

Vascularized Fibular Grafting for Osteonecrosis of the Femoral Head With Unusual Indications

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

Published online: 21 March 2008
© The Association of Bone and Joint Surgeons 2008

Abstract We retrospectively reviewed the charts of 154 patients of various subgroups treated with the free vascularized fibular graft procedure for osteonecrosis of the femoral head (ONFH), evaluating pre- and postoperative Harris hip scores, hip range of motion, radiographs, and number of conversions to total hip arthroplasty (THA). Patients were followed a minimum of 1 year (mean, 6.8 years, range, 1 to 19 years). Athletes and patients with pyarthrosis-related osteonecrosis had high Harris hip scores at final review with scores of 94 and 97, respectively. Patients with ONFH after a slipped capital femoral epiphysis or following pregnancy had a low conversion rate to THA at 6% and 8%, respectively. Twenty-five percent of patients with transplant-related osteonecrosis of the femoral head were converted to THA at an average of 2.7 years. However, with select subsets of patients (athletes, pregnancy, organ transplant, femoral neck non-union, slipped capital femoral epiphysis, infection) the FVFG can result in a high rate of success.

Level of Evidence: Level IV, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

J. M. Aldridge III (✉), J. R. Urbaniak
Division of Orthopaedic Surgery, Duke University Medical Center, 3116 North Duke Street, Durham, NC 27704, USA
e-mail: aldri004@mc.duke.edu; julian.aldridge@duke.edu

Introduction

Free vascularized fibular grafting (FVFG) for the treatment of osteonecrosis of the femoral head (ONFH) was first described in the 1970s concurrent with the emergence of microsurgical techniques and during a time when durable and predictable hip arthroplasty components were not readily available.

Because ONFH tends to affect younger patients, most surgeons have traditionally believed any procedure aimed at preserving the patient's native hip preferable. That remains true today, although our enthusiasm for the FVFG procedure in patients between the ages of 40 and 50 years with preoperative femoral head collapse is tempered with our acknowledgment of time-proven hip arthroplasty as a reasonable surgical alternative. We recognize the FVFG procedure is not a panacea for ONFH nor is it indicated for all patients with ONFH; however, drawing from our experience with over 7000 cases of ONFH and performing over 2800 FVFG procedures, certain trends have emerged with respect to patient selection, outcomes, and technical refinements.

We have reviewed select subsets of patients with ONFH treated with the FVFG and have updated reviews of previously reviewed groups [11, 16, 18] in hopes of identifying in which patients this procedure is beneficial. We provide evidence for our belief that the FVFG procedure remains a reasonable and effective option in patients with ONFH and will and continue to have a role in the foreseeable future.

Materials and Methods

For this article we retrospectively reviewed the charts of selected nonconsecutive subsets of over 2,800 patients who underwent FVFG and whom we presumed had performed better postoperatively than our general population with

ONFH. These subsets included: athletes ($n = 15$, 19 hips), pregnancy ($n = 39$ patients, 41 hips), organ transplant ($n = 36$ patients, 47 hips), femoral neck nonunion ($n = 22$ patients, 22 hips), slipped capital femoral epiphysis ($n = 31$ patients, 36 hips), infection ($n = 11$ patients, 11 hips). We prospectively contacted all patients directly in these subsets with followup questionnaires (Harris hip score and SF-12). For the physical examination portion of the Harris Hip evaluation, we either brought patients back to the clinic for an examination or, for patients who lived too far away to return directly to us, we used hip range of motion measurements from their local orthopaedic surgeon. All patients were diagnosed with osteonecrosis of one or both femoral heads and were referred to our institution where either author (JMA, JRU) performed a vascularized fibular graft. The surgical technique has been described previously [1] and has changed little in the 30 years since it was first introduced. A few minor and recent additions to the procedure are detailed in the Discussion section of this paper. Both authors perform the procedure identically. We obtained prior approval from the Committee on Clinical Investigation of our Institutional Review Board. We offer the procedure to patients under 50 years of age, with symptomatic ONFH, and with little or no articular stepoff in the femoral head.

