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# BONE CEMENT IN ORTHOPAEDIC SURGERY: PROPERTIES, GOOD PRACTICE AND INDICATIONS

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## ABSTRACT

Polymethylmethacrylate (PMMA) bone cement has been used in orthopaedic surgery for more than sixty years. It is not a glue: it acts as a grout, through mechanical interlock with bone, and distributes loads between the implant and the bone. This review describes its composition, its physico-chemical and mechanical properties, the phases of its handling and its main indications.

Polymerisation is an exothermic reaction, but the in vivo temperature remains moderate (40 to 46 °C). The quality of cementation depends mainly on technique: vacuum mixing, canal lavage, cement restrictor and pressurisation. Antibiotic-loaded cement plays a major role in the prevention and treatment of infection. Indications extend beyond arthroplasty to spacers, tumour surgery, the induced membrane technique and vertebroplasty. Bone cement implantation syndrome remains the most serious complication.

**Keywords:** Bone Cement; Polymethylmethacrylate; Arthroplasty; Antibiotic-Loaded Cement; Cementing Technique.

## 1 INTRODUCTION

Bone cement is a viscoelastic material widely used in orthopaedic surgery, mainly to fix joint replacements [1,2]. Its modern use dates back to the work of Charnley, who used it in 1960 to anchor the femoral stem of a hip prosthesis [3].

Cement acts as a volume adapter, a filler and a load distributor between bone and implant. By increasing the contact area between the stem and the bone, it reduces areas of stress concentration ("high spots"). It is used every day, but its results depend largely on how it is prepared and applied. This review recalls the key points needed to use it well.

### 1.1 Composition

Cement comes as two components, a powder and a liquid, which are mixed in the operating room [4]. The powder contains PMMA polymer beads, a polymerisation initiator (benzoyl peroxide), a radio-opaque contrast agent (zirconium dioxide or barium sulphate) and, depending on the product, an antibiotic and a dye.

The liquid contains the monomer, methyl methacrylate (MMA), an activator that speeds up polymerisation (N,N-dimethyl-p-toluidine) and a stabiliser (hydroquinone), which prevents spontaneous polymerisation during storage. The reaction between activator and initiator releases free radicals that trigger the polymerisation of MMA. The contrast agent, the antibiotic and the dye do not take part in this reaction.

## 2 PHYSICO-CHEMICAL PROPERTIES

### 2.1 Polymerisation temperature

The polymerisation of MMA is an exothermic reaction, releasing about 57 kJ per mole of monomer [4]. In vitro, cement temperature reaches 60 to 80 °C. This peak, although brief, was long blamed for bone necrosis and implant loosening.

In vivo, the actual temperature at the bone–cement interface is much lower, around 40 to 46 °C [4,5]. This difference is explained by heat exchange with the tissues and the blood flow, especially when a sufficient layer of cancellous bone is preserved. An overly thick cement mantle, however, increases the heat released.

### 2.2 Volume shrinkage and residual monomer

Polymerisation converts many small monomer molecules into a smaller number of large polymer molecules. This results in a slight shrinkage of the cement volume as it hardens [5].

Polymerisation is never complete. Residual monomer content is 2 to 6% after hardening, then falls to about 0.5% within three weeks [4]. The released MMA is metabolised into carbon dioxide and water. Its blood levels are too low to explain intraoperative haemodynamic disorders, which are now attributed to raised intramedullary pressure and fat embolism [14].

### 2.3 Viscosity

Viscosity measures a fluid's resistance to deformation. The viscosity of bone cement depends mainly on its chemical composition and on the powder/liquid ratio [4]. Cements are classified as high-viscosity or low-viscosity; some are described as "medium" viscosity. The choice depends on the application technique: a low-viscosity cement is injected with a gun, whereas a high-viscosity cement can be handled manually.

## 3 HANDLING OF CEMENT

Cement preparation includes four successive phases, summarised in Table 1 [4,7]. Their duration varies between manufacturers, so the instructions for the cement in use must be read carefully.

