Properties of Materials for Joint Replacement

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Properties of Materials for Joint Replacement

1. Material Science
   Stress-strain curves, corrosion, tribology, wear characteristics

2. Materials
   Metals
   Fe, Co-Cr, Ti, Tantalum
   Ceramics
   Alumina, Zirconia, Bioglass
   Hydroxyapatite
   Diamond
   Polyethylene
   Polymethylmethacrylate

3. Surface Finishes

4. Problems
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**Biomaterial** = A synthetic or treated natural material which is used to replace or augment tissue and/or organ function.
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Biomaterial considerations:

• Physical properties

Chemical composition

Biostability
Bio-integration
Bio-inert
Bio-compatible

Structure
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Biomaterial considerations:

- Effect of processing on structure.
- Cold working
- Casting
- Forging
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• Bench Testing
• Finite Element Analysis
• Clinical Trials
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\[ \text{Stress} = \text{Force/Area} = \text{N/m}^2 = 1 \text{ Pa} \]
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**Strain** \( = \frac{(DL - OL)}{OL} \)

Dimensionless = Microstrain = 10\(^{-6}\) change from OL
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- Proportional Limit (yield pt)
- Ultimate Strength
- Elastic Zone
- Breaking Point
- Stress vs. Strain
  - Elastic Deformation
  - Plastic Strain Deformation
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Relative Values of Young's Modulus (Not to scale)

1. $\text{Al}_2\text{O}_3$ (ceramic)
2. Co-Cr-Mo (Alloy)
3. Stainless steel
4. Titanium
5. Cortical bone
6. Matrix polymers (PS, PEEK)
7. PMMA
8. Cancellous bone
9. Polyethylene
10. Tendon/ligament
11. Cartilage
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Stress vs. Strain Diagram:
- **Proportional Limit (yield pt)**
- **Elastic Zone**
- **Ultimate Strength**
- **Breaking Point**

Graphs indicating resilience and strain.
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- Stress, $\sigma$ (Pa)
- Endurance Limit
- No. of Cycles ($n$)
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- Graph 1: Stiff, Ductile, Strong, Tough
- Graph 2: Stiff, Brittle, Strong
- Graph 3: Stiff, Ductile, Weak
- Graph 4: Stiff, Brittle, Weak
- Graph 5: Flexible, Ductile, Strong, Resilient
- Graph 6: Flexible, Brittle, Strong, Resilient
- Graph 7: Flexible, Ductile, Weak
- Graph 8: Flexible, Brittle, Weak
Early experiments in transportation
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Corrosion ($> 10^{-6}$ M )

1. Uniform
2. Galvanic
3. Crevice
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Corrosion

4. Inter-granular
5. Stress
6. Pitting
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Corrosion

7. Fretting
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- ASTM F-55 - 56
  - 50 alloys
  - Stress, Crevice, Intergranular corrosion
  - Fatigue fractures (F 138)
  - Yield strength 260-896 MPa
  - Elastic modulus 200 GPa (12x Bone)
  - Nitric acid immersion
  - Fracture fixation
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ASTM F-75

- Hot iso-static pressing
- Yield strength 900 MPa
- Elastic modulus 200 GPa
- Cr for corrosion resistance
- Resistant to crevice corrosion
- Good for high stress applications
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ASTM F-67
- No evidence of pitting, intergranular or crevice corrosion
- Supreme biocompatibility
- Yield strength 345-485 MPa
- Easy to sinter for porous layer or use as fiber-metal pads

ASTM F-136
- Ti6AL4V
- Limited O₂ concentration
- Elastic modulus 100 GPa
- Not an articulating surface
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Tantalum

- Like Ti, very corrosion resistant
- Dodecahedral units
- Good biocompatibility
- One shape not composite
- No artifact on MRI
- Acetabular component Hydrocel

ASTM F560-92
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Surface finish

• Uncemented
  Press fit and secondary ingrowth

• Cemented
  Shape closed design
  Force closed design
## Properties of Materials for Joint Replacement

<table>
<thead>
<tr>
<th>Surface Appearance</th>
<th>Typical Manufacturing Methods</th>
<th>Approximate Roughness Range $R_a$ ($\mu$ inch/$\mu$m)</th>
<th>Approximate Roughness Range $R_z$ ($\mu$ inch/$\mu$m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shiny</td>
<td>Polishing</td>
<td>0–5/0–0.1</td>
<td>0–75/0–2.0</td>
</tr>
<tr>
<td>Smooth</td>
<td>Machining, grinding, mass finishing</td>
<td>5–15/0.1–0.4</td>
<td>75–150/2.0–4.0</td>
</tr>
<tr>
<td>Satin</td>
<td>Bead blasting, machining</td>
<td>15–40/0.4–1.0</td>
<td>150–250/4.0–6.0</td>
</tr>
<tr>
<td>Matte</td>
<td>Grit blasting, combination grit + bead blasting</td>
<td>40–100/1.0–2.5</td>
<td>250–750/6.0–20</td>
</tr>
<tr>
<td>Rough</td>
<td>Aggressive grit blasting, plasma spraying, sintering</td>
<td>100–500/2.5–12.5</td>
<td>750–2500/20–60</td>
</tr>
<tr>
<td>Textured</td>
<td>Machining, casting, forging</td>
<td>500+/12.5+</td>
<td>2500+/60+</td>
</tr>
</tbody>
</table>
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Crowninshield et al CORR 335, pp 90-102, 1998
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Clinical importance of surface finish?

