Properties of Bone Cement: Testing and Performance of Bone Cements

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Summary

Although all commercially available bone cements are based on polymethylmethacrylate and other acrylic copolymers, they all differ in their precise chemical formulation and composition. This results in different physical properties like viscosity, heat release, and mechanics. These differences affect surgical handling and clinical outcome. Various testing methods of bone cement are discussed in this chapter. Clinically most relevant is fatigue testing and traditional cements perform best.

Introduction

General

All cements which found widespread use in orthopaedic surgery are based on polymethylmethacrylate (PMMA). This acrylic resin is used now for over 50 years for the fixation of orthopaedic implants. The first published artificial joint implantations occurred in 1949 at Copenhagen by M.S. Kiaer and in 1951 in the hospital for Joint Diseases at New York by E. Haboush [5]. The first commercially available bone cements were released to the market in the beginning of the seventies. Since then many types and makes of bone cement have been introduced. Only few stood the test of time.

Alternative Cements

Many attempts have been made to improve the physical properties of bone cements and many alternatives for acrylic were tested, like:

- glass-ionomeric cements,
- bioactive glass cements,
- resorbable cements.

The main advantages of ionomeric bone cements are the absence of heat generation during polymerization and its adhesive properties to bone. The main disadvantage is its low mechanical strength which makes it unsuitable for load bearing applications. Bioactive glass cements are a composite of bioactive calcium-phosphate (CaP) powder and a high molecular weight acrylic matrix. The mechanical strength is 2 to 3 times higher than of acrylic cement. It has less heat generation and less shrinkage during polymerization. Main disadvantage is its high rigidity and brittleness. It is weak in tensile fatigue loading. Resorbable cements like CaP and polypropylene-fumarate cements all suffer from brittleness and insufficient strength in load bearing applications [3].

Improvement of acrylic cements has been tried in many ways like:

- addition of CaP powders,
- addition of artificial fibres,
- modification of the curing mechanism,
- modification of the radiopacifier.

By addition of CaP powders as a filler material to cement, one has tried to enhance bony ongrowth to the cement surface and bony ingrowth into the cement mantle. Simultaneously, it would decrease the exotherm reaction. To obtain ingrowth high amounts up to 30 to 50 w/w% of CaP powder are needed to obtain a sufficient open structure. This open structure weakens the strength of the cement considerably. In the Far East such cements have been applied for the fixation of endoprostheses.

Addition of artificial fibres is meant to increase the mechanical strength. Fibres will increase the static fracture
strength, the modulus of elasticity and the fatigue strength. Creep is diminished and fracture toughness is increased. Many fibres like Kevlar, carbon, glass and PET have been tested in a magnitude of 1 to 2 w/w%. The major drawback of artificial fibres is the long term biological effect of small wear particles. Many materials which are fully biocompatible as block material will give rise to tissue reactions if they are released on a microscopical scale. No artificial filler materials are at present applied clinically.

Test Standards

ISO standard 5833, which was first released in 1979 and latest revised in 2002, is a standard which describes a number of test methods and minimal requirements for acrylic bone cements [6]. All commercially available cements have to fulfill the requirements set forth in this standard. Unfortunately, the test methods and requirements are set on a low level and can be easily met. Therefore, this »standard« is not capable to discriminate whether a cement is suitable for clinical application or not. The ISO 5833 would for example find a setting time of just 3 minutes acceptable for a doughy cement. Even Boneloc cement, which had dramatic clinical results, fulfilled all requirements of the ISO 5833 standard.

In particular, a straightforward tensile test is missing in ISO 5833. Bone cement is remarkably weak in tension, but relatively strong in compression. It is also much more brittle in tension than in compression. In the 1992 version of this standard a bending test was added. Bending does include a tensile component, but the requirements of this bending test will be easily passed by all available cements. Most importantly there is not any type of fatigue testing in the ISO standard. This type of testing was recently described in ASTM standard F2118–2001 [1]. This standard accurately describes a method for a fully reversed tensile and compression cyclic loading test of acrylic bone cement. Unfortunately, the test does not state a minimum requirement.

Running a fatigue test is a very time-consuming procedure and therefore expensive test. The test results will highly depend on the mixing conditions (temperature, vacuum) and the resulting porosity of the test specimens. Only very few papers have been published which compare fatigue data of bone cements.

Effect of Chemical Composition

Polymers

The type of polymer powder is the most important factor which characterizes the performance of a particular type of bone cement. The most commonly used polymer powders are methylnmethacrylate (MMA) homopolymer, methacrylate (MA) copolymer, butylmethacrylate (BMA) copolymer and styrene copolymer. They are applied in various commercially available bone cements (Table 3.1).

The addition of MA in the MMA-MA copolymer results in a change of physical properties as compared to MMA homopolymer. MA is a small molecule which makes the cement more hydrophilic and flexible (Fig. 3.24). The hydrophilic nature of MA speeds up the monomer absorption and powder dissolving. Hence the higher the MA concentration the higher the cement’s initial viscosity will be. The addition of MA will mechanically result in a more flexible cement with a higher failure strain, relative low compression strength and a relative higher strength and failure strain in tension. Bone cement is a brittle material, which tensile strength is very susceptible for stress risers like air voids. MA cements will be less influenced by porosity due to this flexible behaviour.

Addition of a small percentage BMA, which has a higher molecular weight than MMA, gives the powder a more porous open structure. This may enhance the bond between the polymer matrix chains, which will entangle with the outer surface of the beads. A small percentage of BMA is claimed to result in better mechanical properties [7].

Styrene cements have a more hydrophobic behaviour. The time needed to obtain a homogenous mixture will take longer than for an MMA-MA cement. Addition of styrene copolymers is thought to be beneficial for the fatigue strength. No data exists whether this is true.

Table 3.1. Types of polymer used in various bone cement powders

<table>
<thead>
<tr>
<th>Type of Polymer</th>
<th>Cement Brand</th>
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<tbody>
<tr>
<td>MMA homopolymer</td>
<td>CMW1, CMW3, Cemex RX, Cemex System, Zimmer regular+LVC</td>
</tr>
<tr>
<td>MMA-MA copolymer</td>
<td>Palacos R, Palamed, Osteopal, SmartSet HV, Versabond</td>
</tr>
<tr>
<td>MMA-BMA copolymer</td>
<td>Sulfix-6, Boneloc, Biolos</td>
</tr>
<tr>
<td>MMA-Styrene copolymer</td>
<td>Surgical Simplex RO, Osteobond, CMW Endurance</td>
</tr>
</tbody>
</table>

Fig. 3.24. Properties of various types of acrylic molecules

- Hydrophilic
- Methylacrylate
- Ethylacrylate
- Methylmethacrylate
- Butylmethacrylate
- Styrene
- Compact
- Voluminous