Patients were followed at the following postoperative times: six weeks, 3 months, 6 months, one year, then yearly thereafter. Preoperatively and on each postoperative visit we (JRU, JMA) determined hip range of motion and the Harris hip score. We determined patient satisfaction by the SF-12 form. We consider an outcome as successful if the patient has an improvement in or absence of pain, an improved Harris hip score, and preservation of their native hip (ie, no hip arthroplasty) at last followup.

We also obtained an anteroposterior (AP) pelvis and frog leg lateral radiographs of the operative hip at each visit. We (JRU, JMA) determined on each film the size and location of the necrotic lesion and the presence or absence of collapse and/or joint space narrowing. Size of the lesion was determined by the authors' (JRU, JMA) estimation of percentage involvement on the AP and lateral radiograph and the coronal and axial magnetic resonance imaging. From this, a number is then selected that represents a percentage of a sphere.

Athletes with Osteonecrosis of the Femoral Head

Athletes with their drive to succeed and disciplined approach to overcoming physical challenges appear to have particular benefit from the FVFG procedure. Coincidentally, this is a group of patients in whom a biology-sparing procedure is particularly attractive for allowing unrestricted return to sporting activities. The obligate restrictions of hip

resurfacing or THA frequently herald the end of competitive sports participation and, as such, are typically viewed as last options for this group of patients.

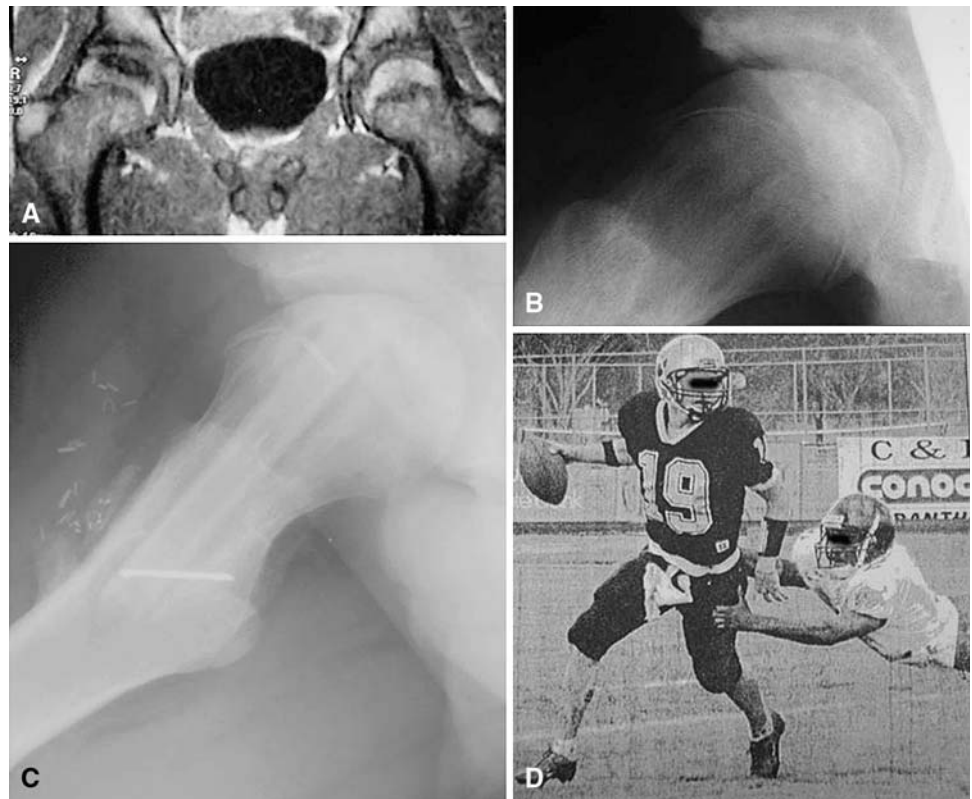
We have performed the FVFG procedure on 15 athletes (19 hips). The various sports included baseball, basketball (one patient was on a national women's basketball team), ballet, football, roping horses, downhill skiing, triathlons, gymnastics, and volleyball. Not included was the typical "weekend athlete," but rather these were all competitive athletes on the high school, intercollegiate, or professional level. The average age of the patients was 27.8 years (range, 11–43 years). There were 10 male and five female patients. The hips were classified as Stage II in six patients, Stage III in two patients, Stage IV in six patients, and Stage V in one patient, using the Steinberg classification. Etiologies of ONFH included idiopathic in eight, trauma in two, alcohol in two, corticosteroids in one, Legg-Calvé-Perthes in one, and hemangioma of the femoral head with osteonecrosis in one. Followup was available for all 15 athletes at a mean of 8 years (range, 1.8–19 years).

