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Evaluation and Treatment of Femoral Osteolysis Following Total Hip Arthroplasty

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Introduction

Total hip arthroplasty (THA) is widely successful for the treatment of end-stage hip disease. It significantly improves the quality of a patient's life by reducing both pain and functional limitation[1]. Many studies have demonstrated excellent survivorship following THA[2,3]. However, bone resorption, or osteolysis, has emerged as a major concern regarding long-term THA survival. The incidence of periprosthetic osteolysis is reported to be greater than the aggregate of all other complications[4].

Pathophysiology

Biomechanics of Femoral Component Design

Adaptive bone remodeling, or stress shielding, can occur in response to an altered mechanical environment following THA. Stress shielding leads to bone resorption, which can lead to an increased risk of periprosthetic fracture. Following implantation of a femoral prosthesis, there is redistribution of loads to the remaining femoral bone stock based on stem design. Most modern stem designs are manufactured with a coating that maximizes bone in-growth and minimize s stress shielding[3]. Reducing the amount of porous coating may decrease biologic fixation, whereas high amounts of porous coating may promote stress shielding[5,6].

Wear and Debris

Wear is defined as the loss of material from a surface due to motion. Linear wear rate refers to the degree of penetration of the metallic head into the plastic liner[6]. The incidence of osteolysis has been shown to rise significantly as linear wear rate rises above 0.1 mm/year, while osteolysis is rare below this threshold[7].

Implant material and design have important implications in wear and osteolysis. Highly cross-linked polyethylene (HXLPE), ceramic-on-ceramic, and metal-on-metal designs have all been employed as strategies in THA to reduce wear and subsequent osteolysis. Ultrahigh molecular weight polyethylene (UHMWPE) has been a reliable material used in THA acetabulum liners. However, the use of ceramic-on-polyethylene and metal-on-polyethylene implants has been associated with accelerated wear. HXLPE is a UHMWPE material that has been modified to resist wear.

Osteolysis

The concept of "effective joint space", which includes the prosthetic-bone interface, has been proposed as an explanation of the mechanism for wear particle migration and resulting osteolysis[8,9]. The flow of synovial fluid into the effective joint space delivers particulate matter that initiates localized macrophage-induced phagocytosis. The macrophages release cytokines, inducing a complex cellular response which initiates focal bone resorption primarily mediated by osteoclasts[5]. Circumferential implant coating has been shown to reduce wear particle migration along the effective joint space by creating a seal at the bone-implant interface[10,11,12].

Patient Evaluation

Evaluation begins with a comprehensive history and physical examination. The history should include the onset, provoking factors, quality, severity and delay between implantation and beginning of symptoms. In all cases of painful THA, infectious etiology must be ruled out.

Plain radiographs including an anterior-posterior (AP) view of the pelvis, AP and frog-leg lateral views of the femur that visualize the entire femoral component are necessary for initial evaluation. Radiographic signs of a stable uncemented implant include spot welds at the ends of the porous coating, absence of radiolucent lines, and calcar atrophy secondary to stress shielding. Osteolysis with a stable implant may be candidate for conservative treatment. Unstable implants may show component migration, divergent or progressing radiolucent lines, and pedestal formation (bony deposit at the distal tip of the implant)[13]. Loose femoral components also often remodel into varus and retroversion. Unstable implants require surgery to prevent further insult.

Classification

The Paprosky classification, provides an algorithm for defining femoral bone loss and directing treatment for femoral revision[14]. The quality and quantity of proximal bone stock, defined by the Paprosky classification system, guides treatment for femoral component revision as summarized in Table 1.

Table I. Paprosky classification of femoral bone loss overview of defect type and treatment strategy.

Paprosky Classification of Femoral Bone Loss		
Type	**Description**	**Treatment**
Type I	Minimal metaphyseal bone loss	Extensively porous coated implant or tapered stem
Type II	Extensive metaphyseal bone loss with intact diaphysis	Extensively porous coated implant or tapered stem
Type III	Extensive metadiaphyseal bone loss, minimum of 4 cm of intact cortical bone in the diaphysis	Extensively porous coated implant or tapered stem
Type IIIb	Extensive metadiaph seal bone loss, less than 4 cm of intact cortical bone in the diaphysis	Tapered stem or cemented stem with impaction bone graft
Type IV	Extensive metadiaphyseal bone loss and a nonsupportive diaphysis	Allograft prosthetic composite, long cemented stem, or proximal femoral replacement

Treatment

Non-operative Management

Non-operative treatment, reserved for asymptomatic patients with stable implants, aims to stop or slow the progression of osteolysis. There is some evidence at short and mid-term follow up after THA that bisphosphonates lead to decreased bone loss from osteolysis. Long term effect, however, is unclear[15].

Operative Management—Surgical Planning

Meticulous pre-operative planning is paramount for revision THA. Planning includes determining the surgical approach, tools necessary for component removal, and implants for reconstruction. The surgical approach for revision THA is based on surgeon experience, prior incisions, region of bone loss, need for additional exposure such as osteotomy, distorted anatomy or presence of heterotopic ossification (associated with the posterior approach to the hip), and planned reconstruction technique[16].

