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The Role of Free Vascularized Grafts in the Management of Osteonecrosis of the Femoral Head

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Abstract: Osteonecrosis of the femoral head is a challenging problem for the orthopaedic surgeon. The multitude of treatment options for osteonecrosis of the femoral head as well as the controversy surrounding these options demonstrate the lack of a clearly superior method of treatment. Free vascularized fibular grafts to the femoral head can arrest the progression of osteonecrosis in the majority of patients if performed prior to subchondral fracture. The procedure is also of benefit in young patients with more advanced osteonecrosis of the femoral head who may benefit by prolonged reduction of symptoms and postponement of prosthetic replacement. This paper will review the indications, surgical technique, and published results of this procedure.

Introduction

Osteonecrosis of the femoral head is a debilitating disease that results in progressive collapse of the femoral head and a degenerative arthrosis. This disorder is common in young patients and is especially debilitating in this population [14,17,30,34]. Prosthetic replacement of the hip is complicated by the relatively long expected life span of the patient and finite life expectancy of the prosthesis. Small particle disease, osteolysis, and stress shielding further complicate late secondary reconstructive procedures. Optimally, surgical treatment of this disease would prevent or arrest the progression of the disease process allowing salvage of the femoral head.

The ideal surgical treatment of osteonecrosis of the femoral head would remove the dead bone from the femoral head, fill the defect with viable structurally sound bone and thereby arrest further articular collapse. For the past two decades free vascularized fibular grafting has evolved as an option for osteonecrosis in the young patient [5,44,52,53, 55]. This technique has been relatively successful in preventing or delaying total hip arthroplasty in the young active patient. This paper will review the indications, surgical technique, and published results of this procedure.

Etiology

Multiple etiologic factors have been associated with osteonecrosis and the development of the disease is probably multifactorial. Trauma, alcohol, corticosteroids, and various blood dyscrasias have all been implicated in the development of osteonecrosis with some studies implicating alcohol and steroid use in as many as 90 percent (90%) of cases [7, 11,18,20]. There is also evidence that anatomic vascular variations or underlying inherent hypercoagulability may be related [15,22,39]. It is probable that a second insult to an "at risk" population results in the subsequent development of the disease.

The etiologic factors remain ill defined; however, the pathologic changes are better understood [39,53]. There are no collateral vessels supplying the distal arterioles in the femoral head and therefore they are prone to ischemic necrosis when these vessels occlude. The resulting ischemia leads to cell death and associated edema increasing local compartment pressure and decreasing vascular ingress. A reparative response is initiated and the necrotic trabecular bone is resorbed. With repeated mechanical loading, stress fractures develop and propagate, eventually leading to subchondral collapse. Progressive deformity of the femoral head results in alterations in contact stresses and compromise of cartilage nutrition. These factors lead to a progressive arthrosis and eventual advanced degenerative changes.

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Free Vascularized Fibular Graft

The rationale, operative indications, surgical technique, and results of free vascularized fibular grafts to the femoral head have been described in detail by Urbaniak et al [52,53].

Rationale

The rationale for the treatment of osteonecrosis of the femoral head with free vascularized fibular grafting is based on four points: 1) Decompression of the femoral head to interrupt the cycle of ischemia and interosseous hypertension thought to be etiologic factors of the disease, 2) Removal of necrotic bone, 3) Grafting of the defect with fresh cancellous bone, and 4) Placement of a viable cortical strut to support the subchondral surface and enhance the revascularization process [52,53]. This "healing construct" is then protected by a period of limited weight bearing.

Operative indications

At this institution, free vascularized fibular grafting is offered to symptomatic patients under the age of 50 years