The mean Harris hip score improved from 73.6 (range, 17–96) preoperatively to 94 postoperatively. Average final hip flexion for 12 hips in which range of motion data were available was 113° (range, 75° – 130°). Radiographic changes were noted in three patients (two joint space narrowing; one femoral head collapse), whereas the remaining 12 patients showed no further collapse or change in their hip joint space. Eleven patients (73%) postoperatively returned to athletic activities and eight of these patients believed they could perform at the same level of competition as before developing ONFH. One such patient returned to competitive football within 9 months following the FVFG procedure (Fig. 1A–D). Three hips were converted to THA at an average of 10 years (one hip at 3 years, one at 9 years, and one at 17 years after FVFG). Patients rated their overall satisfaction (SF-12) with the procedure as extremely satisfied in 10, moderately in four, and slightly satisfied in one.

Pregnancy-related Osteonecrosis of the Femoral Head

We earlier reported treating female patients with the FVFG procedure for pregnancy-related ONFH [14]. The average age in this cohort of 39 patients was 33.1 years. The stage at time of presentation for the group was Steinberg Stage I ($n = 1$), Stage II ($n = 8$), Stage III ($n = 3$), Stage IV ($n = 25$), Stage V ($n = 1$), and Stage VI ($n = 1$). We followed these patients a minimum of 24 months (mean, 46 months; range, 24 to 95 months). Of these 39 patients, one presented with unilateral disease of the right femoral head, whereas two had bilateral involvement and the remainder ($n = 36$) had ONFH of the left femoral head. Our results with the FVFG procedure for pregnancy-related

Fig. 1A–D (A) A pelvic MRI of a sixteen year old with septic-related ONFH is shown. (B) This lateral radiograph shows increased density of the epiphysis and irregularity and collapse of the subchondral bone. (C) The one-year radiograph demonstrates good fibular incorporation and preservation of the femoral head preoperative state. In fact, it appears there has been some improvement. (D) Three years after the FVFG procedure, the patient played quarterback for his high school football team.



ONFH have been consistently good with a 94% success rate at 5 years. Average preoperative Harris hip score was 44.2 (range, 26–93) for the group, improving to 80.2 (range, 22–100) at final followup. Hip motion remained the same or improved for every patient. Two patients' hips were converted to THA at 2 and 14 years after the FVFG procedure. Both of these patients had collapse of the femoral head prior to surgery with approximately 40% involvement of the femoral heads.

When evaluating a pregnant patient with new-onset hip pain, it is important to distinguish ONFH from bone marrow edema syndrome (BME), a condition known to occur with greater frequency in pregnant women. BME is a poorly understood entity but is easily distinguished from ONFH because the latter has a characteristic serpiginous border between viable and nonviable bone seen on T1- and T2-weighted MRI images (Fig. 2). BME will not have this distinct serpiginous border and, unlike ONFH, BME will have bone marrow signal changes extending down the femoral neck into the trochanteric region. Furthermore the MRI changes seen in BME syndrome ultimately reverse to normal, whereas those changes from ONFH persist or enlarge with time.

Patients Who Have Undergone Transplantation

We have performed the FVFG procedure for transplant-dependent steroid-induced ONFH in 36 patients (47 hips).

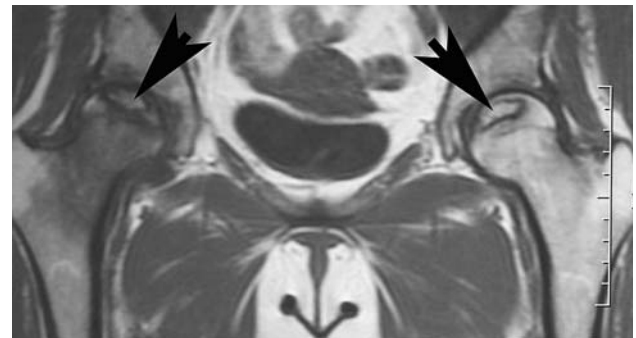


Fig. 2 A T1-weighted coronal MRI image shows a patient with osteonecrosis of the left femoral head. The arrow is pointing to the characteristic serpiginous border between nonviable and viable bone.

