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REVIEW

Hip arthroplasty for treatment of advanced osteonecrosis: comprehensive review of implant options, outcomes and complications

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Abstract: Surgical treatment for late stage (post-collapse) osteonecrosis of the femoral head is controversial. In these situations, the outcome of joint preservation procedures is poor. There are several arthroplasty options for late-stage disease. The clinical outcomes of hemiarthroplasty and hemiresurfacing are unpredictable because of progressive acetabular cartilage degeneration. Total hip resurfacing may be associated with further vascular insult to the femoral head and early failure of the implant. Total hip replacement with metal-on-conventional polyethylene bearing surfaces has been the gold standard, but implant survivorship is limited in young active patients due to wear and osteolysis. Newer alternative bearing surfaces may have improved wear characteristics, but their durability must be confirmed in longer-term studies.

Keywords: hip arthroplasty, advanced osteonecrosis, implant options, outcomes, complications

Introduction

Osteonecrosis is a phenomenon involving disruption of the vascular supply to the femoral head, resulting in articular surface collapse and eventual osteoarthritis. Osteonecrosis of the femoral head (ONFH) was first described in 1738 by Munro. In approximately 1835, Cruveilhier depicted morphologic changes of the femoral head secondary to interruption of blood flow. Since 1962, when Mankin described 27 cases of ONFH, the number of reported cases of ONFH has increased steadily. Although alcoholism, steroid use, and hip trauma remain the most common causes, several other etiologies resulting in osteonecrosis have been identified.

ONFH is a debilitating disease that usually leads to osteoarthritis of the hip joint in relatively young adults (mean age at presentation 38 years). The disease prevalence is unknown, but estimates indicate that 10,000–20,000 new cases are diagnosed in the United States each year.[1,2] Furthermore, it is estimated that 5%–18% of the more than 500,000 total hip arthroplasties performed annually are for ONFH.[2] Late-stage (post-collapse) ONFH occurs when the femoral head is deformed and is no longer congruent with the acetabulum.

Mont et al[3] reported a systematic review of untreated asymptomatic osteonecrosis and found that 49% of cases progressed to collapse of the femoral head after 49 months. Risk factors that affect head collapse include medium to large size (size more than 25% of the femoral head), location at the weight-bearing lateral two-thirds of the femoral head, and diseases such as sickle cell anemia. Once collapse occurs, optimum treatment is controversial. The outcome of joint preservation procedures in this late

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stage of disease is poor. Core decompression alone in Ficat stage III had success rates of only 21%–35%.[4–6]

The modified Ficat classification used for ONFH relies on a combination of plain radiographs of the hip, clinical signs and symptoms, and, more recently, magnetic resonance imaging. Stage III cases demonstrate clinical signs of pain and stiffness, and radiographs show the crescent sign and eventual cortical collapse.[7]

There are few successful femoral head-preserving options for Ficat stage III osteonecrosis. One technique involves use of a "trap door" with nonvascularized bone grafting and has been reported to have a good or excellent result, as determined by the Harris hip scoring system, in 83% of cases.[8,9] However, patient selection is crucial, including no history of steroid use, combined necrotic angle less than 200 degrees, and the need for containment osteotomy for a good outcome.[8,9]

Vascularized fibular grafts have a high rate of failure in the post-collapse stage. Survivorship was reported to be 64.5% at a mean of 4.3 years.[10] Osteotomies of the proximal femur are another technique for treatment aimed at shifting the affected areas of the femoral head away from the major weight-bearing region of the joint. There are two general types of osteotomies, ie, angular intertrochanteric (varus/valgus) and rotational transtrochanteric. In the post-collapse stage, the outcomes of angular and rotation osteotomies are less predictable, with failure rates up to 25%[11,12] at 5 years of follow-up for angular osteotomies, and 40%–70%[13,14] at 4–7 years of follow-up for rotational osteotomies. The factors that influence the prognosis for optimal outcome are area of necrosis (surface involvement $< 70\%$,[15] necrotic angle less than 200 degrees[16]), etiology of disease (no history of high-dose corticosteroid use),[8] stage of disease,[8,17] extent of disease less than 2 mm of initial collapse,[18] and surgical skill. Once the femoral head collapses or arthritis occurs on the acetabular side, the treatment of choice is reconstructive hip replacement. Various types of hip replacement, such as bipolar hemi-arthroplasty, hemiresurfacing, total resurfacing, and total hip arthroplasty, have been used in this population.

In this review, we summarize the indications, advantages/disadvantages, results, and complications for each procedure in the post-collapse stage of ONFH in order to give the reader an overview of the surgical options for the treatment of patients in the different age groups.

Limited femoral head resurfacing

Because the acetabulum is relatively normal in Ficat stage III, the concept of hemiarthroplasty is appealing. Hemiresurfacing of the femoral head with cement fixation was developed and first performed in the early 1980s in young active patients to preserve femoral bone stock and permit later conversion to a total hip arthroplasty with less morbidity.[19–23]

Regarding the advantages of hemiresurfacing, the literature includes the following: only the degenerative cartilage and necrotic bone of the proximal femur are removed; bone stock of the femoral head and neck are preserved; revision to total hip arthroplasty is relatively easy; hemiresurfacing can delay the need for total hip arthroplasty; unlike a bipolar hemiarthroplasty, there is no polyethylene-bearing surface; and the dislocation rate is low.

However, there are limited indications for femoral resurfacing, including: young active patients presenting with Ficat stage III disease; lesions with a combined necrotic angle greater than 200 degrees or more than 30% of the femoral surface; a post-collapse lesion with more than 2 mm of femoral head depression; and no evidence of acetabular cartilage damage.[24] The functional outcome in femoral resurfacing arthroplasty has been reported to yield significant improvement,[25–27] and the short-term outcomes of hemiresurfacing were reported to be good/excellent in 84%–88% of cases.[21,27–29] However, the long-term survivorship of such implants decreased to 50%–60% at 10–11 years of follow-up[22,27] (Table 1).