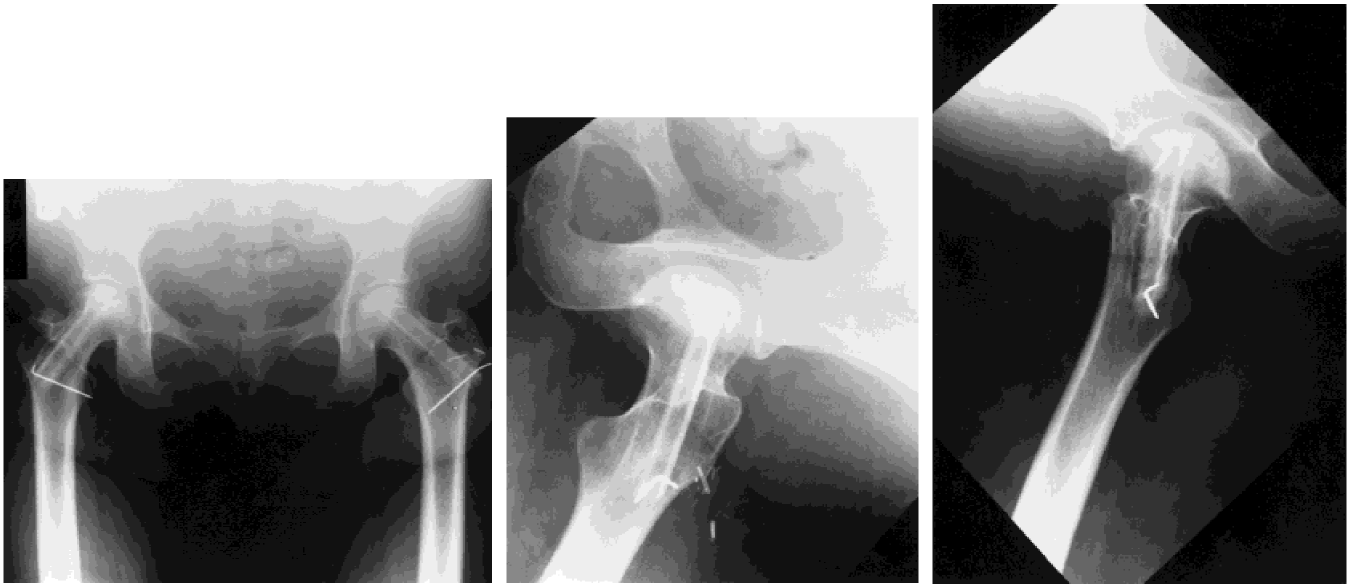

Fig. 1. Anteroposterior radiograph of 32 year old female with bilateral steroid induced Stage II AVN of the femoral heads.

with radiographically documented disease. Patients are evaluated with plain films utilizing bilateral antero-posterior and frog lateral views of the hips. Magnetic resonance imaging is utilized to confirm the diagnosis, to evaluate asymptomatic contralateral hips with no plain radiographic change, and to document the extent of disease. Patients are staged based on plain radiographic findings using a modification of the Marcus and Enneking grading system (Table 1) [31]. The size and location of the lesion are documented.

Patients younger than 20 years of age are considered radiographic candidates if they are Stage II - Stage V. Patients between the age of 20 and 50 are considered radiographic candidates if they are Stage II - IV. In patients greater than 40 years of age with involvement of greater than 50% of the femoral head or advanced Stage IV disease total hip arthroplasty is recommended. Currently, surgery is not recommended for patients with asymptomatic hips; however, these patients are followed closely. If there is radiographic progression or the patient develops clinical symptoms, free vascularized fibular grafting is offered.

Preoperative conferences are carried out with all patients prior to proceeding with surgery. Literature is provided outlining the procedure, hospital stay, and postoperative rehabilitation course. Free vascularized fibular grafting requires a commitment to an extended period of non or protected weight bearing and the importance of compliance is stressed preoperatively. It is important that patients be aware of the commitment preoperatively to ensure compliance, satisfaction, and an optimal outcome.

Surgical technique

Patients undergo routine preoperative evaluation. A complete neurovascular exam is carried out on the operative extremity. If the patient has a palpable or dopplerable DP and PT pulse, a preoperative lower extremity arteriogram is not routinely obtained. At this institution, preoperative arteriograms have been necessary in less than 1% of patients undergoing this procedure.