Followup was available for all 36 patients at a minimum of 1 year (mean, 4.3 years; range, 1–16 years). Eleven patients (23%) have had conversions to THA. The average time to conversion was 2.7 years (range, 1.5–4.0 years). Preoperatively, eight of those 11 patients had at least 50% estimated involvement of the femoral head. We now consider the percentage of femoral head involvement in our decision to offer the FVFG procedure. We are continually challenged in deciding who would benefit most from this procedure, especially because patients having undergone renal transplantation are also not ideal recipients of THA. Although a 25% THA conversion rate might imply to some a contraindication to the FVFG procedure, we believe the many more

patients who continue to function well with their native hips is rather an indication. For example, a 32-year-old man underwent renal transplantation for glomerulosclerosis and 2 years afterward developed left-sided groin pain. Subsequent workup revealed Steinberg et al. [16] Stage IVB ONFH and he was referred to our institution for consideration of the FVFG procedure. Because of his young age, preserved joint space and, equally important, his hip motion, we performed FVFG. He is now 8 years postsurgery and walking without a limp or hip discomfort. His Harris hip score improved from 73 to 100 at final followup. Harris hip scores for this cohort improved from 58.6 (range, 18–83) preoperatively to 81.3 (range, 33–100) postoperatively.

Femoral Neck Nonunion

A unique group of patients to whom we offer FVFG are those patients with concomitant ONFH and femoral neck nonunion. The risk of developing posttraumatic ONFH in patients with femoral neck fractures is well established [3, 18]. The concern for nonunion in this particular fracture is also well recognized in the literature [6]. Despite an awareness of these potential complications and a timely and anatomic reduction of the fracture, not infrequently, either femoral neck nonunion and/or ONFH still occur. This is a particularly devastating problem for the younger

patient (< 40 years of age) in whom THA is considered a salvage procedure and imparts certain lifestyle restrictions, potentially interfering with avocational and vocational interests.

We recently reported our experience with vascularized fibular bone grafting in this particular set of patients [10]. We have performed the FVFG in 23 patients with combined femoral neck nonunion and ONFH. The average age of these patients was 28.7 years (range, 10–49 years). Of these 23 patients, four presented with Steinberg Stage I, 12 with Stage II, 2 with Stage III, four with Stage IV, and one with Stage V ONFH. The minimum followup was 24 months (mean, 82 months; range, 24–195 months). One such case involved an 18-year-old girl who presented with a 2-year-old femoral neck nonunion with ONFH (Fig. 3). We treated her hip with open reduction, internal fixation, and placement of a FVFG. She ultimately healed and reported “occasional aches” in her hip at long-term followup. She was able to deliver two children subsequent to the FVFG procedure. Twenty of the 22 nonunions healed at an average time of 9.9 months (range, 3–23 months). Two underwent additional procedures to facilitate healing. Ultimately all fractures healed. The final median Harris hip score for the group was 78.9 (range, 60–98). Two hips were converted to THA an average of 1 year after surgery because of femoral head collapse and accelerated hip arthrosis. These two patients presented with 40%



Fig. 3 An 18-year-old patient is shown with Stage V osteonecrosis of the femoral head and femoral neck nonunion before surgery, 4 months after, and 10 years after the free vascularized fibular grafting procedure. The femoral neck has healed and there has been no interval collapse of the femoral head with preservation of the joint space. The reduction, screw fixation and FVFG are performed

contemporaneously with placement of the screws preceding the insertion of the fibula, thus ensuring the screw threads do not disrupt the vascular pedicle. Visual inspection of the core with no screw threads visible or palpable, confirms safe placement of the screws. Two screws and one FVFG have proven adequate in our experience treating this entity.

involvement and no preoperative collapse of the femoral head; however, both patients were noncompliant and discarded their crutches prematurely 2 months after the surgery.

