Bone Preparation: The Importance of Establishing the Best Bone-Cement Interface

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Summary

This chapter describes the interface between bone cement and bone, pointing out that the operating surgeon is responsible for establishing that interface at the time of surgery. If the interface is not well established at the start, the replacement joint has no chance of long-term function. The cement-bone interface is a mechanical interlock between the two materials that can be enhanced by the preparation of the bone surface, pressurising cement into that surface and holding the cement under pressure until its viscosity is such that bone bleeding cannot displace it. Effective pressurisation can only be obtained using suitable instruments. The effect of heating the femoral stem before insertion is described. The surgeon has to be aware of the effect of all the variables in order that the strongest possible interface is obtained at the time of surgery.

Introduction

It has been estimated that aseptic loosening of an implant component causes approximately 75% of failures of cemented total hip arthroplasties [17]. Aseptic component loosening implies that the interface between cement and bone has failed in some degree. Consequently, it is plain to see that establishing the best possible interface between cement and bone should be a primary concern of a surgeon performing hip arthroplasty.

Structure of the Interface Between Bone and Cement

It was pointed out by Ling [16] in 1986 that the interface between any orthopaedic implant and bone is not a simple abutment of bone against implant, but is composed of complex junctional tissues that separate the implant from the host bone. The nature of the junctional tissues depends substantially on mechanical factors, given that the implant itself is basically non-reactive. The junctional tissues can vary between a state of osseointegration, to fibrous tissue and fibrocartilage, and cutting out or early mechanical loosening. The junctional tissues that result at the interface are dependent on a balance between the strength of the initial mechanical interlock between implant and host, and the magnitude of the applied loads. The surgeon is responsible for the strength of the initial interlock, the patient applies the loads during activity after the operation. High interface strength plus relatively low loads can result in osseointegration between implant and bone; low interface strength plus high loads will give a thick soft tissue layer between implant and bone. It is the duty of the surgeon at the time of the initial operation to ensure that the mechanical interlock between cement and bone is as good as it is possible to achieve. The clinical verification of the principle stated by Ling has been shown in a number of papers, as an example, Iwaki et al. [13] showed that, with secure initial fixation, minimal migration of the implant component and no radiolucent lines, then no lytic lesions will develop by five years and no aseptic loosening by ten years. On the other hand, insecure initial fixation shown by more rapid migration and progressive radiolucent lines at two years, leads to lytic lesions at five years and loosening at ten years. They state that the outcome of total hip replacement is determined at the initial operation and may be predicted at two years – loosening is due to failure of the operating technique. Loosening occurred, not because of lysis, but because it represented the end point of a process that had been present subclinically from the time of operation.

Obtaining the Best Mechanical Interlock Between Cement and Bone

Details of the surgical technique that should be used to obtain the best possible mechanical interlock between cement and bone are given later in this chapter and the next. However, a number of factors need to be stated at the outset to 'set the scene'. Bone cement is not a glue or adhesive – it does not bond with any significant strength to implant stem or cup, or to bone. The strength of the interface between cement and bone depends on a mechanical interlock between cement and bone – that is, it depends on the establishment of a bone-cement composite by forcing cement into the spaces in trabecular bone before the cement polymerises in place. The strength of this interlock also depends on the nature of the stresses present at the interface. The interface can resist compressive stresses best, then shear stresses and resists tensile stresses worst. Fortunately, tensile stresses at the interface are relatively small, but shear stresses are significant and shear failure of the interface has to be resisted. Halawa et al. [9] investigated the shear strength of trabecular bone from the femur and some factors affecting the shear strength of the cement-bone interface. They determined that the strongest trabecular bone is to be found close to the cortico-cancellous bone junction (within 3 mm of the cortex). In vitro, the strongest cement-bone interface strength is obtained by exposing strong cancellous bone and thoroughly cleaning it, afterwards forcing cement into the bony spaces under pressure. In-vitro tests showed that for push out tests on matching slices of femur/cement:

- With 2–3 mm of cancellous bone, load at failure was 100% higher than with 5 mm of cancellous bone.
- A cleaned bone surface gave 200% higher load at failure than a not cleaned surface.
- Insertion of cement at 3 minutes gave load at failure 60% higher than insertion of cement at 6 minutes.
- Pressurising cement at 0.3 N/mm^2 gave load at failure 100% higher than pressurisation at 0.15 N/mm^2.
- Difference for load at failure between using the best and worst techniques for establishing the cement-bone interface was 800%.