The procedure is typically performed under general an-

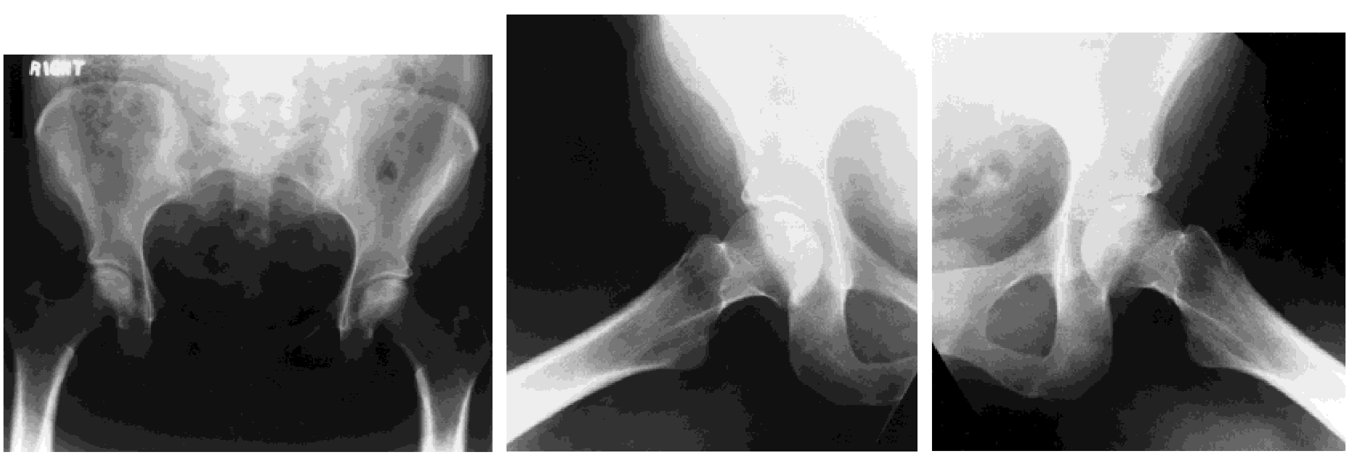

Fig. 2. Anteroposterior radiograph at 2 year postoperative follow up from bilateral free vascularized fibular grafts. Patient is asymptomatic and demonstrates incorporation of the grafts with no radiographic progression in early postoperative period.

esthesia with a supplemental epidural. The patient is positioned in the lateral decubitus position with beanbag support. Care is taken to pad all bony prominences. The extremity is then prepped and draped into the field. A sterile tourniquet is placed about the distal thigh just above the knee to provide hemostasis during harvest of the graft. A team approach is utilized consisting of two surgeons and one scrub nurse with an average operating time of less than three hours.

Operative procedure on the hip

The proximal femur is approached through a curved anterolateral incision splitting the interval between the tensor fascia lata and the gluteus medius. The origin of the vastus lateralis is reflected to expose the lateral femur and approximately 5 cms. of the posterior lateralis is reflected from the linea aspera. The deep plane of dissection is between the rectus femoris and the vastus intermedius. The donor vessels originate from the lateral circumflex vessel and course laterally between the two muscles. Three branches run forward into the wound: ascending, transverse, and descending.

The bridge of aponeurosis between the anterolateral femur and the rectus femoris is dissected. This falx is detached from the anterolateral corner of the femur at the junction of the deep quadriceps muscles. The area beneath the falx is covered with a fat pad which is swept away to reveal the ascending vessels. The pedicle usually consists of an artery and two veins which are mobilized with careful attention to length. Four centimeters of length from the origin is easily obtained and adequate for a tension free anastomosis.

A C-arm fluoroscopic unit is then sterilely draped and positioned over the table. With the patient positioned in the lateral decubitus position, the C-arm is brought across the table and allows an AP and frog lateral image to be obtained during the procedure. A 3 mm. guide pin is inserted approximately 2 cms. distal to the vastus ridge and under fluoroscopic guidance is directed into the center of the necrotic area. Care is taken to ensure that there is enough space between the guide pin and cortex of the neck to allow a reamer of adequate diameter to pass. A somewhat vertical alignment of the pin is optimal to provide support to the subchondral area of the defect.

Table 1. Staging of osteonecrosis (after Marcus et al.) [31]

Stage 1	Normal radiographic abnormal MR image or bone scan
Stage 2	Abnormal density or lucency within the femoral head
Stage 3	Subchondral fracture (crescent sign) without flattening of the head
Stage 4	Flattening of the femoral head with a normal joint space
Stage 5	Narrowing of joint space; loss of articular cartilage of the femoral head
Stage 6	Arthrosis involving both the femoral and acetabular sides of the joint

Cannulated reamers are progressively passed over the guide pin starting with a 10 mm. reamer. The average female requires a final reaming diameter of 16 mms. and the average male 19 mms. Size is dependent upon the largest diameter of the fibular graft. The reaming is extended to within 3–5 mms. of the articular surface of the femoral head. Subchondral reaming is carried out under fluoroscopic guidance. Healthy bone from the trochanter and neck is saved for grafting while the necrotic bone from within the cyst is discarded.

Once the femur has been reamed to an adequate diameter, additional necrotic bone is removed with a ball reamer under fluoroscopic control. Radiographic contrast medium is instilled into the cavity to document the amount of necrotic bone removed. Cancellous bone is then obtained from the greater trochanter with a curette through the lateral cortical window. This is utilized to supplement reamings and loose fragments that are collected during the procedure using a filter suction (KAM super sucker Anspach Palm Beach Gardens, Florida).

Cancellous bone graft is placed into the cavity with the use of a custom-made impaction device. The depth of the cavity is measured to determine the necessary length of the fibular graft. Contrast material is used to document that the cavity has been adequately filled with cancellous bone graft.