Squire et al[30] reported a high overall failure rate of up to 64.8%. The main causes of failure were unpredictable groin pain, further osteonecrosis, and fracture of the neck of femur. The prevalence of groin pain after limited resurfacing has been reported to be 20%–50%.[22,26,31,32]

The durability of acetabular cartilage after hemiresurfacing is multifactorial and includes the initial health of the cartilage (which should be totally unaffected) and the patient should not be symptomatic for long to obtain a successful outcome.[27] A mismatch in the size of the femoral head compared with the inner diameter of the socket results in early failure.[33] Other factors, such as lubrication and nutrition, third body wear, and patient activity, influence the outcome of limited resurfacing.[33]

Hungerford et al[23] reviewed 33 femoral head resurfacings with post-collapse disease and found 61% had a good or excellent outcome prior to revision to total hip replacement at a mean interval of 60 months. The difficulty of performing total hip arthroplasty after limited resurfacing was almost equivalent to primary cases, because there was no loss of bone stock and the medullary canal of the femur was intact.[22]

Ash et al[34] reported 58 hips converted to cemented total hip arthroplasty after cup arthroplasty. The survival rate after

Table 1 Evidence for limited resurfacing in osteonecrosis of the femoral head

Study	Prosthesis	Hips (n)	Mean follow-up (years)	Success rate	Survivorship	Cause of failure
Amstutz et al[22]	THARIES	10	9.5	50%	50% at 11 years	50% groin pain
Siguier et al[35]	Marc Siguier	37	4	76%	76%	19% further collapse
Cuckler et al[31]	Wright Medical Conservprosthesis	59 patients	4.5	68%	68%	40% groin pain 3% fracture neck
Adili et al[32]	Wright Medical Conservprosthesis	29	4	62%	75.9% at 3 years	24% groin pain 3% fracture neck
Mont et al[26]	Hemiresurfacing	30	7	90%	90%	20% groin pain 3% fracture neck
Beaule et al[27]	Hemiresurfacing	37	6.5	86%	79% at 5 years 59% at 10 years 45% at 15 years	27% groin pain 3% loosening implant
Scott et al[21]	TARA	25	3	88%	88%	NA
Hungerford et al[23]	TARA	33	10.5	61%	61% at 5 years	39% groin pain
Sedel et al[29]	Spherocylindric cup	38	6	79%	92% at 6.9 years	3% infection 6% implant loosening 6% neck resorption

Abbreviation: NA, not available.

conversion was 92% at 10 years and 74% at 20 years. The cases did not require femoral bone grafting, and no fractures or femoral loosening occurred.

In conclusion, hemiresurfacing may be a procedure that "buys some time" for young patients. However, the results of hemiresurfacing are uncertain for several reasons, including unpredictable groin pain, further collapse of the head, and fracture of the femoral neck.

Bipolar hemiarthroplasty

The results of hemiarthroplasty involving the use of a fixed-head prosthesis have not been found to be acceptable for treatment of osteonecrosis.[36] The main reasons for the poor results are a high prevalence of destruction of the acetabular cartilage and bone stock by the prosthesis. Bipolar prostheses have been used to prevent erosion of the acetabulum and proximal implant migration, which frequently occur with monopolar Moore-type prostheses. These implants were initially developed by Charnley but popularized by Bateman[37] and Giliberty[38] in 1974. The purpose of the bipolar prosthesis is to decrease shear stress and impact loads on the acetabular cartilage, thereby reducing wear, and a big outer moving acetabular component is used to reduce dislocation and stem loosening.[39]

The indications for bipolar arthroplasty are reported to be the same as for hemiresurfacing. However, bipolar arthroplasty has disadvantages due to the requirement for resection of the femoral neck, engagement of the femoral canal, and use of a polyethylene-bearing surface which will generate wear debris and potentially compromise the longevity of the implant. Moreover, conversion arthroplasty to total hip replacement may need a very complex reconstruction, such as a roof ring, reconstruction cage, or other special implant (due to bone loss), and may require another revision later.[40]

The advantage of a bipolar prosthesis compared with a unipolar prosthesis is less proximal migration and supposedly better preservation of the acetabular cartilage.[41] In patients with osteoarthritis, the long-term outcome of bipolar prostheses in some series demonstrated healthy acetabular cartilage and bone at 15 years after surgery,[42] and survivorship at 8–10 years was acceptable at 89.5%–95%.[43] However, in young active patients with ONFH, successful outcome of bipolar arthroplasty ranged from 59% to 95% (Table 2) and long-term survivorship was only 59%–86.3% at 10–15 years of follow-up.[39,44]

Factors leading to early implant failure include persistent groin pain, proximal migration of the implant, and stem loosening. The prevalence of groin pain in patients with osteonecrosis has ranged from 11% to 53% (Table 2). Groin pain after bipolar arthroplasty may be caused by degeneration of the acetabular cartilage.

Lee et al[45] compared the outcome of cementless bipolar arthroplasty and cementless total hip replacement in matched controlled patients with stage III osteonecrosis, and found the prevalence of groin pain and gluteal pain in the bipolar group was 35% while groin pain was absent in total hip replacements ($P = 0.014$). The treatment of intractable groin

Table 2 Evidence for bipolar hemiarthroplasty in osteonecrosis of the femoral head

Study	Prosthesis	Hips (n)	Mean follow-up (years)	Survivorship	Causes of failure
Cabanela[39]	Bateman	23	9.2	78%	Groin pain 36%
Chan and Shih[46]	Omifit (osteonic)	28	6.4	96%	Proximal migration 10.7% Groin pain 10.7% Femoral osteolysis 3.6%
Meijerink et al[47]	Omifit (osteonic) Hydroxyapatite/nonhydroxyapatite	30	10.4	73%	Proximal migration 60% Subsidence 37% Groin pain 53% Femoral osteolysis 63%
Ito et al[48]	Omifit (osteonic)	48	11	70% at 15 years	Groin pain 42% Proximal migration 42%
Lee et al[45]	Spongiosa I	40	8	NA	Groin pain 20% Proximal migration 23% Dislocation 5%
Murzic and McCollum[49]	Bateman	32	6	81%	Proximal migration 6% Groin pain 18%
Nagai et al[44]	Bateman	12	16.6	75%	Groin pain 33% Osteolysis 17% Migration of stem 8%
Takaoka[41]	Various	83	5.7	NA	Groin pain 17% Proximal migration 8.4% Loosening 17%

Abbreviation: NA, not available.

pain in patients with bipolar arthroplasty is conversion to total hip replacement. However, groin pain may not resolve after conversion. Pankaj et al[50] reported that 83% of patients with bipolar arthroplasty converted to total hip replacement had no pain postoperatively while three patients (17%) reported only partial improvement.

