

Review Article: Polyethylene wear and osteolysis in total hip arthroplasty

YH Zhu, KY Chiu and WM Tang

Department of Orthopaedic Surgery, The University of Hong Kong, Hong Kong

ABSTRACT

Polyethylene wear has been accepted as a major cause of osteolysis in total hip arthroplasty. Submicron particles, which are secondary to abrasive wear, migrate into the effective joint space and stimulate a foreign-body response resulting in bone loss which is mainly mediated by macrophages. Diagnosis depends on serial radiographic evaluation and frequent follow-up. Polyethylene wear and osteolysis can be prevented by reducing the wear such as using a small femoral head, adaptive polyethylene thickness, suitable surgical techniques, non-polyethylene articulation, etc. The presence of cement or circumferential coatings may also retard the distal migration of particles. Medicines such as NSAIDs and bisphosphonate appear to inhibit the progress of osteolysis. As far as treatment, revision surgery is able to reconstruct the joint by replacing partial or total prosthesis and repair the defect by bone grafting according to intraoperative assessment.

Key words: polyethylene, wear, osteolysis, total hip arthroplasty

INTRODUCTION

Periprosthetic osteolysis after total hip arthroplasty now constitutes one of the most common complications and the leading reason for revision after primary replacement^{15,9} and also makes joint reconstruction much more difficult. Although much research work has been done both in animals and patients, the exact mechanism of osteolysis still remains unclear. However, wear particles, especially ultra-high molecular weight polyethylene (UHMWPE) has been gradually accepted to represent a major contributor to the bone loss phenomenon. Research work reveals that many different manifestations of wear are due to the complex interaction of both biological and mechanical factors.

PATHOGENESIS

Initial studies focused on cement failure and mechanical instability as the reasons for postoperative osteolysis. But it is now strongly suggested that biological consequences of wear in both cemented and cementless total hip arthroplasty lead to a series of changes resulting in bone loss,³⁹ due to generation of particles and their access to periprosthetic interface.³

Such a 'particle disease' suggests that many kinds of materials are responsible for this process. However, analyses of failed prostheses and the recognition of problems associated with rapidly progressive osteolysis^{28,2} indicate that polyethylene particles are the major culprit initiating an inflammatory process that results in osteolysis and contributes significantly to implant failure.²¹

STAGE 1: GENERATION OF PARTICLES

In prosthetic joints, the relevant wear mechanisms include adhesion, abrasion and fatigue. The production of these submicron particles in the hip is mainly secondary to abrasive wear.¹⁰ From a mechanical perspective, implant geometry and material properties are the major factors influencing the generation of wear debris and osteolysis that follows. Joint forces and kinematics combined with the contact surface geometries and material properties determine the cyclic stresses that lead to particle generation. Though polyethylene particles are produced in a variety of sizes, studies using different methods have all demonstrated that particles resulting from wear are very small — 90% are less than 10 µm with an average diameter of 0.3–0.5 µm which is submicron.⁸ The reason is that those larger than 10mm are not easily ingested by the macrophage. Apart from the small size, they are present in large amounts at about 1.4×10^{10} in billions to trillions.²⁴

STAGE 2: MIGRATION OF PARTICLES

To understand more accurately the migration of the submicron polyethylene particles, the concept of effective joint space³⁰ including all periprosthetic regions is important. It is not only the space within the hip capsule, but also the entire area surrounding the joint into which particles can escape and still be in contact with bone. It leads to the hypothesis that particulate debris, which often forms primarily at the prosthetic articulation, is able to penetrate the periprosthetic interface and migrate extensively.³¹ That is why lysis can occur at the tip of the femoral stem or at the dome of the acetabulum.