Slipped Capital Femoral Epiphysis

The development of ONFH is a well recognized complication of a slipped capital femoral epiphysis [9]. We have performed FVFG on 31 patients (36 hips; 26 unilateral, five bilateral) with slipped capital femoral epiphysis complicated by ONFH with an average patient age of 13.4 years (range, 9–17 years) [5]. There were 20 male and 11 female patients. All patients in this particular group presented with some degree of femoral head collapse (Fig. 4A–B): one patient with Duke Stage 3 (3.6%), 24 patients with Stage 4 (75%), and six patients with Stage 5 (21.4%) disease. We followed these patients a minimum of 26 months (mean, 75 months; range, 26 months to 120 months). Followup was possible for all patients. Three hips in two patients had been converted to THA at the time of this review. One additional patient's hip had been converted to fusion. The overall hip survival rate was 91.9% at 5 years. Reported pain and functional activity improved in all patients and Harris hip scores increased from an average preoperative score of 55 (range, 11–90) to an average postoperative score of 82.8 (range, 28–100). Twenty-seven of 28 patients were extremely or very satisfied at final followup.

Infection

ONFH after pyarthrosis of the hip can be difficult to treat because there is often bony destruction at the capsular reflection (head/neck junction) in addition to the osteonecrosis within the femoral head. Furthermore, many surgeons consider a history of infection a contraindication to the use of large metal implants if there is femoral head-neck discontinuity. For these patients we routinely use FVFG and have found the structural integrity of the fibular graft is sufficient to allow rigid fixation of the neck while also addressing the

ONFH (Fig. 5A–C). We augment the FVFG with one or two screws, with less concern about implanting nonbiologic materials in a previously infected area, because we believe the extra delivery of blood flow diminishes this concern for reinfection.

We have treated 11 such patients with an average age of 12.5 years (range, 9–20 years) for ONFH after pyarthrosis of the hip [17]. This cohort included eight male and three female patients. Followup was possible for nine patients at a minimum of 2 years (mean, 4 years; range, 2–5 years) after surgery. The mean preoperative Harris hip score for the group was 68 (range, 62–79), which improved to 97 (range, 90–100) postoperatively. All patients presented with femoral head collapse of some degree, ranging from flattening of the femoral head up to 3 mm of articular stepoff. Despite this advanced presentation, none of these patients had subsequent or conversion surgery, and as a subgroup of patients, they have the highest Harris hip scores at most recent followup.

Discussion

We believe it important to review the context in which the concept for vascularized bone grafting for the treatment of ONFH was conceived. In the late 1960s and early 1970s, when so many of the biologic-preserving procedures were developed, a durable and reliable artificial hip prosthesis largely evaded orthopaedic surgeons. Today, technologically advanced metals and polymers provide excellent wear characteristics that have allowed surgeons greater freedom of implanting such components in much younger patients who, only years ago, would have not been offered that option. Similarly, refinements in the surgical technique have provided greater longevity in total hip arthroplasty (THA), as have improvements in component fixation (biologic ingrowth, third-generation cement technique). For these reasons, THA has become a more durable and reliable procedure. However; these implants do have a finite lifespan inversely proportional to the patient's activity level [4, 7, 8, 11, 15], which in younger patients can be very demanding. Because a younger patient will

Fig. 4A–B (A) Preoperative anteroposterior radiograph of a 13-year-old boy shows a slipped capital femoral epiphysis on the left. Notice the large cyst and increased density of the epiphysis, both indicative of osteonecrosis of the femoral head. (B) The same patient is shown at 10-year followup.