It is helpful to determine prior implants used from a patient's operative report that includes implant serial number and registration information. Flexible osteotomes, trephines, high-speed burr (pencil tip, carbide tip, metal cutting wheel), ultrasonic cement removal instruments, and universal extraction tools are also useful to facilitate stem removal[16]. Use of an extended trochanteric osteotomy (ETO) for removal of a well-fixed implant or extraction of a long column of cement distal to the stem can also be helpful[17]. Ultimately, the extent of femoral bone loss determines the reconstructive technique used for treatment[16].

Paprosky Type I defect reconstruction

Paprosky Type I defects have minimal metaphyseal bone loss, an intact diaphysis, and little to no proximal remodeling of femoral component into varus or retroversion. Mainstays for treatment include proximally porous coated femoral stems, extensively porous coated cylindrical stems, and tapered fluted stems. Implant selection depends on surgeon preference, amount of remodeling encountered, and remaining bone stock[18,19].

Proximally-coated stems may be considered when there is minimal proximal metaphyseal bone loss. Extensively porous coated cylindrical stems are versatile and may be used to reconstruct Type I defects and defects with more severe bone loss. Tapered fluted stems achieve axial stability with their geometry and have longitudinal ribs that enhance femoral cortex rotational stability and bony apposition. They are designed to decrease proximal stress shielding and more closely match the implant's modulus to the femur in order to minimize thigh pain.

Paprosky Type II defect reconstruction

Paprosky Type II defects, the most common type of defect, have extensive metaphyseal bone loss with an intact diaphysis. They often present with proximal varus femoral remodeling, making reconstruction more challenging. Type II defects may be reconstructed using extensively porous coated cylindrical stems or tapered fluted stems. When considering reconstruction of these defects, it is most important to bypass metaphyseal bone loss and obtain stable fixation in intact bone.

Paprosky Type III defect reconstruction

Paprosky Type IIIa defects include extensive metadiaphyseal bone loss with a minimum 4cm of intact isthmic cortical bone. These defects may be treated with extensively porous coated stems, tapered fluted stems with splines or cylindrical stems[20]. Modular stems, which offer a greater degree of versatility, can also be used for reconstruction. These stems provide the flexibility of restoring version when the lesser trochanter anatomy is altered by remodeling while also allowing for more adaptable correction of leg length by adjusting the proximal body[21]. They are, however, more expensive than non-modular stems and the modular junction is at risk of fretting corrosion, which may ultimately lead to fracture of the stem.

In contrast with Type IIIa defects, Type IIIb defects include extensive metadiaphyseal bone loss with less than 4cm isthmic cortical bone remaining. Although fully porous coated stems may be used successfully in select patients, the stem is technically challenging to insert and the stiffness of implant may lead to thigh pain. The poor isthmic bone stock in type

IIIb defects necessitates alternative treatment strategies to achieve stable fixation of the prosthesis. Strategies to treat these defects include tapered stems, modular fully porous coated stems, and polished tapered cemented stems.

Another strategy to treat Type IIIb defects is with impaction bone grafting. Impaction grafting may be used to treat scenarios where there is inadequate diaphysis (femoral canal $>$18mm in diameter or $<$4cm isthmic bone stock) to achieve a "scratch fit" for a cementless implant. Contraindications include significant segmental defects with proximal femoral deficiency greater than 10cm. Supporters of impaction grafting advocate its ability to restore bone stock. Although long-term results for impaction grafting are encouraging, this reconstruction technique is labor intensive and requires experience.

Paprosky Type IV defect reconstruction

Paprosky Type IV defects are the most extensive, with complete loss of the isthmus. Successful reconstruction of these defects is unlikely to be achieved using biologic fixation alone. To augment fixation, multiple strategies can be employed including impaction grafting with a long cemented femoral component, allograft prosthetic composite (APC) and proximal femoral replacement (PFR) [22].

APC can be performed by removing deficient proximal bone and cementing a long-stem prosthesis into a proximal femoral allograft, and press fitting or cementing the distal stem into the femoral canal. APC may be particularly advantageous to restore bone stock in young patients. Disadvantages of APC include potential for infectious transmission, difficulty in obtaining an allograft, risk of nonunion or resorption of the allograft, and high technical demand of the procedure[23].

PFR is traditionally used to treat elderly and low demand patients with massive bone loss. A sufficient amount of bone must be present distally to ensure secure fixation of the implant or cementation of the megaprosthesis. The main advantages of PFR are early return to weight bearing and no risk of disease transmission. Disadvantages of PFR include poor soft tissue attachment to the prosthesis that may lead to instability and dislocation, severe stress shielding and bone remodeling, and difficulty with fixation.

Summary

Femoral osteolysis following THA is a complex problem that requires meticulous evaluation and pre-operative planning. Location of bone loss, available proximal femoral bone stock, and the residual isthmus available for diaphyseal fixation determine which treatment option should be employed. The Paprosky classification system may be used to define bone loss and determine treatment strategies. Our preference is to treat defects with less bone loss and an intact isthmus (Type I, II, IIIa) with an extensively porous coated implant. Tapered fluted stems may also be used. We treat large diameter IIIa defects and IIIb defects with modular or non-modular tapered stems to decrease modular mismatch and prevent thigh pain. Defects with more extensive bone loss and limited or non-existent isthmic support (Type IIIb and IV) are treated with more complex reconstruction including impaction bone grafting with cement, long cemented stem fixation, allograft prosthetic composite, or proximal femoral replacement with reconstruction technique determined on a case by case basis.

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