Based on the erroneous premise that the lytic process was regarded as cement disease, the major innovation of the 1980s was to use cementless components for total hip replacement. But for all various cementless femoral components, the femoral osteolysis comes on earlier, progressively and extensively.⁴⁰ Polyethylene particles may enter into the

interface between the prosthesis and the bone through the so-called effective joint surface. With the current development of modern techniques, femoral lysis among patients with cemented femoral components using second or third generation cementing techniques remains low^{4,32} though it still can be found in patients treated with first generation techniques (Fig. 1). Thus, femoral lysis with cementless components is believed to be more common since its prevalence is significantly higher when compared with cement ones, which suggests that the use of cement with new techniques may protect these femurs against lysis in a way that cementless may not. The explanation seems to be that cement seals off the femoral cavity and delays the ingress of particulate polyethylene.

STAGE 3: CELLULAR RESPONSE TO PARTICLES

Histologic examination of tissues taken from osteolytic lesions adjacent to both loose and well-fixed implants shows that many types of cells including macrophages, fibroblasts, osteoclasts and also some bioactive products such as enzymes, cytokines and growth factors can be found.²⁰ This indicates that particulate debris stimulates a foreign-body response resulting in release of bone resorption mediators. Among them, macrophages appear to play a central role in the process. Though the mechanisms of chronic inflammatory and foreign body response to wear debris and the importance of mechanical and host factors to the development of implant loosening and osteolysis are complex, phagocytosis of particulate debris by macrophages at the interface appears to be a critical step in the whole process.^{26,38} In general, the number of macrophages present had a direct relationship to the degree of bone resorption.

DIAGNOSIS

Since implant wear and osteolysis is usually asymptomatic, it is of great importance to identify such a process as soon as possible before major complications occur secondary to progressive bone loss. One of the most reliable tools for the evaluation of wear and osteolysis is serial radiographic evaluation (Fig. 1) both in anteroposterior and lateral view.^{22,7}

Osteolysis in the femur was reported to be first identified at 12–60 months (mean 39) postoperatively.³⁶ However, the accuracy with which the onset of osteolysis could be determined was limited by the frequency with which the postoperative radiographs had been taken, especially for those patients who



Figure 1 Serial X-rays showing femoral osteolysis in cemented total hip arthroplasty (a) Total hip replacement in which first generation cement techniques were used. (b) Half a year later, an obscure radiolucent line was seen in zone 3 (arrow). (c) One year later, the radiolucent line became wider and clearer (arrow). (d) One and a half years later, the radiolucent region became much larger than and covered both zones 3 and 4 (arrow), and can be definitely diagnosed as osteolysis.

developed osteolysis more than two years later. It is said that the traditional visualization of periacetabular osteolysis by standard anteroposterior radiographs usually underestimates the extent of osteolytic lesions around a metal-backed acetabular component.³⁵ To evaluate the osteolytic lesions in the femur, we usually divided it into seven zones.¹⁴ The size of lesion was graded according to its largest dimension — Grade 1: 1–2 cm., Grade 2: 2–3 cm., Grade 3: 3–4 cm. and Grade 4: >4 cm.¹⁹ The lesions were classified as focal if there

was only one isolated region of endosteal erosion, as multifocal if there were multiple but clearly separate regions of osteolysis, or as diffuse.

Polyethylene wear only becomes obvious after the femoral head penetrates into the insert and becomes eccentric (Fig. 2a, 3c, 4b). Thus, a small amount of wear is difficult to observe in its early stage. However, early diagnosis is valuable for those patients who have progressive polyethylene wear because it will give them an opportunity to be treated earlier and more

effectively. Research should be directed toward development and validation of diagnostic techniques for early detection of wear, such as potent biochemical markers.

For asymptomatic wear and osteolysis, routine follow-up must be frequent enough to establish a rate of progression. Once it is established, follow-up should be at least yearly, unless symptoms dictate earlier evaluation. For patients with higher risks, the intervals of appropriate follow-up should be more frequent, even if no evidence of wear exists initially.