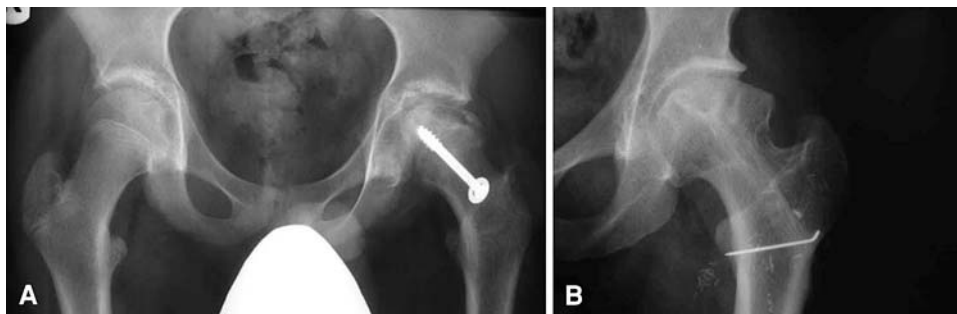


Fig. 5A–C (A) Lateral radiograph shows the proximal femur of a 14-year-old girl. The infection resulted in femoral head-neck discontinuity and femoral head osteonecrosis. (B) One year after the free vascularized fibular grafting procedure. Screws are placed before inserting the fibula to prevent the head from spinning during the reaming portion of the case. Notice the femoral head has healed to the neck and there is continued remodeling of the anterior portion of the femoral head. (C) Two years after free vascularized fibular grafting, the cortices of the fibular graft are less noticeable indicating good incorporation. Femoral head shape and joint space are relatively well preserved.



likely outlive his or her hip prosthesis, a scenario requiring one or more revision surgeries, preserving the native hip of a patient with some disabling hip abnormality for as long as possible has obvious benefit.

We acknowledge the lack of uniform longer-term followup among the various groups studied. The senior author (JRU) has been performing the FVFG procedure for 30 years and a full-time research analyst has been engaged in clinical data collection on these patients for nearly 20 years. Consistent long-term followup is often difficult because the majority of patients are referred from all regions of the United States and other countries, which challenges consistent acquisition of yearly followup. Also, there are small numbers of patients in all groups because of the unusual circumstances leading to the development of the ONFH. We also acknowledge that since our patients are all relatively young they and their surgeon jointly want to delay arthroplasty as long as possible. Such deferment of

arthroplasty can lead to bias in interpreting the benefit and/or longevity of the FVFG procedure. Finally, the estimates of involvement of the femoral head were based on the subjective evaluations, rather than a formal attempt to quantify involvement. These evaluations limit any interpretation regarding lesion size.

It is well established ONFH, if left untreated, progresses to femoral head collapse with subsequent hip degeneration in the majority of cases [13]. Despite recent technologic advances in THA, an excellent option for the older patient with an arthritic hip joint, it remains difficult for the arthroplasty surgeon to feel justified in proceeding with THA in patients younger than 50 years of age simply for ONFH-related pain. This is particularly true for the symptomatic patient without femoral head collapse, a preserved joint space, and no acetabular involvement. As we have contended since the original procedure was performed over 30 years ago by the senior author (JRU), the

ideal patient is young with a small lesion, no femoral head collapse, and good hip motion. Any deviation from this ideal candidate must be the result of careful consideration of numerous variables by the operative surgeon, which often comes only with experience.

Several approaches to treatment for osteonecrosis of the femoral head have been described, including weight restriction and observation, core decompression, various osteotomies, bone grafting (structural or nonstructural and vascularized [2] or nonvascularized), and arthroplasty (hemiarthroplasty, resurfacing techniques, and THAs). Few centers around the world perform the FVFG with great frequency. From China, Zhang and colleagues [21] reported their experience with 48 patients (56 hips) undergoing the FVFG procedure with an average patient age of 37.7 years and an average followup of 16 months. Etiologies included trauma, steroids, alcohol, and idiopathic. Patients who had Steinberg Grade [16] II ONFH had better Harris hip scores at last followup than did patients who had Steinberg Stage [16] III or IV disease. The preoperative Harris hip scores for patients who had Steinberg Grades [16] II, III, and IV ONFH were 78.5, 69.3, and 58.4, respectively. At the most recent followup, the Harris hip scores improved to 94.4, 85.7, and 76.4, respectively. Shaffer [12] reported his series of 101 hips treated with the FVFG procedure with a minimum followup of 5 years. 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 ± 13 preoperatively to 80 ± 15 at the 5-year mark. The majority of these patients had preoperative femoral head collapse [12].