Fibular harvest

The fibula is approached through a lateral incision. The skin incision is carried down to the level of the fascia and full thickness flaps are elevated exposing the lateral compartment. The lateral compartment is opened and sharp dissection is carried out to reflect the peroneal muscles from the lateral fibula. The periosteum is not violated during this dissection and a thin 1–2 mm. layer of muscle is left on the fibula. This results in a “cobblestone” appearance of the periosteum.

Anteriorly and posteriorly the exposed fascia is incised and the thick fascial layer at the distal tip posteriorly is cut on the bone to afford exposure of the distal pedicle. A right angle dissector is run directly on the anterior aspect of the bone removing all muscle from the fibula. This allows visualization of the interosseous membrane deep in the wound and this is incised along its length with a scalpel.

Incision of the deep fascial layer posteriorly allows visualization of the flexor hallucis longus. The pedicle is located directly beneath this muscle and care must be taken as it is divided to avoid injury. The fibula is then osteotomized. A right angle clamp is utilized to create a tunnel where the bone is to be cut distally and proximally. The clamp is passed between the pedicle and the fibula and protective malleable retractors are placed to protect the pedicle during the osteotomy. A Gigli or oscillating saw is then utilized to cut the fibula allowing mobilization. Fibular bone cuts should be 15 cms. apart with the distal cut 10 cms. proximal to the distal fibular tip.

Beginning distally, the pedicle is dissected free from muscle and divided with the application of medium hemostatic clips. Care is taken to ensure that all perforating branches are ligated and divided to avoid tethering of the pedicle within the wound as the fibula is elevated. The fibula is rotated anteriorly and posteriorly in the wound during dissection to allow access to perforators and constant visualization of the pedicle. The fibula is elevated from distal to proximal until it is tethered only by the proximal vascular pedicle. This dissection is carried proximally until a pedicle length of at least 5 cms. is obtained. Optimally, the pedicle can be ligated and divided at its origin from the posterior tibial artery.

During dissection care must be taken to visualize and protect the posterior tibial neurovascular structures. A small branch of the nerve to the Flexor Hallucis Longus often runs within the pedicle and should be preserved if possible. Compromise of this nerve does not appear to have a clinical effect on patient outcome.

After the fibular graft is freed from the leg, the tourniquet is deflated, the wound copiously irrigated, and hemostasis obtained. The deep fascial layers are not closed. The subcutaneous tissues are approximated with a 2-0 absorbable suture and the skin closed with a 4-0 subcuticular suture. Steristrips are placed at the termination of the procedure and the leg is placed in a bulky dressing. Fibular harvest time averages approximately 45 minutes at this institution.

Final preparation of the fibula occurs on the back table. Forty milliliters of lactated Ringer's solution is immediately injected into both veins and the artery of the pedicle to inspect for leaks. The pedicle is then reflected from the proximal fibula until a large nutrient vessel is found entering the cortex. When this nutrient vessel is located, the proximal fibular osteotomy is performed at this level with a reciprocating saw and the use of copious irrigation. The pedicle is then cut to the appropriate length based on the measurement taken in the proximal femur and the distal pedicle is secured to the fibula with non-absorbable sutures. This prevents stripping of the pedicle during insertion into the femoral head. The proximal end of the pedicle is prepared with microsurgical dissection and the artery and one vein are chosen as the recipient. The second vein is ligated with a hemostatic clip.

Placement of the fibular graft

The fibula is inserted with the broadest surface in the AP plane. The pedicle is located superiorly and anteriorly and is positioned into the fibular sulcus to prevent compression. The fibula is then inserted and gently impacted. Prior to impaction a final cancellous plug is placed in the distal aspect of the tunnel. The fibula is then gently tapped into position and fixed with a 0.62 K wire that crosses both cortices of the fibula and the medial cortex of the lesser trochanter. The wire is then bent and cut short. Final position of the graft is confirmed and the fluoroscopic unit is removed.

The operating microscope is then positioned to perform the anastomosis. The vein is repaired first to diminish bleeding. In this institution a coupling device is generally utilized for the venous anastomosis to diminish operative time. The artery is repaired with 8-0 or 9-0 nylon sutures using standard microsurgical technique.

After the vessels have been anastomosed, endosteal bleeding must be observed from the fibula to document vascularization of the graft. The tensor fascia lata is not reattached during closure to prevent compromise of the vascular pedicle. The gluteal fascia is closed over a drain. Subcutaneous and skin closure is identical to that of the fibula.