PREVENTION

It is suggested that the first step in the management of osteolysis is prevention. Accordingly, we can avoid such complications several ways. Firstly, it is believed that the basic strategy for addressing the problem of osteolysis is to reduce the number of polyethylene particles in the interfacial tissues. Improvement of the materials and geometry of the articulating counterface might help. To avoid wear, design features including modularity, geometry and implant fixation have been shown to be among the most important variables relating to the generation of wear particles.^{7,16} The femoral head size has been shown to be an important factor affecting wear. Volumetric wear of polyethylene increases with increasing the head diameter. The dimension of the femoral head should be selected to assure a minimum of 6mm and ideally 8mm in polyethylene thickness.⁵ As for the material, titanium femoral heads should not be used because they have been shown to wear excessively.¹ Instead, now we use a cobalt alloy head that is well polished in the articulating surface. A decrease in polyethylene debris could be accomplished by development of a more wear-resistant polyethylene or by improvement of the wear characteristic of currently used polyethylene. The position of the cup also appears to be important. Vertical positioning of the component may be associated with pelvic osteolysis since it wears in the more lateral aspect of the polyethylene liner.²⁹ With the acetabular component, if a modular socket is used, the polyethylene liner must be rigidly fixed to the shell and fully supported by the shell.

Entirely different combinations of articulating materials which eliminate polyethylene altogether have been used, such as ceramic-on-ceramic, metal-on-metal, etc. Ceramic-on-ceramic implants may become common in the future of total hip arthroplasty because of their resistance to wear and following

inapparent osteolysis. The clinical literature has revealed no apparent osteolytic response regarding all-ceramic articulations of total hip replacement.³³ Metal-on-metal articulation appears to be effective in reducing wear and loosening when compared with metal-on-polyethylene in a four to seven-year follow-up.¹² However, metal-on-metal bearings generate systematic release of cobalt that can be detected in serum.⁶

Apart from primary bearing surface wear and secondary nonbearing surface wear, three-body wear, which refers to motion between two primary bearing surfaces with third-body particles trapped between, is also an important wear mode.²⁵ Since fragments of cement, bone, metal or polyethylene particles are included, surgeons should remove all the particulates produced during the operation. Therefore, irrigating the joint space appears to lower the chance of polyethylene wear.

Secondly, it is important to prevent debris from gaining access to the bone-implant interface. The presence of cement or circumferential coatings may retard the distal migration of particles. Cementing a femoral stem into the medullary cavity with third generation cement techniques will diminish the effective joint space and seal the entrance to the femoral component. Also, circumferential porous coating in cementless femoral prosthesis aims at creating a seal at the proximal femur since a bioactive surface with osseointegration has an efficient sealing effect.³⁰ The same phenomenon can be postulated on the acetabular side. Prostheses that have a non-circumferential porous surface allow the formation of fibrous channels through which particulate debris may pass. The integrity of such a barrier may depend to some extent on the design of the component.

Thirdly, one must deal with the cellular response which may result in osteolysis. The aim is to reduce the lysis of bone caused by the activity of osteoclasts. The bone lysis occurring in tissue culture secondary to the presence of the tissue membrane can be partially inhibited by indomethacin.¹³ Bisphosphonate was originally used successfully for conditions such as osteoporosis and Paget's disease that share the common pathway of bone resorption by osteoclastic activity. It has also been shown clinically to increase the bone mineral density in osteoporosis in postmenopausal women. *In vivo* study in an animal model of total hip arthroplasty has been available to show that bisphosphonate significantly reduces osteolysis which was induced in an uncemented system with polyethylene and alloy particles.^{11,34}

TREATMENT

In acetabular and femoral component osteolysis, if the patient is asymptomatic, non-surgical treatment such as activity modification can be initiated, and regular follow-up is essential to determine the rate of progression. For symptomatic cases, non-surgical options may include activity modification, limited weightbearing with walking aids, NSAIDs, and follow-up on a frequent basis every three months. Bisphosphonate has proved to be able to reduce osteolysis in animal experiments. However, there are few reports on the clinical use of bisphosphonate.