The second cause of failure of bipolar prostheses is radiographic stem subsidence. The prevalence of stem loosening in osteonecrosis has been reported to be 8%–37%.[44,46,47,51] Early loosening of the stem is caused by poor canal fit, such as with Moore-type stems, which showed a high prevalence of loosening (47%) compared with the press fit Omnifit stem (6%).[41] Periprosthetic osteolysis is another cause of stem loosening.

Kim and Rubash[52] reported that polyethylene debris in bipolar arthroplasty was significantly higher than in matched-control cementless total hip replacements ($P < 0.05$), and caused osteolysis and aseptic loosening. The prevalence of femoral osteolysis in bipolar prostheses in patients with osteonecrosis has varied from 4% to 63% at a mean follow-up of 6–10 years.[46,47,53] Meijerink et al[41] reported a high prevalence of femoral osteolysis (63%) with the Omnifit stem, and an inferior locking mechanism caused a high amount of polyethylene wear debris and extensive osteolysis, especially in young active patients.

In conclusion, bipolar arthroplasty for osteonecrosis has a high failure rate and unpredictable results. Furthermore, the use of bipolar arthroplasty violates the femoral canal and maintains a polyethylene-bearing surface, which will generate wear debris and potentially compromise the longevity of the implant. Conversion to total hip replacement may require complex reconstruction and another revision later on.

Resurfacing hip arthroplasty

Limited resurfacing may be an option in young patients without evidence of acetabular disease (Ficat stage III), but the outcome is guarded. Pain relief is not predictable, especially when there is evidence of articular cartilage involvement. In this setting, total hip resurfacing may be a better option. The advantages of total resurfacing are a low wear rate, preservation of bone stock for further revision, use of a large diameter head to reduce dislocation rate, improved function as a consequence of the retained femoral head and neck, more precise biomechanical restoration, and decreased morbidity at the time of revision arthroplasty.[54] First-generation (metal-on-polyethylene) and second-generation (cementless metal-on-metal) total resurfacing were abandoned because of failures from high volumetric wear resulting in osteolysis and loosening.[55]

Third-generation total resurfacing began in 1996, and cementless acetabular fixation combined with a cemented femoral component has been shown to be more durable. The combination of a large-diameter metal-on-metal bearing surface has shown a low wear rate after several decades of use.[56]

However, a recent study showed that small diameter femoral components (less than 51 mm) are a risk factor for increased wear, corrosion, and higher metal ion concentration levels in the blood.[57] Conditions such as inflammatory arthropathy, osteonecrosis, and developmental hip dysplasia have been associated with higher rates of early failure.[58]

Osteonecrosis is a disease of bone substance which is different from osteoarthritis. Moreover, patients with advanced osteonecrosis often have associated risk factors, such as continued alcohol abuse or corticosteroid use, which compromise bone quality and the surface area available for implant fixation, resulting in continued femoral head collapse.[59] A contraindication for hip resurfacing is a necrotic area involving more than 50% of the femoral head (regardless of Ficat stage).

According to the US Food and Drug Administration protocol, Seyler et al[60] have developed a guideline algorithm for decision-making to proceed to resurfacing or total hip replacement. The algorithm has been based on gender, age, and etiology of disease. In patients with osteonecrosis, candidates for resurfacing must have a necrotic area less than 35% preoperatively, normal configuration of the proximal femur intraoperatively, no femoral head cysts, no head-neck junction abnormality, no large bone defects, and a neck-shaft angle of more than 120 degrees. Similarly, Revell et al[61] used three criteria to decide whether to proceed to hip resurfacing intraoperatively, ie, if the femoral head had a necrotic area of less than 35%, the integrity of the head-neck junction was preserved, and good bone stock remained after femoral preparation. They reported survivorship of Corin resurfacing implants to be 93.2% at a mean follow-up of 6 years.

The successful outcome and survivorship of third-generation total resurfacing was greater than 93% at 3–7.5 years of follow-up[59–64] (see Table 3). When compared with osteoarthritis, Mont et al[62] and Aulakh et al[64] found no significant difference in survivorship or outcome between osteonecrosis and a matched cohort of patients with osteoarthritis.

However, serious complications after total or hemiresurfacing leading to early unexpected failure of the implant may occur, and include progressive osteonecrosis (collapse) and femoral neck fracture. In Australia, the most common reason for revision of resurfacing has been femoral neck fracture.[65]

There is evidence that mechanical risk factors, such as notching of the superior part of the femoral neck during implantation, incomplete seating or varus alignment, and postoperative lengthening of the femoral neck are commonly associated with subsequent femoral fracture.[66] Further osteonecrosis as a result of femoral head resurfacing may play a role in femoral neck fracture.[67]

Steffen et al[68] compared biopsies in 19 retrieved femoral head resurfacings that failed as a result of neck fracture with 13 retrieved femoral head resurfacings that failed for other reasons. Histologic analysis showed empty lacunae in a large proportion of both groups. These researchers found empty lacunae in 9% of control patients with osteoarthritis undergoing primary total hip replacement compared with 85% of those with osteonecrosis ($P < 0.01$). In the revision situation, 71% in the neck fracture group and 21% of the other group ($P < 0.01$) demonstrated empty lacunae.

McMinn et al[69] reported 104 hip resurfacings (94 patients) for osteonecrosis Ficat stage III and IV at a mean follow-up of 4.3 years. They found four hips (3.8%) had further collapse of the femoral head compared with 0.35% further collapse in other diagnoses.