**Table 1: The four phases of cement handling**

| Phase | Description | Practical landmark |
|---|---|---|
| Mixing | Powder + liquid, by hand or under vacuum | Homogeneous dough, low viscosity |
| Waiting (dough) | Viscosity increases | Ends when the cement no longer sticks to the glove |
| Working (application) | Insertion of cement and implant | Viscous enough to resist bleeding, fluid enough to penetrate cancellous bone |
| Setting | End of polymerisation | Do not move the implant; check on the patient |

During the working phase, the cement must be viscous enough to resist blood pressure, yet fluid enough to penetrate the cancellous bone trabeculae. At the end of the procedure, setting must be checked on the cement in place: a control sample kept in room air is not enough, because it hardens more slowly.

Temperature is the main factor that changes these times. A high temperature speeds up the reaction and a low temperature slows it down, with differences of several minutes. Other factors are involved: the patient's temperature, the size of the implant, the thickness of the cement mantle and the timing of injection [4].

### 3.1 Mechanical properties

Cement has no chemical or biological adhesive power, either to bone or to the implant. Its action relies on mechanical interlock with bone. In Charnley's words, "it acts as a grout, not as a glue" [3].

At the hip, cement is subjected to multidirectional stresses: compression, bending, shear, torsion and tension. They are greatest during weight-bearing and can reach several times body weight [1,5]. The ISO 5833 standard sets the minimum values that all commercial cements must meet (Table 2) [6].

**Table 2: Minimum mechanical values according to ISO 5833**

| Property | Minimum value |
|---|---|
| Compressive strength | 70 MPa |
| Bending strength | 50 MPa |
| Bending modulus | 1800 MPa |

Cement porosity markedly reduces its strength, especially in fatigue. It depends on the mixing method: vacuum mixing reduces the number of bubbles and improves mechanical properties [5]. Conversely, poor handling of mixing systems or premature insertion of the implant promotes failure.

### 3.2 Evolution of cementing techniques

Cementing technique has evolved considerably, especially for the femur (Table 3) [1,7]. Each generation has sought to obtain a continuous, homogeneous cement mantle that is well anchored in cancellous bone.

**Table 3: Generations of femoral cementing techniques**

| Generation | Technique |
|---|---|
| 1st | Finger packing of cement into an unplugged canal |
| 2nd | Distal cement restrictor, careful canal lavage, retrograde gun injection |
| 3rd | Cement pressurisation, pulsatile lavage |
| 4th | Vacuum mixing, stem centralisers |

### 3.3 Antibiotic-loaded cement

The addition of antibiotics to cement was proposed by Buchholz in the late 1960s [8]. The antibiotic is released locally from the cement matrix at high concentrations, without systemic toxicity. Gentamicin is the most widely used antibiotic for primary fixation [9].

Gentamicin has several advantages: a broad spectrum against Gram-positive and Gram-negative bacteria, a bactericidal effect even at low concentrations, a low allergenic potential, good thermal and chemical stability and good water solubility. In the Norwegian registry, the combination of systemic antibiotic prophylaxis and antibiotic-loaded cement gave the lowest revision rate for total hip replacements [10].

For one- or two-stage revision of infected prostheses, cement containing gentamicin alone or combined with clindamycin or vancomycin is used. These combinations broaden the spectrum and increase the amount of antibiotic released [11].

### 3.4 Indications

The indications for bone cement are numerous [1,2]:

- fixation of total or partial joint replacements;
- filling and stabilisation of bone defects;
- two-stage revision of infected prostheses (spacers);
- management of bone loss;
- tumour surgery;
- vertebroplasty and kyphoplasty.

#### 3.4.1 Arthroplasty

Prosthesis fixation remains the main indication (Figure 1). It requires good knowledge of the cement in use and a rigorous technique, which determine implant longevity [1,7].

**Figure 1: Cemented arthroplasties. Left: total hip replacement with a cemented cup (radiograph and intraoperative view). Right: loosening of the tibial insert revised with a hinged constrained total knee replacement.**

### 3.4.2 Infection

In the setting of infection, antibiotic-loaded cement is used to treat osteitis or prosthetic joint infection. In a two-stage revision, an antibiotic-loaded spacer is placed in the cavity left after removal of the prosthesis [11]. It maintains the joint space and delivers the antibiotic locally. It can be hand-made in the operating room or obtained with preformed moulds (Figure 2).