The major indications for surgical intervention include pain and radiographic evidence of progressive bone resorption that compromises future reconstruction. However, surgical intervention may also be necessary in some patients who have definite evidence of polyethylene wear and osteolysis without any symptoms¹⁸. Such active intervention seems to be of great value since polyethylene wear alone is an impending failure and thus may lead to revision when symptoms develop. Therefore, the natural history of

osteolytic lesions and relevant follow-up will be important in deciding the suitable time for surgery.³⁷

For many of the special problems outlined, there are no current management guidelines. Intraoperative assessment may be the only means to determine what is appropriate for the particular situation. If the femoral stem is still stable though osteolysis can be found, debridement of granulation tissues and articulation changing may help in addition to postoperative observation (Fig. 2). Surgical debridement is the key method of stabilizing defects regardless of the ultimate fixation mode since it removes the enzymatic and particulate debris responsible for osteolysis¹⁷. If the femoral component is loose and bone loss is not too severe, it may be replaced with a long stem cemented prosthesis. The recurrence of lysis still remains low if a femoral component is cemented into a hip that has developed osteolysis before revision.²⁷ Alternatively, cementless prosthesis can also be used (Fig. 4d). When a severe bone defect appears, structure bone grafting may be needed before implanting a new prosthesis. As for pelvic osteolysis, if a metal-backed acetabular component is solidly fixed, it is not necessary to