William H Harris CORR 335, pp 137 -143 , 1998

• Some successes but also some spectacular failures.

• To find causal relationship is difficult:

  Cementing technique    Cement used
  Patient Weight          Size of implant
  Torsional moment        Torsional resistance
  Neck length and offset of implant
Surgeons report uncemented THA success using hydroxyapatite coating

Investigators call 10-year postop results encouraging

BEAUNE, France—As hydroxyapatite (HA) enters its second decade of use as a bioactive coating for hip prostheses, orthopaedic surgeons report good 10-year results using HA-coated femoral and acetabular components.

At the same time, more patients under age 50 are undergoing THA with HA-coated implants because the stems permit a high degree of functional ability. "Hip replacement in younger patients is the most challenging," said Jean-Alain Epinette, MD, of the Clinique Medico-Chirurgicale of Bruay Labussière, France.

Epinette reported what he called "very encouraging" clinical results at five to 10 years in the younger patient population at the 3rd Domestic Congress of the European Hip Society held here. Based on these results, and others, industry experts predict that this success will continue well into the next decade.

See story on page 8

At six weeks postop, direct bone to implant contact was seen with this HA-coated ABG cup retrieved from a patient due to infection.
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(Ca₅PO₄)₃(OH)
Cappello et al., CORR (355): pp 200-211, 1998

**Hydroxyapatite (HA)**

1. Does HA enhance bone ongrowth?
2. Will HA lead to increased polyethylene wear or an increased incidence of osteolysis?
3. Will HA disappear and if so what will be left to maintain fixation?
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Does HA enhance bone ongrowth?

1. Retrieval studies, post revision
2. X-Ray
3. Animal studies
4. RSA Studies
5. Bone densiometry
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Will HA lead to increased polyethylene wear or an increased incidence of osteolysis?

Cappelo et al, CORR (355): pp 200-211, 1998

Not after 8 years

Prevents polyethylene migration (Geesink and Hoefnagel)

Third body wear (Bauer et al)
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Will HA disappear and if so what will be left to maintain fixation?

- Number of reports show that HA disappears from the stem to a varying degree.
- Osteoclastic resorption, delamination, dissolution, and abrasion.
- Femoral component, clinically appears not relevant.
- Threaded cups also maintain fixation but smooth cups show increased failure rates.
To the horror of the lifeboat’s other members, Madonna loses her balance and falls on her face.
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- 4669 implants
- 21% revised at 5 yrs

HAZARD MDA HN 9801 February 1998

3M Capital™ Hip System
(also known as the Modular/Monoblock Cemented Hip System MCHS)

MANUFACTURER/SUPPLIER
3M Health Care Ltd

PROBLEM
Reports of poor short term performance of the femoral component of the 3M Capital™ Hip System.

IMMEDIATE ACTION
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Exeter Matte
Osteoarthritis/Aseptic loosening

Exeter Polished
Osteoarthritis/Aseptic loosening

Percent not revised

Years postoperatively

12y = 83.1% (80.0-86.4), n = 2,734

Charnley 1984-1994
10y = 92.6% (91.9-93.4), n = 23,517
Exeter Polished
8y = 96.5% (95.2-97.8), n = 7,587
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Migration of the Duraloc cup at two years

B. Stöckl, M. Sandow, M. Krismer, R. Biedermann, C. Wimmer, B. Frischhut

From the University of Innsbruck, Austria

We carried out 71 primary total hip arthroplasties using porous-coated, hemispherical press-fit Duraloc ‘100 Series’ cups in 68 consecutive patients; 61 were combined with the cementless Spotorno stem and ten with the cemented Lubinus SP II stem. Under-reaming of 2 mm achieved a press-fit. Of the 71 hips, 69 (97.1%) were followed up after a mean of 2.4 years. Migration analysis was performed by the Ein Bild Röntgen Analyse method, with an accuracy of 1 mm.

The mean total migration after 24 months was 1.13 mm. Using the definition of loosening as a total migration of 1 mm, it follows that 30 out of 63 cups (48%) were loose at 24 months.

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The Journal of Bone and Joint Surgery

EDITORIAL

MALIGNANCY AND JOINT REPLACEMENT: THE TIP OF AN ICEBERG?

In 1984 we received a report of a patient in whom a malignant tumour had developed in bone adjacent to a total hip replacement. We reflected on the wisdom of publishing a paper which might cause unwarranted alarm but eventually decided to do so (Penman and Ring disorder which led to replacement, the particular type of prosthesis used and whether or not it was cemented, the interval before malignancy appeared, the histological diagnosis and the subsequent fate of the patient.

Our aim is to discover if the association between
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Thank you