Postoperative Care

Suction drains are removed at 24 hours postoperatively. The bulky dressing on the leg is removed on postoperative day two and active motion of the ankle and toes is initiated and encouraged. Passive extension of the great toe is stressed to prevent flexion contracture due to scarring of the dissected flexor hallucis longus muscle. The patient is out of bed to a chair on the first postoperative day. On the second postoperative day non-weight bearing ambulation is begun with crutches or walker. Most patients are discharged from the hospital on postoperative day number four.

Non-weight bearing is maintained for a minimum of six weeks and then the patient progresses to partial weight bearing of 30 lbs. for an additional six weeks. Heel-to-toe gait pattern is encouraged. Patients progress from protected weight bearing to full weight bearing as tolerated over three to six months. In patients who require bilateral stage procedures, the second operation is done three months after the first.

Complications

Vail and Urbaniak previously reported on donor site morbidity in 247 consecutive grafts in 198 patients [54]. At five year follow up an abnormality was noted in 24% of limbs. Sensory deficit was present in 11.8%, and 2.7% had some motor weakness. Pain at the ankle was a complaint in 11.5% of limbs and pain at other sites reported in 8.9% of patients. Flexor hallucis longus contracture was present in 2% of patients due to intramuscular dissection necessary to protect the pedicle. This complication is avoidable with careful stretching of the toes in the first few days following surgery.

Urbaniak and Harvey have reported on complications in 822 vascularized fibular graft procedures [53]. Three thromboembolic complications occurred with two patients developing deep venous thromboses that were treated successfully with anticoagulation. One patient suffered a massive pulmonary embolus six weeks postoperatively and died. Two patients had arterial anomalies which required harvesting of the contralateral fibula in one patient and a reverse saphenous jump graft in the other. Two patients developed superficial infections that responded to incision and drainage and antibiotics, and four patients developed reactive ulcerations along the suture line in the initial healing phase. One patient developed transient paralysis in the distribution of the deep peroneal nerve and a branch of the superficial peroneal nerve was injured in another patient.

Discussion

It is generally accepted that radiographically apparent osteonecrosis of the femoral head almost uniformly leads to collapse and subsequent degenerative changes [27,32,35, 36]. Mont and Hungerford reviewed the results of nonoperative management in 21 pooled studies [34]. Only 22% of 119 hips had a satisfactory result over a relatively short average follow-up interval of 34 months.

Surgical approaches to the management of this disorder can be divided into two broad categories: prosthetic replacement vs. head salvage. Prosthetic options have primarily been limited to standard hemiarthroplasty or total hip replacement. Historically, total hip arthroplasty in this population has not been as successful as in patients with other degenerative etiologies [8,9,10,40,41]. This fact is probably related to the relatively young age of the patients, high physical demands, and longevity required of the prosthesis. Revision surgery is further complicated by problems such as stress shielding, osteolysis, and particulate wear. Recently attention has been focused on more conservative techniques including surface replacement arthroplasty, limited total hip arthroplasty, and alternate biomaterials for bearing surfaces [19].

Several operative approaches aimed at salvaging the native joint have been advocated. Proximal femoral osteotomies have been described to rotate the necrotic portion of the femoral head away from the critical weight bearing area [12,16,21,2942,47–49]. These procedures are technically demanding and have very strict indications, however, acceptable results have been reported in patients with small areas of involvement in precollapse stages. Proximal femoral osteotomy alters the biomechanics of the hip and will often result in a limp. Additionally, alteration of the proximal femoral anatomy may complicate subsequent primary total hip replacement in the event of failure [3].

Core decompression is perhaps the most commonly performed procedure for avascular necrosis. Acceptable clinical outcomes have been reported in the early precollapse stages; however, the value of this technique in higher more advanced grades of osteonecrosis remains unclear [13,25, 26,46,50]. This procedure has also been performed in conjunction with electrical stimulation with no clear benefit yet demonstrated [1,45,51].

Various bone-grafting techniques have also been reported. These range from core decompression with impaction of cancellous bone graft to non-vascularized cortical strut grafts [4,6,37,38]. Success rates of nearly eighty percent (80%) have been reported; however, these have typically been in asymptomatic patients. Various vascularized grafts have been utilized including local pedicled grafts, vascularized iliac crest grafts, and the free vascularized fibular graft [2,28,33,52,55].