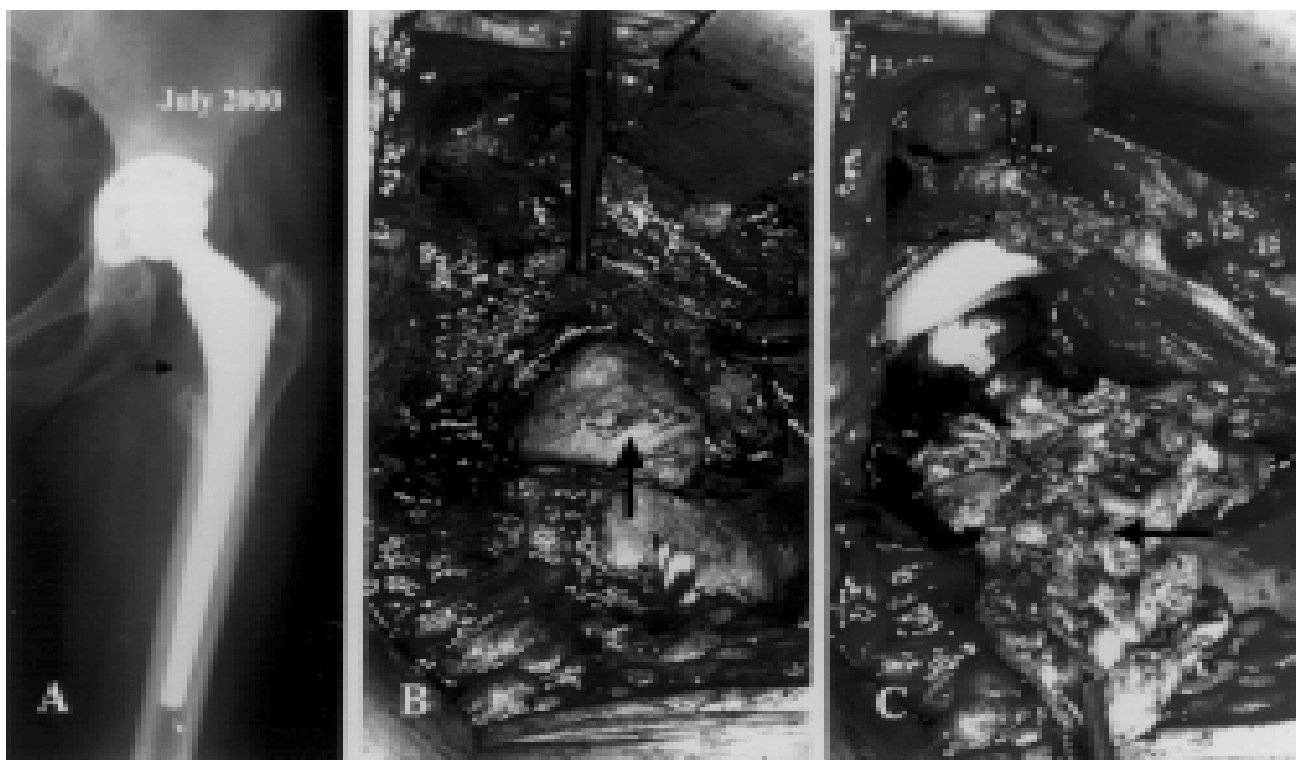


Figure 2 Debridement of granulation tissues in revision total hip arthroplasty. (a) Total hip replacement nearly 5 years after primary operation: wear can be seen due to obvious eccentric location of the femoral head in the polyethylene insert; osteolysis can be found in the lesser trochanter (zone 7) of the femur (arrow). (b) Revision procedure showing granulation tissues around the femoral head (arrow). (c) Revision procedure showing granulation tissues (arrow) to be removed. Complete debridement will follow.



Figure 3 The progress and treatment of osteolysis in cementless total hip arthroplasty. (a) Pre-operative X-ray showing avascular necrosis of the left femoral head and secondary hip osteoarthritis. (b) Post-operative X-ray taken three months later showing cementless total hip replacement in a good position. (c) Post-operative X-ray taken 5 years later showing polyethylene wear due to obvious eccentric location of the femoral head in the polyethylene insert; osteolysis in lesser trochanter (zone 7) can be seen clearly (arrow). (d) X-ray taken after revision. Wear insert has been replaced and a 28 mm femoral head has been changed to 22 mm in diameter.

