Wear in Total Joint Arthroplasty

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Wear

Removal of material, with the generation of wear particles, which occurs as a result of relative motion between two opposed surfaces under load.
Wear Damage

The change in the appearance of the bearing surface due to wear.
Differences in Wear Mechanisms

Hip: Adhesive Abrasive

Knee: Fatigue
Flat Polyethylene

Conforming Polyethylene
Schmalzried, T.:

**Pedometer**

<table>
<thead>
<tr>
<th>Avg Activity yr</th>
<th>0.9 million/cycle</th>
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<tbody>
<tr>
<td>Range difference</td>
<td>4.5 fold</td>
</tr>
<tr>
<td>Most Active yr</td>
<td>3.2 million/cycles</td>
</tr>
<tr>
<td>Patients Under 60</td>
<td>30% more</td>
</tr>
<tr>
<td>Meals</td>
<td>28% more</td>
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Time Line of Wear Process

Particles ➔ biologic response ➔ bone loss
 ➔ component loosening ➔ symptoms
ACETABULAR LOOSENING

p = 0.0008

Years

0
2
4
6
8
10
12
14

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Cable
Wire
Unstable Prosthesis → Particles ← Motion

→ IL-1

→ PGE₂

MP's

Bone Resorption

MØ

MØ/FB

Chemoattractants
McKellop Wear Modes

Mode 1: intended wear primary surfaces

Mode 2: primary surface against secondary surface

Mode 3: primary surfaces with 3\textsuperscript{rd} body particulates

Mode 4: two secondary surfaces
In the Race to Address Wear Debris, Nobody Finishes Better.

DePuy's hip systems address all facets of the “bearing couple”, from the stem taper/femoral head interface, through fixation of the polyethylene liner into the acetabular shell.

- Femoral head form and finish surpass ISO requirements and establish new industry benchmarks.¹

All femoral stem tapers combine optimal geometry and surface finish to help eliminate corrosion concerns.

- Duraloc® Cementless Cups - 6+ year clinical success.¹

- Eliminating sterilization induced oxidation with gas plasma sterilized Enduron™ Polyethylene.²

- Addressing postoperative dislocation through unique polyethylene options.

For more information, contact your DePuy representative, call (800) 366-8143 or visit our web site at http://www.depuy.com.

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³. ISO specification 4689
⁴. Data on file at DePuy Orthopedics, Inc.

DePuy
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LFIT™
Low Friction
Ion Treatment

Ion Implanted CoCr Heads

Features

- Lower coefficient of friction

Ion Implantation

Passivation

nitric acid
oxide layer
metal

nitrogen ions

surface
What Can the Surgeon and Manufacturers Do To Optimize the Performance of UHMWPE?

1. Bearing Surface
2. Non Articulating Intra Articular Surfaces
3. Extra Articular Environment
Non Articulating Intra-Articular Surfaces

1. Modular Heads
2. Extended Lip Liners
3. Modular Shells (back side wear)
4. Screws & Screw Holes
5. Metal Back / Bone
Extra-Articular Environment

1. Avoid Third Body
   A. Cables
   B. Abrasive Cemented Stems
   C. Porous Coatings / Ceramics

2. Avoid Access Channels
   A. Patch Coated Porous Stems
Surgical Technique

1. Avoid potential third body particulates (cables, modularity, abrasive stems)

2. Assure optimum modularity connections and designs

3. Assure polish of the femoral head

4. Avoid debris in acetabular cup when locating the hip
Cross-Linked Polyethylene

Gamma Radiation

- C-C-C-C-
  H H H H
  H H H H

Free Radicals

Polyethylene Molecule

Main Chain Scission

C=C-C-C-

No O₂

O₂

Crosslinking

Oxidation

Residual Free Radicals

In Crystalline Zones

- C-C-C-C-
- C-C-C-C-
- C-C-C-C-
- C-C-C-C-
Especially in our younger patients we have to do something differently
Wear Rate

0.14 mm/yr

(0 - 0.6) mm/yr
22 millimeter heads are not the solution!
Group-average Penetration

![Graph showing linear wear over years from surgery]

- Linear Wear [mm]
  - 22-mm: 0.2986 mm/yr
  - 28-mm: 0.1677 mm/yr

- Years from Surgery:
  - Run-in period
  - 0.2737 mm/yr
  - 0.1173 mm/yr

The graph illustrates the linear wear over time for different implant sizes, with distinct wear rates for each.
Fig. 32-10. When traction is applied to dislocate (by pulling the head out of socket) a large ball travels a larger distance to escape the cup than a small ball. In practice, however, larger head components are not associated with fewer postoperative dislocations than small heads. **A**, Large head. **B**, Small head; arrows indicate the distance each must travel to escape the mouth of the cup.
Significantly higher than expected
p=0.002 for 1992; p<0.0001 for 1993

N=298
Design A vs Design B at Dislocation

- 38mm
- 28mm

Flexion (deg) vs Adduction (deg) graph showing the comparison between Design A and Design B at different dislocation points.
Use of Trial Components
The Options

Better Polyethylene

Ceramics

Metal on Metal
Problems with Ceramics

1. Chipping on insertion
2. Impingement
3. Fracture
4. Third bodies?
Problems with Metal on Metal

1. Tolerances
2. Impingement
3. Carcinogenesis
4. Third bodies
Why Consider the New Polyethylenes?
Historical Polyethylene

- Worked *very well* in the majority of patients:
  - 90% success at 10 years
  - 80% success at 20 years
- Were moderately crosslinked (2.5 to 4 Mrads)
- Problems caused by:
  - Oxidation (delamination and fracture)
  - Excessive wear (young/active patients)
Historical Gamma-Air Sterilized PE

Historical Method

Extruded bar or molded block

Machine cup

Sterilized with 2.5 to 4 Mrads gamma in air

Moderate crosslinking, but surface and subsurface oxidation!

