up. J Reconstr Microsurg 1991;7:285–95.

[16] Yoo MC, Chung DW, Hahn CS. Free vascularized fibular grafting for the treatment of osteonecrosis of the femoral head. Clin Orthop 1992;277:128–38.

[17] Zhang C, Zeng B, Xu Z, et al. Treatment of femoral head necrosis with free vascularized fibula grafting: a preliminary report. Microsurgery 2000;25(4):305–9.

[18] Marciniak D, Furey C, Shaffer JW. Osteonecrosis of the femoral head. A study of 101 hips treated with vascularized fibular grafting. J Bone Joint Surg-A 2005;87(4):742–7.

[19] Kim S-Y, Kim Y-G, Kim P-T, et al. Vascularized compared with non-vascularized fibular grafts for large osteonecrotic lesions of the femoral head. J Bone Joint Surg Am 2005;87(9):2012–8.

[20] Yoshimura M, Shimamura K, Iwai Y, et al. Free vascularized fibular transplant. A new method for monitoring circulation of the grafted fibula. J Bone Joint Surg Am 1983;65(9):1295–301.

[21] Kane SM, Ward WA, Jordan LC, et al. Vascularized fibular grafting compared with core decompression in the treatment of femoral head osteonecrosis. Orthopedics 1996;19:869.

[22] Scully SP, Aaron RK, Urbaniak JR. Survival analysis of hips treated with core decompression or vascularized fibular grafting because of avascular necrosis. J Bone Joint Surg Am 1998;80:1270.

[23] Davidson JJ, Coogan PG, Gunneson EE, et al. The symptomatic contralateral hip in osteonecrosis of the femoral head. In: Urbaniak JR, Jones JP, editors. Osteonecrosis: etiology, diagnosis, and treatment. Rosemont (IL): American Academy of Orthopaedic Surgeons; 1997. p. 231–40.

[24] Urbaniak JR. Osteonecrosis of the hip: management in the 21st century. Presented at the meeting of the American Academy of Orthopaedic Surgeons. San Francisco, March 10–14, 2004.

[25] Aldridge JM, Berend KH, Gunneson EE, et al. Free vascularized fibular grafting for post-collapse osteonecrosis of the femoral head: a technique guide. J Bone Joint Surg Am 2004;86-A(Suppl 1):87–101.