INTRODUCTION

There is acute concern, particularly with noncemented implants, about polymeric and metallic debris generation and accumulation in total hip arthroplasty and its association with osteolysis and implant loosening. The purpose of this paper is to describe the problems associated with particulate debris, the sources of particulate debris in THA, and potential solutions or approaches to minimize particle formation.

BASIC PROBLEMS

Polymeric Debris

It has been almost two decades since Willert first described the problem of polyethylene wear leading to peri-prosthetic inflammation, granuloma, bone resorption, and implant loosening. Since then, many studies have documented the finding of particulate bone cement and polyethylene in peri-prosthetic tissues. The underlying biologic mechanism is thought to be mediated by the activity of macrophages which, upon ingestion of foreign material, release a number of factors (prostaglandins, interleukins) that stimulate osteoclastic activity. Particles less than about 10 microns are more important in this mechanism because they are most easily phagocytosed by macrophages. Histologic study of synovium and granuloma biopsies from THA has shown intracellular polyethylene particles in the sub-micron size range.

Metallic Debris

Metallic particles in sufficient quantities could potentially activate macrophage-mediated osteolysis. Metal debris could also migrate into the articulation, scratch the femoral head, and cause increased third-body wear of polyethylene.
PROBLEM: Wear Related to Polyethylene Quality

In normally wearing artificial joints, linear wear rates of 0.05 to 0.2 mm per year result in the generation of about 25 to 100 mm³ (25 to 100 mg) of polyethylene debris annually.¹³⁻¹⁵ On the basis of known dimensions of polyethylene particles found in tissues around hip prostheses, this equates to the annual production of tens to hundreds of billions of particles.

Variations in polyethylene wear rates probably relate, at least in part, to the quality of the polyethylene used.¹⁵ Wide variations are known to exist between batches of polyethylene and between different polyethylene suppliers.

SOLUTION:

Use ultra high molecular weight polyethylene (UHMWPE) with high ratings in key mechanical and physical properties (Table 1). Use UHMWPE with a consistently high level of quality control over parameters such as starting powder composition, extrusion processing (extruded rod generally results in better consolidation and improved properties compared with compression molded UHMWPE sheets), post-extrusion annealing (to increase crystallinity and dimensional stability), ultrasound inspection for voids and inclusions, oxidation, and mechanical properties. In general, polyethylene that exceeds minimum ASTM standards is available from several implant manufacturers (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Properties of UHMWPE</th>
<th>ASTM Standard</th>
<th>Commercially Available PE¹⁶</th>
<th>Commercially Available PE¹⁷</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Weight</td>
<td>3 x 10⁶</td>
<td>5 x 10⁶</td>
<td>—</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>4000 PSI</td>
<td>6700 PSI</td>
<td>6000 PSI</td>
</tr>
<tr>
<td>Tensile Yield</td>
<td>2800 PSI</td>
<td>3300 PSI</td>
<td>4100 PSI</td>
</tr>
<tr>
<td>Izod Impact</td>
<td>20 FT-LB</td>
<td>No Break</td>
<td>No Break</td>
</tr>
<tr>
<td>Hardness</td>
<td>60 Shore D</td>
<td>69 Shore D</td>
<td>65 Shore D</td>
</tr>
<tr>
<td>Elongation to Failure</td>
<td>200%</td>
<td>350%</td>
<td>330%</td>
</tr>
</tbody>
</table>

PROBLEM: Polyethylene Wear Related to Modular Acetabular Implants

Additional sources of polyethylene wear can result from the use of modular (2-piece) acetabular implants. These include:

- Polyethylene liner/metal back motion - related to mechanical integrity of the locking mechanism
- Incomplete conformity of liner with metal back can result in cold flow, plastic deformation, increased stress, increased wear
- Thin polyethylene resulting from modular design can cause higher stress, increased wear, liner fracture
- Abrasion of screw heads against the convex polyethylene surface
- Liner fracture 4 yrs postop, head wear of cup metal backing, tissue metallosis
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SOLUTIONS:

- Use non-modular acetabular components
- Use modular acetabular components with:
  - high degree of liner/metal back conformity and support (with smooth concave metal surface to minimize abrasive wear)
  - highly secure liner/metal back locking mechanism
  - minimum polyethylene thickness of 6 to 8 MM²²,²³
**PROBLEM: Polyethylene Wear Related to Femoral Head Size**

Clinical evidence indicates that the use of 32 mm heads in THA increases the volumetric wear. This problem is accentuated with cups possessing relatively thin polyethylene, as occurs with smaller size modular prostheses.

**SOLUTION:**

A recent clinical study by Livermore et al indicated that a 28 mm head size was preferred for optimization of both linear and volumetric wear. Choosing head size to maximize polyethylene thickness is a priority. The recommendation is to use 26 mm or 28 mm heads more often, although 32 mm heads are still appropriate with larger cups having thick polyethylene.

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**PROBLEM: Polyethylene Wear Related To Femoral Head Material**

Polyethylene wear is generally increased with the use of femoral heads made of titanium alloy because of its lower hardness and abrasion resistance. Problems with osteolysis due to excessive head and cup wear have been reported with titanium bearing surfaces.