The rationale for the treatment of osteonecrosis of the femoral head with a free vascularized fibular graft is based upon 1) decompression of the femoral head interrupting the cycle of ischemia and interosseous hypertension, 2) removal of necrotic bone, 3) grafting of the defect with fresh cancellous bone, and 4) placement of a viable cortical bone strut to support the subchondral surface and enhance the revascularization process by providing a source of mesenchymal stem cells [52]. Satisfactory results utilizing this procedure have been reported by several authors. In 1991 Bernelli and Bernelli reported seventy-eight percent (78%) good to excellent results with greater than 5 year follow up utilizing this procedure [5]. Yoo et al have reported a ninety-one percent (91%) success rate in a follow-up interval of 3–10 years [55]. In 1995 Urbaniak et al published the results of a prospective study of 103 consecutive hips treated with free vascularized fibular grafting for symptomatic osteonecrosis of the femoral head [52]. Kaplan-Meier survivorship analysis demonstrated that the probability of conversion to a total hip arthroplasty within 5 years following free vascularized fibular grafting was eleven percent (11%) for Stage II hips, twenty-three percent (23%) for Stage III hips, twenty-nine percent (29%) for Stage IV hips, and twenty-seven percent (27%) for Stage V hips. There was also a statistically significant improvement in average Harris hip scores over preoperative values.

Several studies have compared the results of free vascularized fibular grafting with other procedures. Kane et al published a comparative study of core decompression and free vascularized fibular graft [23]. Patients undergoing core decompression had a statically significant higher incidence of conversion to total hip arthroplasty. Scully et al performed a survival analysis of hips treated with core decompression or vascularized fibular grafting because of avascular necrosis [43]. Patients with Ficat Stage II and III had a statistically significant decrease in progression to joint replacement when compared with core decompression. Kim et al evaluated vascularized versus non-vascularized fibular grafting for the treatment of osteonecrosis of the femoral head [24]. This retrospective review of 85 vascularized and 17 non-vascularized fibular grafts evaluated Harris hip scores and radiographic progression. Seventy percent (70%) of the patients in the vascularized group had excellent or good results as compared with 39% in the non-vascularized group. 42% of the vascularized group progressed radiographically as opposed to 71% of the non-vascularized group. These findings support the rationale that in addition to the core decompression and biomechanical support provided by the strut graft, the microvascular anastomosis enhances the revascularization process by providing vascular inflow and a source of mesenchymal stem cells.

Summary

The multitude of treatment options for osteonecrosis of the femoral head as well as the controversy surrounding these options demonstrate the lack of a clearly superior method of treatment, however, if performed prior to the development of a subchondral fracture, free vascularized fibular grafting can arrest the progression of osteonecrosis in the majority of patients. The procedure is also of benefit in young patients with more advanced osteonecrosis of the femoral head who may benefit by prolonged reduction of symptoms and postponement of prosthetic replacement.