In osteonecrosis, the femoral head has already had a vascular insult, so the question is how to prevent further vascular damage during the surgical procedure. The extraosseous blood supply of the femoral head from the

Table 3 Evidence for total resurfacing in osteonecrosis of the femoral head

Study	Prosthesis	Hips (n)	Mean follow-up (years)	Survivorship	Causes of failure
Mont et al[62]	Conserve plus	42	3.4	94.5%	2% fracture neck 2% femoral loosening
Sayeed et al[63]	Conserve plus and Corin comet 2000	20 (age $<$ 25 years)	5	100% at 7.5 years	None
Sayeed et al[63]	Conserve plus and Corin comet 2000	87 (age $>$ 25 years)	6	94%*	6% aspetic reasons
Aulakh et al[64]	Birmingham	101	7.5	98%	2% fracture neck
Revell et al[61]	Corin and Birmingham	73	6	93%	1% femoral loosening 1% further collapse 1% subtrochanteric fracture
Beaule et al[59]	Conserve plus	28	4.5	93%	7% femoral loosening

Note: *No difference (P=0.58) between the 7.5 years of survivorship in the groups under and over 25 years of age.

medial circumflex artery can be destroyed during the posterior approach. In the standard posterior approach, the medial circumflex artery is divided, decreasing blood flow to the head. Other procedures performed using the posterior approach, such as tenotomies of the short external rotators and dissection of the capsule distal to the piriformis, are likely to damage the branches of the medial femoral circumflex artery and potentially render the femoral head avascular.[66,70–72] Preserving the attachment of the obturator externus protects the ascending branch of the medial circumflex artery from injury.

Steffen et al[66] reported the effect of resurfacing on oxygen concentration of the femoral head with an extended posterior approach, causing a mean 60% decrease in oxygen concentration that did not improve significantly after wound closure. The surgical dislocation approach described by Ganz et al[73] (anterior surgical dislocation and trochanteric flip) has been developed to preserve vascularity of the femoral head.

Amarasekera et al[71] used laser Doppler flowmetry to measure the effect on blood flow to the femoral head-neck junction of two surgical approaches during resurfacing arthroplasty and found that the main reduction in blood flow occurred during exposure and capsulotomy in both groups. There was a significantly greater reduction in blood flow with the posterior approach (40%) than with the trochanteric flip approach (11%, $P < 0.01$). Reaming the femoral head is another procedure that can damage blood flow to the femoral head.

Beaulé et al[74] reported ten hips with advanced osteoarthritis having metal-on-metal hip resurfacing by means of the Ganz surgical dislocation approach which had femoral head blood flow measurements using laser Doppler flowmetry. Nine hips had a mean decrease of 70% in femoral head blood flow after standard reaming ($P = 0.0003$). They concluded that the cylindrical reamer substantially compromised blood flow to the femoral head by encompassing the whole circumference of the femoral head-neck junction, potentially disrupting all of the retinacular vessels. To preserve the blood supply while reaming, one must direct the cylindrical reamer superolaterally, staying as close as possible to the inferomedial neck. The final step that can be harmful to the viability of the femoral head is cement preparation.

Campbell et al[75] retrieved failed metal-on-metal resurfacings from femoral neck fracture or loosening and compared these cases with other causes of failure. They found that the total percentage of the femoral head section occupied by cement ranged from 11% to 89% in the femoral neck fracture/loosening group. The temperature was high enough to produce thermal necrosis of the femoral head. Because of this, excessive cement penetration may result in necrosis of bone secondary to the heat of polymerization and may cause early failure of the implant.

In conclusion, the short-term to mid-term outcome of total resurfacing in ONFH has been reported to be excellent in young patients. However, total resurfacing in the osteonecrotic femoral head has some issues for concern. Patient selection is crucial, and femoral heads with extensive necrosis that would require shortening or downsizing to resect dead bone may be better served by total hip replacement. Long-term outcome and the prevalence of unexpected failure in the patient with osteonecrosis should be monitored closely.

Total hip replacement

Total hip arthroplasty is indicated in advanced stage osteonecrosis once the femoral head has collapsed and the hip joint has degenerated. However, the longevity of total hip arthroplasty for treatment of osteonecrosis is less when compared with other indications.[76–79] There are several factors that contribute to the high failure rate.[80] Age is the most important factor that affects the outcome of total hip replacement.[81] The age at presentation of nontraumatic osteonecrosis has been reported to range from 24 to 65 years, and 75% of these patients are aged 30–60 years.[82,83] Younger patients have a higher activity level, increased wear, and osteolysis. Young age at the time of surgery has been associated with mechanical failure in 14%–37% of total hip replacements at a mean follow-up of 6–7.5 years.[78,79,81,84–88] However, age is not an isolated factor accounting for these poor results.

Sarmiento et al[85] found the prevalence of acetabular radiolucencies was higher in young patients who had rheumatoid arthritis or osteonecrosis (32%) compared with older patients (11%) with cemented total hip replacement. On the other hand, the prevalence of acetabular wear did not differ between younger and older patients who had osteoarthritis. They concluded that the quality of trabecular bone available for fixation of the component was an important factor. In osteonecrotic bone, the common histomorphometric profile is reduction of trabecular bone volume, thickness of the osteoid seams, and calcification. The framework of cancellous bone in osteonecrosis is apparently weak. Defective cancellous bone might not support the interdigitation of cement and subsequent loading.[89] Therefore, the outcome of cemented total hip arthroplasty using a first-generation cementing technique was poor, and the prevalence of implant loosening was as high as 57%, especially on the acetabular side.[79,81–91] Calder et al[91] described extensive osteocyte death and an abnormal remodeling capacity in the proximal femur in osteonecrosis, and proposed that premature implant loosening may be related to the presence of abnormal cancellous bone at the implant-bone and cement-bone interfaces.

The etiology of osteonecrosis is another factor influencing the outcome of total hip replacement. Osteonecrosis encompasses a heterogeneous group of disease entities, with a spectrum of severity that makes treatment particularly challenging.

Post-traumatic osteonecrosis refers to the onset of the condition after experiencing significant trauma. Nontraumatic osteonecrosis refers to conditions unrelated to trauma, such as alcoholism, smoking, blood clotting disorders, kidney disease, connective tissue disease, and corticosteroid use. Often the condition has no known causes, and is referred to as idiopathic osteonecrosis.