A recent level IV study [20] reported the use of the new commercially available tantalum implant from Zimmer (Warsaw, IN). The authors contend the early results are equal to those of patients treated with the FVFG. The 24-month survival rate for the tantalum dowel was 81.7%, which decreased to 68.1% at 48 months. The survivorship improved to 92% at 48 months if patients with systemic disease were excluded. However, it is typically these excluded patients who comprise our series and whom we believe would be underserved with a nonvascularized, nonbiologic implant. We also avoid implanting metal in women who are pregnant or of child-bearing age, and those patients with a history of a hip infection, or renal compromise (i.e., renal transplants). We are further concerned about the presence of metal in the femur at the time of THA should that be needed in the future.

Some modifications to the FVFG surgical technique are worthy of mention. We have recently begun obtaining an intraoperative arteriogram after the fibula has been placed within the femoral head but before the anastomosis is completed. This ensures the pedicle is not kinked,

strangulated, or otherwise not flowing properly. Renograffin can be visualized flowing up the main pedicle into the femoral head and diffusing into the periosteal and endosteal vessels. If this is not confirmed, the fibula is removed, the pedicle is checked, and the core may be enlarged slightly. Also, in 2007 we began using, in certain cases, computer navigation with standard fluoroscopy and/or CT for exact localization of the necrotic lesion. This serves to increase accuracy of the core placement into the necrotic lesion while decreasing the total radiation exposure. We are scientifically studying the benefit of this modality.

There are several unique benefits to this procedure, namely its ability to preserve the native hip in young patients. In addition, there are no bridges burned should this procedure fail [5]. Lastly there is the potential to return to full-time activity in heavy work or athletics. The greatest drawback is prolonged protective weightbearing approximately 3 to 4 months if no preoperative collapse, or 6 months if preoperative collapse was present. The procedure is criticized for prolonged operative time; however in our hands it is usually 3 hours \pm 30 minutes. The donor site morbidity has been minimal [19]. The most common complication, occurring in 3% of patients, is a flexion contracture of the flexor hallucis longus (FHL). If this becomes bothersome to the patient it can easily be corrected with "Z" lengthening of the tendon at the ankle level. Only one patient has had a persistent distal tibiofibular syndesmotic problem advanced enough to warrant surgery. Expense is also often cited as a negative factor; however, there is no cost for the implant (which may be considerable in the lifetime of a young patient) and the duration of hospital stay is only 3 days.

We believe the left femoral head is uniquely involved in pregnancy-related osteonecrosis because the growing fetus and uterus compress the left common iliac vein, which is directly posterior to the uterus on the left side. Such compression decreases venous egress from the femoral head, in turn increasing vascular capacitance, thus decreasing arterial perfusion, and ultimately resulting in an intraosseous compartment syndrome. This local anoxia leads to the demise of bone-forming and supporting cells. Perhaps there is also some synergy between the hypercoagulability of pregnancy and this femoral head venous congestion.

Patients who have undergone either solid organ or bone marrow transplantation are, with few exceptions, committed to a prolonged period of corticosteroid administration to curtail immunologic-mediated rejection. Although the benefits of steroids in this context are unquestioned for prolonging life, such chronic exposure to high levels of steroids exposes this group of patients to a high risk of developing osteonecrosis of the femoral head(s). We have observed several unique features within this particular group of patients. Patients who have undergone

transplantation and who have ONFH tend to have larger necrotic areas within the femoral heads; bilateral involvement is more common than unilateral disease, and these patients tend to present later in the disease process than patients with ONFH from other causes. We believe this is primarily because the requisite steroids suppress the osteonecrosis-related synovitis, which often alerts the patients to the presence of the disease process.

While we continue to have success with the FVFG in younger patients with idiopathic ONFH, we have also used this procedure to treat special subsets of patients represented in this paper. We present our data for these groups and contend the FVFG remains a reasonable option in the treatment of ONFH.

Acknowledgments We thank Dawn Pedrotty, PhD, MS, and Jennifer Friend for their assistance in gathering the data for this paper.