Severe oxidation
If Oxidation Can Do This to Your Paint, Just Think What It Can Do to Your Poly!

ArCom — Proven Performance.
Gamma Radiation

Polyethylene Molecule

Main Chain Scission

Free Radicals

No O₂

Crosslinking

O₂

Oxidation

In Crystalline Zones

Residual Free Radicals

- C - C - C - C -
- C - C - C - C -
- C - C - C - C -
- C - C - C - C -
- C - C - C - C -
Why Continue to Crosslink?

- Because crosslinking markedly improves the resistance to wear of UHMW polyethylene
- Clinical studies:
  - Grobbelaar et al., 1978
  - Oonishi et al., 1988
  - Wroblewski et al., 1996
- Hip Simulator studies:
  - Wang et al., 1998
  - McKellop et al., 1999
  - Muratoglu et al., 1999
Achieving optimal crosslinking

- If there is no oxygen present, then the polyethylene gets the *full benefit* of the crosslinking dose
- Then a *moderate* level of crosslinking is sufficient
Wear Reduction with Crosslinking
(McKellop et al., JOR 1999)

Wear Volume (mm$^3$)

Cycles (Millions)

Non-croslinkeled PE

Gamma Dose, Mrads

- 3.3
- 5
- 10
- 15

Non-croslinkeled PE
Modifying the Historical Fabrication Method

**Historical Method**

Extruded bar stock

Machine cup

Sterilized with 2.5 to 4 Mrads gamma in air

Some crosslinking, but surface and sub-surface oxidation!
New Crosslinked Polyethylenes

**Longevity™**

**Durasul™**

- Electron beam crosslinked
- Remelted
- Free radicals extinguished

- Durasul 9.5 Mrad @ 125°C
- Longevity 10 Mrad, warm

**Marathon™**

- 5 Mrads & Remelted
- Free radicals extinguished

**Crossfire™**

- 7.5 Mrads
- Anneal @ 130°C
- Free radicals remain
- Gas Plasma Sterilized
- 5 Mrads total
- No free radicals
- Gamma sterilized
- 10.5 Mrads total
- Increased free radicals
- Gas Plasma
- Durasul
- Et-O
- Sterilized
- No free radicals
- N₂ Atm
Method for Producing Marathon™
Radiation Crosslinked UHMWPE Acetabular Cups

- Extruded bar of GUR 1050 UHMW
- Crosslink with 5 MRad gamma radiation
- Remelt in oven at 155 °C for 24 hours to extinguish free radicals
- Machined into acetabular cups, removing oxidized surfaced of bar
- Packaged and sterilized by gas plasma
- Shelf storage does not cause oxidation
Problems with Newer Polyethylenes

1. Fatigue issues because of strength

2. Third bodies
Strength of 5 Mrad Crosslinked-Remelted PE

Yield Strength
Ultimate Strength
Elongation

ASTM Minimums

Non-Sterilized UHMWPE
3.3 Mrad Gamma-Air
5 Mrads Remelted
5 Mrads Remelted

5 Atm O₂
70 deg. C
2 weeks

Ratio

1

Aged
Brittle Fracture
Aged
DePuy Knee Simulator Wear Test

Gamma-air sterilized PE
Thermally Aged
Worn 1 million cycles

Marathon™
Thermally Aged
Worn 10 million cycles

Delamination

Polishing wear
Wear Rate vs. Incidence of Osteolysis

(H. McKellop in The Adult Hip, Callaghan, Rosenberg & Rubash, Eds.)

Wear Rate (mm/yr)

Likelihood of Lysis

Always

Often

Sometimes

Very Rare

Greater reduction at 10 Mrads, but
Biologically significant?

Wear Rate vs. Incidence of Osteolysis

Average Activity

Extremely Activity

Conventional PE

5 Mrads

Conventional PE

5 Mrads

85% Reduction

3 to 4 times average
The New Choices

Clinical standard for three decades, withdrawn.

- Ethylene Oxide or Gas Plasma Sterilization
  - Gamma sterilized in Low Oxygen
    - Marathon™ 5 Mrads Remelted
    - Durasul™, Longevity™ 9.5-10 Mrads Remelted
  - Crossfire™ 10.5 Mrads Annealed

Increasing level of crosslinking

- High crosslinking Electron beam radiation
  - No free radicals
  - High crosslinking
  - Increased free radicals
  - Potential oxidation

- Slightly increased crosslinking
  - No surface oxidation
  - No free radicals

- Moderate crosslinking
  - Residual free radicals
  - Potential oxidation

- Markedly reduced crosslinking, therefore
  - Higher wear
  - No oxidation, but
  - Moderate crosslinking
  - Ethylene Oxide or Gas Plasma Sterilization

- Immediate surface oxidation
- Free radicals caused long-term oxidation

The New Choices

Clinical standard for three decades, withdrawn.
The Surgeon’s Role

• Become familiar with each of the new materials
  Metal-metal
  Ceramic-ceramic
  Crosslinked polyethylenes

• Use the one that offers the best chance for improvement with the least opportunity for new problems
Discussion

1. Wear is the main long term problem associated with total joint arthroplasty.

2. Surgeons, designers, and manufacturers need to do all they can to minimize the problem.