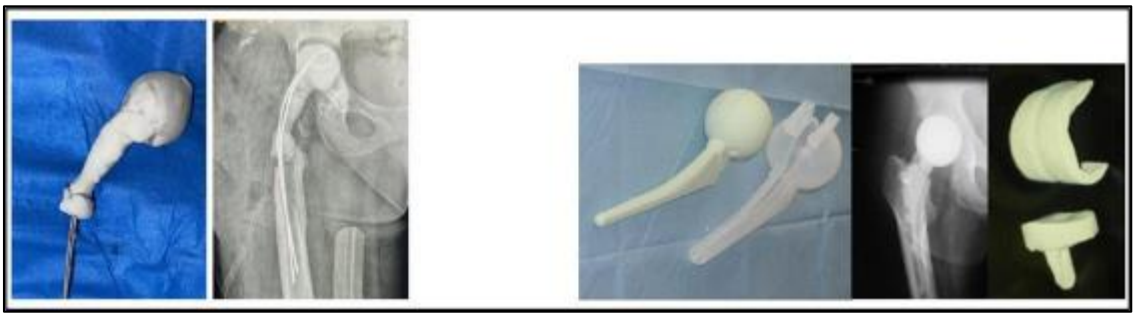

**Figure 2: Antibiotic-loaded spacers. Left: hand-made hip spacer and its radiograph. Right: moulded hip and knee spacers.**

### 3.4.3 Tumour surgery and bone loss

In tumour surgery, curettage and cement filling is used less often than before, in favour of bone grafting. It still has a role in giant cell tumours, where the heat of polymerisation is thought to have a local adjuvant effect (Figure 3).

The induced membrane technique, developed by Masquelet, is performed in two stages [12]. Cement is first placed in the bone defect and induces the formation of a biological membrane. A few weeks later, it is removed and replaced by a cancellous bone graft placed inside this membrane. This technique is useful after resection of an infected focus or in post-traumatic bone loss (Figure 4).

**Figure 3: Left: tumour of the distal femur treated by curettage, cement filling and plate fixation. Right: diaphyseal bone loss of the femur.**

**Figure 4: Induced membrane technique in the distal tibia: cement in place (left), induced membrane at the second stage (centre) and follow-up after grafting (right).**

### 3.4.4 Vertebroplasty

Percutaneous vertebroplasty consists of injecting cement into a weakened vertebral body. First described in 1987 for vertebral haemangiomas [13], it is now used for osteoporotic compression fractures and tumour lesions of the spine, alone or combined with kyphoplasty.

### 3.4.5 Contraindications

The use of cement is contraindicated in patients with known hypersensitivity to any of its components. It is also contraindicated in the presence of active or inadequately treated infection at the surgical site, and when muscular or neuromuscular disease of the limb makes the procedure unjustified.

### 3.4.6 Complications

The most serious complication is bone cement implantation syndrome. At the time of cementation or implant insertion, it combines hypotension, hypoxia and even cardiac arrest [14]. It is mainly related to raised intramedullary pressure, which drives fat, marrow and bone particles into the circulation. Elderly patients operated on for a femoral neck fracture are at greatest risk.

Several measures reduce this risk: pulsatile lavage of the canal, a distal cement restrictor, venting of the canal during injection, 100% oxygen and good communication with the anaesthesia team [14]. Other complications are rare: allergic reactions to gentamicin and, exceptionally, allergy to a cement component.

## 4 CONCLUSION

Bone cement retains a central place in orthopaedic surgery, well beyond arthroplasty. Its properties are now well known: it acts as a grout, its polymerisation is exothermic and its strength depends mainly on the quality of its preparation.

The best results rely on rigorous technique: respect for the handling phases, vacuum mixing, lavage and pressurisation. The surgeon and the whole operating team must master these steps to obtain durable fixation and limit complications.

## STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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*Disclosure of conflict of interest*

The authors declare that they have no conflict of interest.

*Statement of informed consent*

Informed consent was obtained from the patients for the publication of their clinical images, which have been anonymised.

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