References

- Aldridge JM 3rd, Berend KR, Gunneson EE, Urbaniak JR. Free vascularized fibular grafting for the treatment of postcollapse osteonecrosis of the femoral head. Surgical Technique. *J Bone Joint Surg Am.* 2004;86(Suppl 1):87–101.
- Aldridge JM 3rd, Urbaniak JR. Avascular necrosis of the femoral head: role of vascularized bone grafts. *Orthop Clin North Am.* 2007;38:13–22.
- Bachiller FG, Caballer AP, Portal LF. Avascular necrosis of the femoral head after femoral neck fracture. *Clin Orthop Relat Res.* 2002;399:87–109.
- Berend KR, Gunneson E, Urbaniak JR, Vail TP. Hip arthroplasty after failed free vascularized fibular grafting for osteonecrosis in young patients. *J Arthroplasty.* 2003;18:411–419.
- Dean GS, Kine RC, Fithc RD, Gunneson EE, Urbaniak JR. Treatment of osteonecrosis in the hip of pediatric patients by free vascularized fibular graft. *Clin Orthop Relat Res.* 2001;386:106–113.
- Dedrick DK, Mackenzie JR, Burney RE. Complications of femoral neck fracture in young adults. *J Trauma.* 1986;26:932–937.
- Herberts P, Malchau H. How outcome studies have changed total hip arthroplasty practices in Sweden. *Clin Orthop Relat Res.* 1997;344:44–60.
- Johnsen SP, Sorensen HT, Lucht U, Soballe K, Overgaard S, Pedersen AB. Patient-related predictors of implant failure after primary total hip replacement in the initial, short- and long-terms. A nationwide Danish follow-up study including 36,984 patients. *J Bone Joint Surg Br.* 2006;88:1303–1308.
- Krahn TH, Canale ST, Beatty JH, Warner WC, Lourenço P. Long term follow-up of patients with avascular necrosis after treatment of slipped capital femoral epiphysis. *J Pediatr Orthop.* 1993;13:154–158.
- LeCroy CM, Rizzo M, Gunneson EE, Urbaniak JR. Free vascularized fibular bone grafting in the management of femoral neck nonunion in patients younger than fifty years. *J Orthop Trauma.* 2002;16:464–472.
- Manley MT, Capello WN, D'Antonio JA, Edidin AA, Geesink RG. Fixation of acetabular cups without cement in total hip arthroplasty. A comparison of three different implant surfaces at a minimum duration of follow-up of five years. *J Bone Joint Surg Am.* 1998;80:1175–1185.
- 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 Am.* 2005;87:742–747.
- Merle D'Aubigne R, Postel M, Mazabraud A, Massias P, Gueguen J, France P. Idiopathic necrosis of the femoral head in adults. *J Bone Joint Surg Br.* 1965;47:612–633.
- Montella BJ, Nunley JA, Urbaniak JR. Osteonecrosis of the femoral head associated with pregnancy. A preliminary report. *J Bone Joint Surg Am.* 1999;81:790–798.
- Prudhommeaux F, Hamadouche M, Nevelos J, Doyle C, Meunier A, Sedel L. Wear of alumina-on-alumina total hip arthroplasties at a mean 11-year followup. *Clin Orthop Relat Res.* 2000;379:113–122.
- Steinberg ME, Hayken GD, Steinberg DR. A quantitative system for staging avascular necrosis. *J Bone Joint Surg Br.* 1995;77:34–41.
- Stubbs AJ, Gunneson EE, Urbaniak JR. Pediatric femoral avascular necrosis after pyarthrosis. Use of free vascularized fibular grafting. *Clin Orthop Relat Res.* 2005;439:193–200.
- Tooke SM, Favero KJ. Femoral neck fractures in skeletally mature patients, fifty years old or less. *J Bone Joint Surg Am.* 1985;67:1255–1260.
- Vail TP, Urbaniak JR. Donor-site morbidity with use of vascularized autogenous fibular grafts. *J Bone Joint Surg Am.* 1996;78:204–211.
- Veillette CJ, Mehdian H, Schemitsch EH, McKee MD. Survivorship analysis and radiographic outcome following tantalum rod insertion for osteonecrosis of the femoral head. *J Bone Joint Surg Am.* 2006;88:48–55.
- Zhang C, Zeng B, Xu Z, Song W, Shao L, Jing D, Sui S. Treatment of femoral head necrosis with free vascularized fibular grafting: a preliminary report. *Microsurgery.* 2000;25:305–309.