The functional outcome and mortality rate of post-traumatic osteonecrosis and idiopathic osteonecrosis is usually better than alcohol-induced and steroid-induced osteonecrosis or osteonecrosis with systemic disease.[78,90–95] Corticosteroids have a direct inhibitory effect on bone formation (osteoblast activity) and increase bone resorption. Patients on steroids also have a high incidence of infection, poorer quality soft tissues, and impaired wound healing. In patients with steroid-induced osteonecrosis treated with cementless total hip replacement, the reliability of bone ingrowth may be reduced.

Phillips et al[96] reported a high incidence of acetabular loosening (15%) which increased over time with steroid-induced osteonecrosis, but bone ingrowth and stable fixation were less of a problem with regards to the femoral component if there was a good initial fit. With cemented implants, the effect of corticosteroids may lead to trabecular weakness, resulting in progressive radiolucency at the bone cement interface. The prevalence of radiolucency around cemented acetabular components ranged from 16% to 50% at 44–86 months.[96,97–100]

In alcohol-induced osteonecrosis, the outcome and mortality rate of total hip replacement is worse than for idiopathic osteonecrosis.[94] Yuan et al[101] studied 19 patients with alcohol-induced osteonecrosis (24 hips) and concluded that the continued use of alcohol was associated with a slightly increased risk of cementless implant failure (61% implant survivorship at 10 years in those with continued alcohol intake compared with 75% 10-year survivorship in those without).

Osteonecrosis of the femoral head in renal transplant patients occurs as a result of use of corticosteroids and other medications. Cemented total hip replacement[102] seems to be a better option in these patients because of poor bone stock. The short-term implant survivorship was 85%–100%[103–105] at 3–5 years of follow-up and the long-term survivorship (free for revision) was 78%–100% at 10 years[106,107] (Table 4).

Goffin et al[106] reported a large series of 63 renal transplant patients who had 99.8% survivorship of cemented Charnley total hip replacements without loosening at a mean of 10 years. However, the survival rate dropped to 63.8% at 20 years and survival rate with death as the endpoint was 81.7% at 10 years and 35.8% at 20 years. Factors such as the type of dialysis prior to transplantation (hemodialysis versus peritoneal), persistence of post-transplant hyperparathyroidism, incidence of acute rejection episodes in the first post-transplant months (indicative of administration of higher steroid doses) appeared to affect the outcome. The incidence of aseptic loosening for cemented components was as high as 46% at 10 years.[108]

Renal osteodystrophy causes increased bone resorption and decreased bone formation, resulting in osteopenia. Diminished parathyroid hormone levels after transplantation, as well as accompanying steroid use, further decrease osteoblastic activity. Interestingly, the long-term results of cementless implants in transplant patients have not been reported. There are some short-term studies that demonstrate similar outcomes and survival rates between cementless and cemented implants in steroid-taking versus nonsteroid-taking age-matched patients with renal disease, but complications in the former group of patients, such as dislocation rate, are still higher (14.8% versus 3%–5.8% in the nonimmunosuppressive group).[92]

Murzic et al[108] followed 13 porous-coated cementless total hip replacements in renal transplant patients for a mean duration of 3.1 years and found that none of the hips had to be revised. They concluded that the early results of porous-coated implants were satisfactory. During the last decade, the number of short-stem arthroplasties is increasing, although there are no reports on the outcome of short-stem arthroplasties in patients with ONFH. One study reports the use of a metaphyseal-fitting anatomic cementless femoral component in 84 total hip replacements in patients with a mean age of 78.9 (range 70–88) years. The mean follow-up duration was 4.6 (4–5) years. The mean preoperative Harris hip score was 26 (0–56), which improved to 89 (61–100) at the final follow-up. No patient had thigh pain. Osseointegration was seen in all femoral and acetabular components. All hips had grade 1 stress shielding of the proximal femur. No acetabular or femoral osteolysis was identified.[109]

Table 4 Evidence for the outcome of total hip replacement in post-renal transplant patients

Study	Prosthesis	Hips (n)	Mean follow-up (years)	Survivorship	Causes of failure
Alpert et al[92]	Madreporic surface femoral screw ring cup (cementless)	27	4	97% (for any reason)	7% fracture 11% dislocation 3.7% infection
Bradford et al[103]	T-28 (51) Charnley (2) Charnley Muller (7) (cemented)	60	3.4	93% (for any reason) 98% (revision free for aseptic loosening)	2% femoral loosening 2% infection 17% dislocation
Chmell et al[104]	Cemented	9	3.6	100%	11% dislocation
Deo et al[105]	Cemented (31) Cementless (2) Hybrid (1)	34	5.2	85% (revision free for aseptic loosening)	3% infection 14.7% loosening
Goffin et al[106]	Cemented	93	18	100% at 10 years 78.8% at 20 years (revision free for aseptic loosening)	1% dislocation 2% infection 10% aseptic loosening
Cheng et al[107]	Cemented T 28 (67) Muller (9)	76	10	91% at 5 years 78% at 10 years (revision for any reason)	13% acetabular loosening 13% femoral loosening 1.3% infection 16% dislocation
Murzic et al[108]	Cemented	32	8.7	69% (revision free for aseptic loosening)	46% loosening 0% infection
Murzic et al[108]	Cementless	13	3.1	100% (revision free for aseptic loosening)	0% loosening for cementless 10% infection

Sickle cell disease has been associated with poor outcomes of total hip replacement because of high intraoperative complications, such as vaso-occlusive crises, congestive heart failure, major transfusion reaction, intraoperative femoral fracture, and perforation. Hanker et al[110] performed total hip replacement in 14 sickle cell patients with a complication rate of 100%, increased blood loss and transfusion requirements, and prolonged hospitalization. They recommended that the risk-benefit ratio should be carefully assessed for each individual patient. The outcome of total hip replacement was poor because of a higher rate of loosening and infection associated with functional asplenia, an abnormal immune system, and relatively poor perfusion of blood in bone secondary to sickling. Marrow hyperplasia may compromise long-term implant fixation. Marrow hyperplasia may lead to thin femoral cortices, diminution of medullary trabeculae, widening of the medullary cavity, and focal areas of sclerosis, leading to difficulties in femoral canal preparation. The survival rate of the implant was poor, with a 50%–60% revision rate at 3.6–9.6 years, and early and late infection rates of 20%–36%, respectively.[111–113]

Implant design and surgical technique are other important factors influencing the outcome of total hip replacement in osteonecrosis. New implant designs and bearing surfaces decrease wear and osteolysis in young active patients with osteonecrosis.[114] A summary of the outcome of total hip replacement categorized by type of implant and bearing surface appears below.

