Bone cement in Orthopaedics

D Raj
Introduction

- Polymethylmethacrylate remains one of the most enduring materials in orthopaedic surgery.
- It has a central role in the success of total joint replacement and is also used in newer techniques such as percutaneous vertebroplasty and kyphoplasty.
Introduction

• the current uses and limitations of polymethylmethacrylate in orthopaedic surgery

• mechanical and chemical properties
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Introduction

• Polymethylmethacrylate (PMMA) was first employed by orthopaedic surgeons over 60 years ago
• not strictly a cement, but a grout
• unveiled by the chemical industry in 1843 and named ‘acide acrylique’ on account of the acrid smell of the monomer
• Charnley first used in total hip replacement
Chemistry

• The structure of methylmethacrylate monomer allows polymerisation at room temperature to produce solid PMMA
## Commercial constituents of bone cement

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Powder components</strong></td>
<td></td>
</tr>
<tr>
<td>Polymer</td>
<td>Polymethylmethacrylate</td>
</tr>
<tr>
<td>Co-polymers (e.g. MA-MMA*)</td>
<td>Alter physical properties of the cement</td>
</tr>
<tr>
<td>Barium sulphate or zirconium dioxide</td>
<td>Radio-opacifiers</td>
</tr>
<tr>
<td>Antibiotics†</td>
<td>Antimicrobial prophylaxis</td>
</tr>
<tr>
<td>Dye (e.g. chlorophyll)</td>
<td>Distinguish cement from bone</td>
</tr>
<tr>
<td><strong>Liquid components</strong></td>
<td></td>
</tr>
<tr>
<td>Monomer</td>
<td>Methylnmethacrylate monomer</td>
</tr>
<tr>
<td>N,N-dimethyl-p-toluidine (DMPT)</td>
<td>Initiates cold curing of polymer</td>
</tr>
<tr>
<td>Benzoyl peroxide</td>
<td>Reacts with DMPT to catalyse polymerisation</td>
</tr>
<tr>
<td>Hydroquinone</td>
<td>Stabiliser preventing premature polymerisation</td>
</tr>
<tr>
<td>Dye (e.g. chlorophyll)</td>
<td>Distinguish cement from bone</td>
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</tbody>
</table>

* MA-MMA, methacrylate-methylmethacrylate

† plain bone cements do not contain antibiotics
STERILISATION

- Gamma radiation shortens the polymer chains, probably affecting many mechanical properties, but this does not occur with ethylene oxide sterilisation
Working properties and viscosity

• The cement must be liquid enough during the working phase to be forced through a delivery device and then flow under pressure to penetrate the interstices of cancellous bone, achieving micro-interlock
Viscosity

- Low
- Medium
- High

Waiting/sticky phase - working phase - hardening phase
Viscosity

High Viscosity Cement

- A short waiting/sticky phase is followed by a long working phase.
- The viscosity remains constant until the end of the working phase.
- The hardening phase lasts between one minute 30 seconds and two minutes.
High viscosity cements are therefore forgiving for the surgeon and are in predominant use in the United Kingdom.
Heat production during polymerisation

- The polymerisation of PMMA is exothermic. Catalysts form free radicals which break the covalent C=C bonds of the monomer, allowing them to bind to the lengthening polymer chains. This reaction releases 52 KJ/mole of monomer equating to heat production of 1.4 to 1.7 × 10^8 J/m3 of cement.

- Recorded temperatures range between 70°C and 120°C.
Percutaneous vertebroplasty

- This procedure is increasing in popularity. There are over 700,000 osteoporotic vertebral compression fractures each year in the USA, one third being symptomatic.
- They represent a difficult problem in management and are predicted to increase fourfold by 2050
Percutaneous vertebroplasty
Percutaneous vertebroplasty

- It controls the symptoms of compression fractures by recreating mechanical stability

- The technique involves the percutaneous transpedicular injection of low viscosity biomaterial into the vertebral body guided by an image intensifier.
Potential pitfalls of Polymethylmethacrylate Cement

- thermal necrosis
- aseptic loosening is suggested to be a result of monomer-mediated bone damage
- during end-polymerisation there is volumetric shrinkage of the cement potentially compromising the bone/cement interface
Potential pitfalls of polymethylmethacrylate cement

• conflict between the stiffness of cement and the adjacent bone
  – Young’s modulus
    • cancellous bone 0.5 GPa to 1 GPa,
    • cortical bone 15 GPa to 20 GPa
    • Cement 2 GPa
    • titanium 1 GPa
    • Cobalt chrome 220 GPa
Potential pitfalls of polymethylmethacrylate cement

- cement mantle and its interfaces may be the weak link in the construct
- a biological cause of aseptic loosening
Mechanical properties of polymethylmethacrylate

• brittle
• notch sensitive material
Mechanical properties of polymethylmethacrylate

- In the context of THR its relative properties are crucial.
- Its modulus of elasticity (Young’s modulus) is usually tested in tension and is approximately 2400 MPa. This is approximately ten times lower than that of the surrounding cortical bone and 100 times lower than that of the metal stem. It thus acts as an elastic interlayer between two stiff layers.
Mechanical properties of polymethylmethacrylate

• has the unique property of continued polymerisation *in vivo* but this is a prolonged process lasting for between 28 and 70 days.

• The long-term properties of bone cement, including fatigue behaviour, the visco-elastic properties of creep and stress relaxation are central to the success of cemented hip replacement and designs that exploit these properties have been clinically validated.
Visco-elastic properties of polymethylmethacrylate

• The visco-elastic properties of bone cement are creep and its ‘inverse’ stress relaxation, which are both time and temperature dependent.
Visco-elastic properties of polymethylmethacrylate

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Visco-elastic properties of polymethylmethacrylate

**Creep**

- This is the deformation of a material under constant load.
- Under constant load a material capable of creep will deform by an amount dependent on the size of the load and the length of time it is applied.
- The rate of loading is also important, where visco-elastic materials demonstrate a higher Young’s modulus at higher loading rates.33

**Stress relaxation**

- This is the time-dependent change in stress within a material under constant strain.
- The force needed to maintain a set deformation will reduce with time if stress relaxation occurs.
Antibiotic-loaded acrylic cement

• Gentamicin is the most common additive because it has, amongst other features, a good spectrum of concentration-dependent bactericidal activity, thermal stability and high water solubility
Antibiotic-loaded acrylic cement

• Concerns
  – Resistance: Hope et al found that 90% of Staphylococcal strains isolated from infected hip replacements were resistant to gentamicin but if plain cement had been used at the initial operation the rate was only 16%.
  – Hypersensitivity and toxic side effects
  – Unsuitable antibiotics
    • heat labile: flucloxacillin, and possibly other penicillins, chloramphenicol and tetracycline.
    • cause deleterious effects upon cement: . Rifampicin preventing setting for several (7) days
Orthopaedic bone cement. DO WE KNOW WHAT WE ARE USING?

The role of polymethylmethacrylate bone cement in modern orthopaedic surgery