**SOLUTIONS:**

- Do not use titanium alloy femoral heads
- Use titanium alloy femoral heads with improved wear characteristics. This can be accomplished by shallow implantation of nitrogen or oxygen into the surface or chemical deposition of a harder bearing surface such as titanium nitride.
- A preferred option is to use femoral heads made of cobalt-chrome because of its superior wear characteristics.
- Laboratory evidence supports the use of femoral heads made from ceramic materials, alumina or zirconia oxide, for reduced polyethylene wear. Preliminary clinical evidence from Europe and Japan suggests a reduced wear rate in patients but the data are not yet definitive. At the very least, ceramic bearing materials are more resistant to scratching from third bodies such as PMMA or metallic debris from fretting, corrosion, or loosened fragments of porous coating.
- Based on favorable clinical trials in Europe during the past decade, improved ceramic-on-ceramic and metal-on-metal bearing combinations have been renewed as possible solutions to the problem of polyethylene wear. Further research and development in this area will be required to establish reliability and efficacy.

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**SOURCES OF METALLIC DEBRIS**

**PROBLEM: Fretting Wear of Metallic Implant Components**

Fretting wear of mechanically joined metallic implant components is inevitable given sufficient load and number of load cycles. Thus, all modular implant junctions are prone to fretting and the generation of metallic debris. This includes:

- Junctions between screws and metal backing of modular cups
- Head/neck taper junctions
- Other stem modular junctions utilizing locking mechanisms such as tapers or dovetails to connect sleeves, pads, or stem segments.

**SOLUTIONS**

- Minimize the number of modular junctions (e.g., use cups without screw holes or reduce use of screws for acetabular cup fixation)
- Use modular junctions with secure locking mechanisms, high quality fabrication tolerances, surface finishes that reduce debris generation, and proven mechanical safety in laboratory testing.
**PROBLEM:** Corrosion at Head/Neck Taper Junctions

Recent analysis of retrieved femoral implants used in THA has revealed that corrosion sometimes occurs at the modular head/neck junction. Corrosion in varying degrees has been reported both with dissimilar (Co-Cr head/Ti alloy neck) and similar (Co-Cr head/Co-Cr neck) metal combinations. The corrosion problem has not been the cause of clinical failure except in a few rare cases with Co-Cr/Co-Cr tapers that have fractured. Galvanic corrosion, crevice corrosion, and fretting corrosion have all been suggested as mechanisms that are responsible for this problem.

**SOLUTIONS:**

For head/neck tapers with dissimilar metals, the risk of corrosion can be reduced by using tapers with tight manufacturing tolerances. This reduces fluid ingress and the extent of fretting which could trigger corrosion by depassivating the protective metallic oxide layers and setting up a crevice corrosion cell. In response to the corrosion problem, the orthopaedic implant industry is improving the tolerances and quality control of head/neck tapers.

- For all modular tapers, lock the femoral head onto the neck with adequate force. It is helpful to initially twist the femoral head into position and then apply 3 or 4 seating taps. Ensure that both male and female surfaces are clean and dry prior to assembly.

- For tapers on Co-Cr stems, in addition to high quality manufacturing, ensure that heat treatments used to apply porous coatings do not create intergranular zones that are prone to corrosive attack and eventual mechanical failure.

**PROBLEM:** Particulate Release Through Implant Bone-Abrasion

Noncemented implants which move relative to the implant site can release particulate debris through simple abrasion mechanisms. This problem is worse with Ti-based implants because of lower hardness and abrasion resistance. Furthermore, cosmetic implant preparation techniques such as bead blasting tend to leave residual contaminants (silica or alumina) and create tenuous surface irregularities -these are prone to being dislodged by abrasion against bone.

**SOLUTIONS:**

- Increase the surface hardness and abrasion resistance of Ti-based implants through creation of a surface-rich zone of nitrogen or oxygen.

- Increase the cleanliness and smoothness of implant surfaces by avoiding grit-blasting or sandblasting. Instead, leave the implant surface simply polished or cleaned and micro-etched with chemical-milling techniques.

- Use noncemented implants with design features that maximize the opportunities for stability, thereby minimizing the risk of interface micromotion and abrasion.
**PROBLEM:** Third-Body Wear From Debonded Porous Coating

There are numerous reports of loosened fragments of porous coating migrating into the joint space and causing third-body wear of the bearing surfaces.\(^{49-51}\) This problem has also been reported with loosened fragments of hydroxyapatite coating.\(^{52,53}\) Excessive polyethylene wear can result in particulate debris-induced granuloma, bone loss, implant loosening, and revision.

**SOLUTIONS:**

- Use noncemented implants with well-bonded porous coatings and a proven history of use without this problem. In general, metallic porous coatings with metallurgical bonds (e.g., diffusion bonded or sintered) are more mechanically resistant than metallic or calcium phosphate coatings applied with plasma spray techniques.
- Use noncemented implants with design features that increase the likelihood of secure fixation. Coatings debond more easily in the presence of motion.

**MIGRATION OF PARTICULATE DEBRIS**

**PROBLEM:**

Regardless of origin, through the cyclic pumping action of joint pressure, polymeric or metallic debris can migrate throughout the effective joint space, accessing bone-implant interfaces and articulating surfaces.\(^{4,54}\) Particle migration has been documented with both cemented and noncemented implants.

**SOLUTIONS:**

- For noncemented hip prostheses, it has been suggested that circumferential porous coating will allow more complete tissue ingrowth and help restrict the access of particulate material along bone-implant interfaces.\(^{6,55}\) There is experimental evidence to support the theory that smooth implant interfaces allow greater access of polyethylene debris.\(^{56,57}\)
- Press-fitting of noncemented acetabular implants results in a tight peripheral fit which may impede access of particulate debris to the bone prosthesis interface.\(^{58}\)
- Minimize the overall generation of particulate debris through all of the above recommendations.

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REFERENCES