Cemented implants for total hip replacement

The first-generation cement technique, initially advocated by Charnley, uses hand mixing and manual insertion with finger packing. The second-generation technique uses retrograde cement insertion with a gun, more aggressive rasping and bushing, pulsatile lavage for canal preparation, and a cement plug distally. Vacuum mixing of cement and use of proximal and distal centralizers constitutes the third-generation cementing technique. First-generation and second-generation cementing techniques in osteonecrosis had high mechanical failure rates of 9.1%–48%[78,81,84,115] and high revision rates of 13%–28% at 7–14 years of follow-up[78,81,115–117] (Table 5). The third-generation cementing technique has been shown to improve survivorship, especially on the femoral side.

Kim et al[118] reported the outcome of polished tapered stems in 50 hips with osteonecrosis using the third-generation cementing technique. The survival rate was 100% at 10 years of follow-up. Similarly, Simon et al[119] reported the longevity

Table 5 Evidence for outcome of cemented total hip replacement in osteonecrosis of the femoral head

Study	Prosthesis and cementing technique	Hips (n)	Mean follow-up (years)	Survivorship (free of aseptic loosening)	Causes of failure
Saito et al[78]	Cemented Charnley-Muller (first cementing technique)	29	7.2	72%	28% aseptic loosening 17% femoral loosening 7% acetabular loosening 4% both component
Fyda et al[81]	Charnley (29) Iowa (19) First cementing (16) Second cementing (32)	48	14.5	87% at 10 years	7% femoral loosening 13% acetabular loosening 2.% sepsis 2.% dislocation
Kantor et al[115]	Second cementing technique	28	7.7	85.7% at 10 years	12.5% aseptic loosening
Katz et al[117]	Cemented (second cementing) (24) Cementless (14)	34	3.8	100%	3% sepsis 6% dislocation
Simon et al[119]	Hybrid (28) Cemented (6) (third cementing) All polished tapered stem	34	10.9	91%	15% acetabular loosening 0% femoral loosening
Garino and Steinberg[120]	Cemented (71) Hybrid (53) (third cementing)	123	4.6	97.5%	0.8% infection 0.8% dislocation 5% cemented cup loosening (at 6.6 years)
Kim et al[118]	Cementless Duraloc cup Cemented Elite stem	50	9.3	100% at 10 years	2% deep infection No loosening

of polished tapered stems in 34 osteonecrotic hips and found 100% survivorship at 10 years of follow-up. However, cemented acetabular component loosening remains the main problem in young active patients.[79,90,121] The failure rate of cemented acetabular components in patients with osteonecrosis is 7%–15% at 10–15 years of follow-up.[78,81,119] Using the third-generation cementing technique, the failure rate of acetabular components is still as high as 15% at 10 years of follow-up.[120–123]

Cementless implants for total hip replacement

Cementless femoral components

Porous-coated devices were originally intended for biologic fixation by bone ingrowth for young active patients. The theoretical advantage of biologic fixation is that, once the implant has become ingrown with bone, failure at the implant-bone interface is unlikely. However, two potential problems, especially in young active patients, are stress shielding and osteolysis due to wear debris. The outcome of first-generation proximally ingrown stems such as the porous-coated anatomic implant (PCA, Howmedica Osteonics Corporation, Mahwah, NJ) and the Harris-Galante I (HG-I, Zimmer Corporation, Warsaw, IN) was unfavorable.

Kim et al[124] found a high incidence of failure of the PCA (21%) and HG-I (19%) components at 7.5 years of follow-up in patients with osteonecrosis. Long-term survivorship of HG-I components reported by Kim et al[125] was 80% at 12.5 years. The HG-I has a noncircumferential proximal porous coating that facilitates distal wear particle migration and osteolysis. Second-generation proximal porous-coated implants have been developed to improve stem canal fill in both the coronal and sagittal planes. The circumferential porous coating on the proximal one third of the stem provides more reliable ingrowth and limits distal osteolysis. Examples of second-generation proximal-coated femoral components include the anatomic profile stem (DePuy, Warsaw, IN) and anatomic hip (Zimmer Corporation).

Kim et al[121] reported the long-term outcome of the anatomic profile stem in young patients less than 50 years (66% with osteonecrosis) and found the survivorship was 96% at 18 years of follow-up. Ha et al[126] reported that the survivorship of the hydroxyapatite-coated anatomic profile stem in 46 osteonecrosis hips was 93.3% at 13 years. Hartley et al[127] reported on 48 anatomic medullary locking (AML, DePuy) stems with extensive porous coating in patients with osteonecrosis using several cementless cup designs and found no femoral revisions at 10 years of follow-up. Piston et al[128] reported that the survivorship of 35 AML stems was 97% at 7.5 years of follow-up (only one patient has been revised for a loosening stem). In conclusion, second-generation proximal porous coating and extensive porous-coated stems have shown a successful long-term outcome in patients with osteonecrosis.

Cementless acetabular components

The revision rate for cemented components is usually higher on the acetabular side than on the femoral side in osteonecrosis. Second-generation or third-generation cementing techniques have not improved implant longevity. Therefore, the cementless acetabular implant was developed to provide long-term fixation.[129] The early design of porous-coated acetabular components included the PCA (chromium-cobalt beads, peg fixation), HG-I (titanium mesh optional screw fixation), and the AML (chromium-cobalt beads, spike fixation). The outcome of HGP-I and PCA cups in osteonecrosis was unsatisfactory. HGP-I had a high prevalence of failure of up to 15% at mean follow-up of 6.5–12.5 years[124,125,130] because of dissociation of the polyethylene liner with breakage of the locking mechanism. The PCA cup had a high failure rate in osteonecrosis similar to that of the HG-I. The failure rate of the PCA cup was 11%–24% at 8–10 years of follow-up[124,131] because of a poor polyethylene locking mechanism, polyethylene wear, acetabular osteolysis, and cup migration. Second-generation cups were developed to improve the outcome and survival rate.