References

1. Aaron RK, Lennox D, Bunce GE, Ebert T: The conservative treatment of osteonecrosis of the femoral head: A comparison of core decompression and pulsing electromagnetic fields. *Clin Orthop* 249:209–218, 1989.
2. Baksi DP: Treatment of osteonecrosis of the femoral head by drilling and muscle pedicle bone grafting. *J Bone Joint Surg Br* 73:241–245, 1991.
3. Benke GH, Baker AS, Dounis E: Total hip replacement after upper femoral osteotomy: A clinical review. *J Bone Joint Surg Br* 64:570–571, 1982.
4. Bonfiglio M, Voke EM: Aseptic necrosis of the femoral head and nonunion of the femoral neck: Effect of treatment by drilling and bone grafting (Phemister technique). *J Bone Joint Surg Am* 50:48–66, 1968.
5. Brunelli G, Brunelli G: Free microvascular fibular transfer for idiopathic femoral head necrosis: Long term follow up. *J Reconstr Microsurg* 7:285–295, 1991.
6. Buckley PD, Gearen PF, Petty RW: Structural bone grafting for early atraumatic avascular necrosis of the femoral head. *J Bone Joint Surg Am* 73:1357–1364, 1991.
7. Chung SMK, Ralston EL: Necrosis of the femoral head associated with sickle Cell anemia and its genetic variants: A review of the literature and study of thirteen cases. *J Bone Joint Surg Am* 51:33–58, 1969.
8. Collis DK: Cemented total hip replacement in patients who are less tha fifty years old. *J Bone Joint Surg* 66:353–359, 1984.
9. Cornell CN, Salvati EA, Pellicci PM: Long-term follow-up of total hip replacement in patients with osteonecrosis. *Orthop Clin North America* 16:757–769, 1985.
10. Coventry MB, Beckenbaugh RD, Nolan DR, Ilstrup DM: 2012 total hip Arthroplasties: A study of postoperative course and early complications. *J Bone Joint Surg AM* 56:273–284, 1974.
11. Cruess RL, Ross D, Crawshaw E: The etiology of steroid induced avascular necrosis of bone: A laboratory and clinical study. *Clin Orthop* 113:178–183, 1975.
12. Dean MT, Cabanela ME: Transtrochanteric anterior rotational osteotomy for avascular necrosis of the femoral head: Long term results. *J Bone Joint Surg Br* 75:597–601, 1993.
13. Fairbank AC, Bhatia D, Jinnah RH, Hungerford DS: Long term results of core decompression for ischemic necrosis of the femoral head. *J Bone Joint Surg Br* 77:42–49, 1995.
14. Ficat RP: Idiopathic bone necrosis of the femoral head: Early diagnosis and treatment. *J Bone Joint Surg Br* 67:3–9. 1985.
15. Glueck CJ, Freiberg R, Glueck HI, et al: Hypofibrinolysis: A common, major cause of osteonecrosis. *Am J Hematol* 45:156–166, 1994.
16. Gottschalk F: Indications and results of intertrochanteric osteotomy in osteonecrosis of the femoral head. *Clin Orthop* 249:219–222, 1989.
17. Hungerford DS: Nontraumatic avascular necrosis of the femoral head. *J Bone Joint Surg Am* 77:459–474, 1995.
18. Hungerford DS, Zizic TM: Alcoholism associated ischemic necrosis of the femoral head: Early diagnosis and treatment. *Clin Orthop* 130:144–153, 1978.
19. Hungerford MW, Mont MA, Scott R, Fiore C, Hungerford DS, Krackow K: Surface replacement hemiarthroplasty for the treatment of osteonecrosis of the femoral head. *J Bone Joint Surg* 80:1656–1664, 1998.
20. Jacobs B: Epidemiology of traumatic and nontraumatic osteonecrosis. *Clin Orthop* 130:51–67, 1978.
21. Jacobs MA, Hungerford JS, Krackow KA: Intertrochanteric osteotomy for avascular necrosis of the femoral head. *J Bone Joint Surg Br* 71:200–204, 1989.
22. Jones JP Jr: Intravascular coagulation and osteonecrosis. *Clin Orthop* 277:41–53, 1992.
23. Kane SM, Ward WA, Jordan LC, Guilford WB, and Hanley EN Jr: Vascularized fibular grafting compared with core decompression in the treatment of femoral head osteonecrosis. *Orthopedics* 19:869–872, 1996.
24. Kim S, Plakseychuk AY, Park B, Sotereanos DG, Rubash HE: Vascularized versus nonvascularized fibular grafting for the treatment of osteonecrosis of the femoral head. Presented at the 65th Annual Meeting of the American Academy of Orthopaedic Surgeons, New Orleans, March 20, 1998.
25. Koo KH, Kim R, Ko GH, Song, HR, Jeong ST, Cho SH: Preventing collapse in early osteonecrosis of the femoral head: A randomized clinical trial of core decompression. *J Bone Joint Surg Br* 77:870–874, 1995.
26. Kristensen KD, Pedersen NW, Kiaer T, Starklint H: Core decompression in femoral head osteonecrosis: 18 stage I hips followed up for 1–5 years. *Acta Orthop Scan* 62:113–114, 1991.
27. Lausten GS, Mathiesen B: Core decompression for femoral head necrosis: Prospective study of 28 patients. *Acta Orthop Scand* 61:507–511, 1990.
28. Leung PC: Use of vascularized pedicle iliac crest graft in treatment of ischemic necrosis of femoral head, in Urbaniak JR (ed): Microsurgery for Major Limb Reconstruction. St. Louis: CV Mosby, 1987, pp 200–204.
29. Maistrelli G, Fusco U, Avai A, Bombelli R: Osteonecrosis of the hip treated by intertrochanteric osteotomy. A four to 15 year follow-up. *J Bone Joint Surg BR* 70:761–76, 1988.
30. Mankin HJ: Nontraumatic necrosis of bone (osteonecrosis). *N Engl J Med* 326:1473–1479, 1992.
31. Marcus ND, Enneking WF, Massam RA: The silent hip in idiopathic aseptic necrosis: Treatment by bone grafting. *J Bone Joint Surg Am* 55:1351–1366, 1973.
32. Merle D'Aubigne R, Postel M, Mazabraud A, Massias P, Gueguen J: Idiopathic necrosis of the femoral head in adults. *J Bone Joint Surg Br* 47:612–633, 1965.
33. Meyers MH: The treatment of osteonecrosis of the hip with fresh osteochondral allografts and with the muscle pedicle graft technique. *Clin Orthop* 130:202–209, 1978.
34. Mont MA, Hungerford DS: Nontraumatic avascular necrosis of the femoral head. *J Bone Joint Surg Am* 77:459–474, 1995.
35. Musso ES, Mitchell SN, Schink-Ascani M, Bassett CAL: Results of conservative management of osteonecrosis of the femoral head: A Retrospective review. *Clin Orthop* 207:209–215, 1986.
36. Ohzono K, Saito M, Takaoka K, et al: Natural history of nontraumatic avascular necrosis of the femoral head. *J Bone Joint Surg Br* 73:68–72, 1991.
37. Phemister DB: Treatment of the necrotic head of the femur in adults. *J Bone Joint Surg Am* 31: 55–66, 1949.
38. Rosenwasser MP, Garino JP, Kiernan HA, Michelsen CB: Long term follow up of thorough debridement and cancellous bone grafting of the femoral head for avascular necrosis. *Clin Orthop* 306:17–27, 1994.
39. Saito S, Ohzono K, Ono K: Early arteriopathy and postulated pathogenesis of osteonecrosis of the femoral head: The intracapital arterioles. *Clin Orthop* 277:98–110, 1992.
40. Saito S, Saito M, Nishina T, Ohzono K, Ono K: Long-term results of total hip arthroplasty for osteonecrosis of the femoral head. A comparison with osteoarthritis. *Clin Orthop* 244:198–207, 1989.
41. Salvati EA, Cornell CN: Long-tem follow-up of total hip replacement in patients with avascular necrosis. In Instructional Course Lectures, The American Academy of Orthopaedic Surgeons. Vol 37, pp 67–73. Park Ridge, Illinois, The American Academy of Orthopaedic Surgeons, 1988.
42. Scher MA, Jakim I: Intertrochanteric osteotomy and autogenous bone grafting for avascular necrosis of the femoral head. *J Bone Joint Surg Am* 75:1119–1133, 1993.
43. 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* 80:1270–1275, 1998.
44. Sotereanos DG, Plakseychuk AY, Rubash HE: Free vascularized fibula transfer for the treatment of aseptic necrosis of the femoral head: Follow-up results. Presented at the 64th Annual Meeting of the American Academy of Orthopaedic Surgeons, San Francisco, February 13, 1997.
45. Steinberg ME, Brighton CT, Hayken GD, Tooze SE, Steinberg DR:

Early results in the treatment of avascular necrosis of the femoral head with electrical stimulation. *Orthop Clin North Am* 15:163–175, 1984.

46. Stulberg BN, Davis AW, Bauer TW, Levine M, Easley K: Osteonecrosis of the femoral head: A prospective randomized treatment protocol. *Clin Orthop* 268:140–151, 1991.
47. Sugioka Y, Hotokebuchi T, Tsutsui H: Transtrochanteric anterior rotational osteotomy for idiopathic and steroid induced necrosis of the femoral head: Indications and long-term results. *Clin Orthop* 277:111–120, 1992.
48. Sugano N, Takaoka K, Ohzono K, Matsui M, Saito M, Saito S: Rotational osteotomy for nontraumatic avascular necrosis of the femoral head. *J Bone Joint Surg Br* 74:734–739, 1992.
49. Tooke SMT, Amstutz HC, Hedley AK: Results of transtrochanteric rotational osteotomy for femoral head osteonecrosis. *Clin Orthop* 224:150–157, 1987.
50. Tooke SM, Nugent PJ, Bassett LW, Nottingham P, Mirra J, Jinnah R: Results of core decompression for femoral head osteonecrosis. *Clin Orthop* 228:99–104, 1988.
51. Trancik T, Lunceford E, Strum D: The effect of electrical stimulation on osteonecrosis of the femoral head. *Clin Orthop* 256:120–124, 1990.
52. Urbaniak, JR, Coogan PG, Gunneson EB, Nunley JA: Treatment of osteonecrosis of the femoral head with free vascularized fibular grafting: A long term follow up study of one hundred and three hips. *J Bone Joint Surg Am* 77:681–694, 1995.
53. Urbaniak JR, Harvey EJ: Revascularization of the femoral head in osteonecrosis. *J Am Acad Orthop Surg* 6:44–54, 1998.
54. Vail TP, Urbaniak JR: Donor site morbidity with use of vascularized autogenous fibular grafts. *J Bone Joint Surg Am* 78:204–211, 1996.
55. Yoo MC, Chung DW, Hahn CS: Free vascularized fibula grafting for the treatment of osteonecrosis of the femoral head. *Clin Orthop* 277:128–138, 1992.