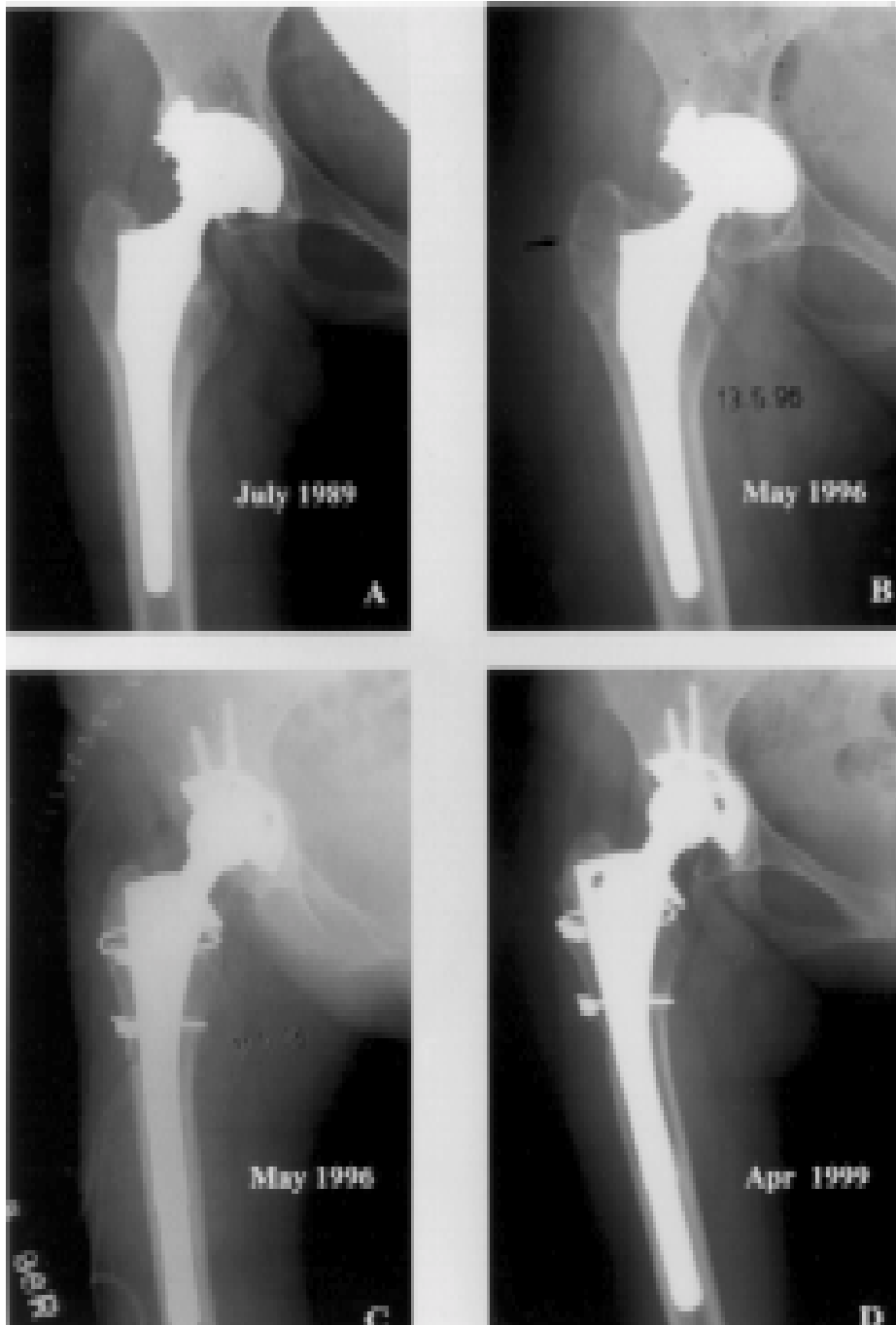


Figure 4 Revision total hip arthroplasty treated with bone graft in osteolytic defect. **(a)** Post-operative X-ray showing total hip replacement in a good position. **(b)** Post-operative X-ray taken 7 years later showing eccentric location of femoral head in polyethylene insert, osteolytic lesions both at the dome of the acetabulum (small arrows) and in greater trochanter (zone 1) (big arrow); loosening of the acetabular component can be diagnosed due to its displacement. **(c)** Revision was done in the same month. Osteolysis in the acetabulum was debrided and treated with morselized bone graft (thin arrows) and a new acetabular cup was implanted by screw fixation. The former femoral component was replaced by a long stem cementless prosthesis. **(d)** X-ray taken nearly 3 years after revision. Both femoral and acetabular components were well implanted, and no osteolysis or loosening can be seen.

remove it and revision may require exchange of a modular polyethylene liner and a femoral head of suitable size (Fig. 3). The periarticular inflammatory tissue in osteolytic lesions should be completely debrided and allograft bone chips are packed into the defect if necessary (Fig. 4).^{23,28} To deal with a large bone defect in the acetabulum, structural grafting is usually necessary. Total revision of the acetabular component is needed only when the shell is unstable. An anti-protrusion ring is indicated for severe acetabular bone loss when a cementless hemispherical cup has little stability or poor contact with the host bone. The bony defect will be packed with a morselized allograft. An

acetabular cup is then cemented into the ring.

When polyethylene wear and osteolysis occurs, it seems that a surgeon has no other choice in the end except revision total hip arthroplasty. As described at the beginning, polyethylene wear and osteolysis still remain a serious potential problem for all patients who have had a total hip arthroplasty. Despite a large amount of work having been done, there are still many questions to be answered and many problems to be solved. Whether such a difficult problem can be dealt with will determine the development and the future of joint replacement surgery.

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