Kim et al[118] reported on the second-generation (rim locking design) Duraloc (DePuy) in 78 osteonecrotic hips and found no loosening at 9.4 years of follow-up. The long-term outcome of the Duraloc cup in patients younger than 50 years reported by Kim et al[121] was an 18% failure rate at 18 years due to wear and osteolysis (66% of patients in this group had osteonecrosis).

In conclusion, cementless cups need adequate primary stability to achieve osseointegration, and modern cups appear to achieve this goal. However, polyethylene wear and osteolysis remain matters of concern in this group of active patients. Highly cross-linked polyethylene and other newer alternative bearings, such as ceramic and metal-on-metal articulation, may reduce wear and improve the outcome of cementless cups.

Wear and osteolysis in patients with osteonecrosis

Conventional polyethylene wear limits survivorship of total hip replacement in young active patients. Particle-induced periprosthetic osteolysis and aseptic loosening are major complications. The average wear rate of conventional polyethylene has been estimated to be 0.10 mm per year in osteoarthritis.[132,133] In young active patients with osteonecrosis, the annual wear rate has been reported to be 0.03–0.18 mm.[96,124,126] The prevalence of osteolysis with cementless implants ranges from 11%–80% on the femoral side and 7.6%–36% on the acetabular side at 7–18 years of follow-up (see Table 6). Factors that correlate with osteolysis are polyethylene wear rate, duration of implantation, and implant design. The prevalence of osteolysis for cementless implants (HG-I, PCA, Profile) in young osteonecrosis patients (aged 31–53 years) was 7.6%–80% and the linear wear rate was 0.14–0.21 mm per year. This is not different from patients with osteoarthritis of the same age.

Hallan et al[134] reported wear rates for HG-I, PCA, and Profile components in 96 primary and secondary osteoarthritis at 12–16 years of follow-up. They found the same range of wear rate of 0.17–0.21 mm per year, and the prevalence of osteolysis was 48%–64% depending on the type of implant. Newer cementless implant designs that improve canal fit may help to decrease the rate of osteolysis.[110] However, the wear rate of conventional polyethylene bearing surfaces is still high in young active patients. New polyethylenes and

Table 6 Prevalence of osteolysis and wear rate with conventional polyethylene in osteonecrosis

Study	Implant design	Hips (n)	Mean age (years)	Mean follow-up (years)	Linear wear rate (mm/year)	Femoral osteolysis (%)	Acetabular osteolysis (%)
Kim et al[125]	HGP-I	65	53	12.5	0.14	29	7.6
Kim et al[121,*]	Duraloc cup and Elite (plus) or Profile stem	109 (hybrid) 110 (cementless)	43 47	18 18	0.21 0.21	28 22	32 36
Ha et al[126]	Profile hydroxyapatite stem	36	48.6	10	0.18	80	30
Piston et al[128]	AML	35	32	7.5	NA	11	17
Hartley et al[127]	AML Prodigy	38	31	9.4	NA	21	16

Notes: *Study in young patients. Approximately 66% in each group were osteonecrosis patients.
Abbreviations: AML, anatomic medullary locking; NA, not available.

hard-on-hard bearing surfaces are strategies to decrease the wear rate in this group of patients.

Highly cross-linked polyethylene

The use of high cross-linked polyethylene (HXPE) in total hip arthroplasty has become more popular because of a reduced linear wear rate of up to 40% compared with conventional polyethylene.[135–137] HXPE in patients young than 60 years yielded mean wear rates for 0.02–0.04 mm per year, significantly less than conventional polyethylene, with no cases of osteolysis (Table 7). Only one study has published results for HXPE in patients with osteonecrosis.

Mont et al[138] found no prevalence of osteolysis using the Crossfire HXPE in 81 osteonecrotic hips at 4 years of follow-up. We recently reviewed the outcome for 66 patients with osteonecrosis of the hip requiring total hip replacement, and use of HXPE after a mean of 4 years of follow-up yielded a linear wear rate of 0.07 mm per year with no evidence of osteolysis. However, the wear rate in this study may be slightly more than in other studies because of a younger patient age. In conclusion, the short-term to mid-term outcome of HXPE in young patients is excellent. However, the long-term outcome of total hip replacement with HXPE is unknown.

Metal-on-metal bearing surface

The rationale for use of metal-on metal articulations is that it produces less volumetric wear than metal-on-polyethylene and may result in a decreased incidence of osteolysis, particularly in young active patients.[139,140] First-generation metal-on-metal McKee-Farrar total hip replacements have been abandoned because of suboptimal implant design, inconsistent manufacturing tolerances, and poor surgical technique. In the 1990s, second-generation metal-on metal Metasul (Zimmer Corporation) hip prostheses were introduced with improved materials, design, and better quality control during manufacturing.

Dastane et al[141] reported the clinical and radiographic results of Metasul implants in patients with osteonecrosis or osteoarthritis at 5 years of follow-up. They found no significant differences and no evidence of osteolysis. Sieber et al[142] reported volumetric wear after the run-in period to be 0.3 mm^3 per year, which is 60 times less than with metal-on-conventional polyethylene articulations. The prevalence of osteolysis in young patients with metal-on-metal implants has ranged from zero to 6% (Table 8). The survivorship of metal-on-metal in young active patients was 94.5%–100% at 5–10 years of follow-up.

However, many studies have reported early osteolysis following second-generation metal-on-metal implants. Kim et al[143] found that 2.8% of Metasul-bearing surfaces had osteolysis, and histologic examination of pelvic osteolytic lesions showed multiple lymphocytes with a perivascular distribution and a small number of macrophages. This suggests that the cause of the osteolysis was a metal-associated hypersensitivity reaction with vasculitis rather than a simple foreign body reaction. Park et al[144] reported early osteolysis in 165 S-ROM® hips with metal-on-metal bearings. They found osteolysis in 6% of cases at 24 months, with a similar histologic picture as described above. Neither particle-laden

Table 7 Evidence for osteolysis and wear rates of highly cross-linked polyethylene in osteonecrosis patients

Study	Bearing surface	Mean age (years)	Mean follow-up (years)	Survivorship (free of loosening)	Mean linear wear rate (mm/year)	Mean volumetric wear rate (mm^3/year)	Osteolysis
Mont et al[138]	Crossfire (81 hips) Trident (23 hips)	38	4	99% at 4 yrs	NA	NA	0%
Lachiewicz et al[145,*]	Longevity (102 hips) (20% ON)	61	5.7	NA	0.04	80.5	0%
Dorr et al[136,*]	Durasul (37 hips) (16% ON)	60	5	NA	0.02	NA	0%
Bitsch et al[146,*]	Marathon (32 hips)	60	5.8	NA	0.03	15.4	0%
Waewsawangwong et al**	Longevity (66 hips)	48	4	100% at 4 years	0.07	NA	0%

Notes: *Study in young patients; **unpublished data.
Abbreviations: ON, osteonecrosis; NA, not available.

Table 8 Evidence for prevalence of osteolysis and survival rate for metal-on-metal total hip replacement

Study	Implant	Hips (n)	Mean age (years)	Mean follow-up (year)	Survival rate (%)	Osteolysis (%)
Dastane et al[141]	Metasul (multicup design mated with APR stem)	30	44.7	5.5	100% at 5 years	0%
Girard et al[147]	Metasul Armor/Allofit cup Zweymuller SL stem/ Muller cemented stem	47 (ON 54%)	25	9	94.5% at 10 years*	6% on femur 4% on pelvis
Kim et al[143]	CLS Metasul bearing	68 (ON 87%)	37	7	100% at 7 years	1.4% on femur 1.4% on pelvis
Park et al[144]	S-ROM (DePuy)	165 (ON 54%)	56.7	2.3	98.8% at 2 years	6% on femur

Note: *No significant differences in survival rate with different preoperative diagnoses.
Abbreviation: ON, osteonecrosis.

macrophages nor polymorphonuclear leukocytes were seen. Antigen-specific sensitization of T cells (delayed-type hypersensitivity) may play a role in the development of early osteolysis following second-generation metal-on-metal total hip replacement. Moreover, metal-on-metal implants generate smaller wear particles and ions with systemic distribution that have to be monitored closely. Regarding the generation of metal ions seen in the blood and urine of patients with metal-on-metal implants, these elevated metal ions have theoretical although not proven risks related to hypersensitivity and carcinogenesis as well as other biologic concerns. There are also concerns regarding increased costs.[148]

Ceramic-on-ceramic bearing surface

Alumina or zirconia heads have both increased hardness and strength, which reduces abrasive wear by up to 50% compared with metal-on-polyethylene bearings, and may reduce the prevalence of osteolysis.[149,150] Early prostheses had high failure rates as a result of poor acetabular fixation, implant fracture, and sporadic excessive wear of the bearing surface.

Hamadouche et al[151] reported a 61.2% 20-year survival rate for cemented cups in a long-term review of 118 aluminum total hip replacements. Third-generation ceramic implants were introduced in 1994. These improvements include decreased ceramic grain size, higher density, lower porosity as a result of hot isostatic pressing, laser etching, nondestructive proof-testing, and a metal-backed socket for acetabular fixation.[152–157]

The survivorship of ceramic-on-ceramic implants in patients with osteonecrosis varied between 85% and 100% at 10–15 years of follow-up depending on implant design. No osteolysis has been reported. However, complications after ceramic-on-ceramic implants in high-demand young active patients are not uncommon. In patients with osteonecrosis, clicking or squeaking occurs in 2%–20%,[158,159] dislocation in 2%–4%,[158,160] intraoperative ceramic insert chipping in

Table 9 Evidence for survival rate and prevalence of osteolysis in ceramic-on-ceramic implants

Study	Implant	Hips (n)	Age (years)	Follow-up (years)	Survival rate (revision)	Osteolysis
Bizot et al[156]	4 type socket		32.3 (17–40)	2–22	Socket type	
	1. Cemented alumina	41			90.4% at 10 years	0
	2. Screw in ring with aluminum insert	22			88.8% at 10 years	
	3. Press fit plain aluminum socket	32			95.1% at 7 years	
	4. Metal back aluminum insert	33			94.3% at 7 years	
Nich et al[160]	Cemented cup at first 39 cups Press fit aluminum cup (later 13 cups)	52	41 (22–79)	16	84.5% at 10 years 65% at 16 years	0
Seyler et al[161]	ABC I, ABC II, Trident	79	45.2 (21–67)	4.2 (0.7–7.7)	95.5%	0
Kim et al[158,*]	IPS femoral component Duraloc cup Biolox forte (bearing)	93	38.2 (24–45)	11.1 (10–13)	Acetabular 99% at 10 years Femoral 100% at 10 years	0
Baek and Kim[159]	Biolox forte bearing Plasmacup BiContact (Aesculap)	71	39.1	7.1	100% at 6 years	0

Note: *Study in young patients (55% of patients in this group had osteonecrosis).

1%–2.6%,[161,162] and intraoperative fracture of the femur in 2.8%–5.7%[159,160] (Table 9). Methods to prevent these complications include obtaining optimal implant position, absence of a trochanteric osteotomy, efforts to preserve and reconstruct soft tissues, and restoration of limb length.

In conclusion, ceramic-on-ceramic bearing surfaces have an advantage over metal-on-metal bearing surfaces in this patient population because of their chemical inertness. However, ceramic-on-ceramic bearings have issues of concern, such as cup fixation, femoral head or acetabular component breakage or chipping, and squeaking, especially in young active patients.

Summary

Treatment of advanced post-collapse ONFH is challenging and controversial. Patient selection is very important. Limited resurfacing and total resurfacing may be options for young patients with limited involvement of the femoral head. However, unexpected failure, including further osteonecrosis, femoral neck fractures, and in the case of hemiresurfacing, acetabular cartilage degeneration, is of concern. Total hip replacement may be more appropriate for older patients with extensive femoral head and acetabular involvement. The use of new bearing surfaces, such as HXPE, metal-on-metal, and ceramic-on-ceramic, have been reported to improve the longevity of implants. However, each of these new bearing surfaces has potential advantages and shortcomings that will become more apparent with longer follow-up.

Disclosure

The authors report no conflicts of interest in this work.

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