Consequential Effects of Establishing the Bone-Cement Interface

It is shown above that the strongest bone-cement interface is a composite of bone and cement formed by pressurising cement into the open trabecular spaces of the bone. It is necessary to examine the effects that such techniques may have on the patient at the time of the operation and subsequently.

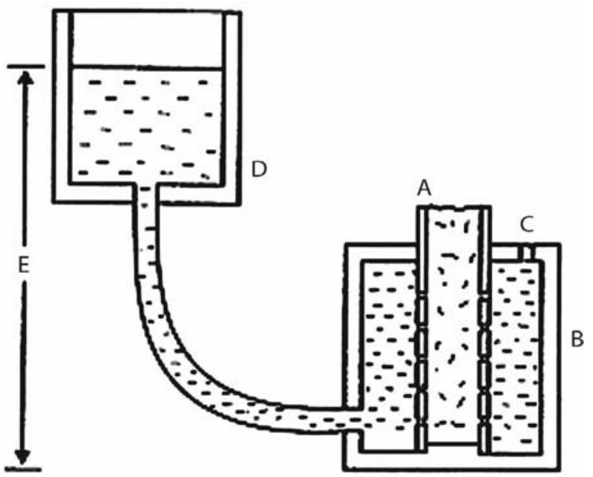
In order to clean the bony spaces after the cavity has been formed in the bone, pressure lavage is used (see section 5.2.1 below). Following lavage, the bone should be dried and blood flow discouraged at the interface. Ribbon gauze soaked in 10 vol% hydrogen peroxide is often used for this purpose and has been used by the author's surgical colleagues for more than 30 years. The effectiveness of hydrogen peroxiode as a haemostatic agent has been shown by Hankin et al. [10]. They used hydrogen peroxide and saline to treat metaphyseal bone sites in ten mongrel dogs, six sites in each dog. Hydrogen peroxide was used at three sites, saline (control) at three sites and the haemostatic effect of both noted. Post treatment blood loss was significantly less for the hydrogen peroxide treated sites than for the saline controls – for hydrogen peroxide there was a mean reduction in bleeding of 38.7 $mg/cm^2/min$, saline had a mean increase of 26.0 $mg/cm^2/min$. When using hydrogen peroxide in the femoral cavity, it is important to have a catheter vent tube in the cavity below the level of the ribbon gauze to allow any oxygen liberated to be vented to atmosphere, preventing the possibility of (air) embolism. When used properly, hydrogen peroxide soaked gauze is a safe and effective way of treating bone before cement pressurisation.

After cleaning the bone, cement is pressurised into its open trabecular spaces. According to Askew et al. [1], bone cement should be maintained at a pressure of at least 76 kPa (0.75 bar) for 5 seconds to achieve adequate penetration of cement into bone. This paper presented results from in-vitro studies, these do not take bone bleeding into account. Bleeding pressure in femora during total hip replacement operations was measured by Heyse-Moore and Ling [11] who reported bleeding pressures of between 0 and 36 cm of saline (0–27 mm of Hg). The effect of bone bleeding was assessed experimentally by Benjamin et al. [2]. They used a simple model to demonstrate the ability of blood to displace bone cement after it has been introduced into the femoral cavity. Their apparatus consisted of a cylinder of Perspex into which 80×1 mm diameter holes had been drilled. Bone cement was introduced into the cylinder and levelled off at the top. An annulus surrounded the cylinder, which could be filled with blood at a known pressure. Blood pressure was controlled by raising or lowering the reservoir containing the blood (Fig. 5.1).

When blood was allowed to surround the cement in the cylinder, at pressures up to the maximum measured in patients, the cement was displaced upwards, out of the cylinder, for times up to six minutes after the start of mixing (Simplex RO cement at room temperature). A second simple experiment was then carried out, in which the apparatus previously used was modified by the addition of a tube filled with liquid and placed over the opening of the central cylinder (Fig. 5.2).

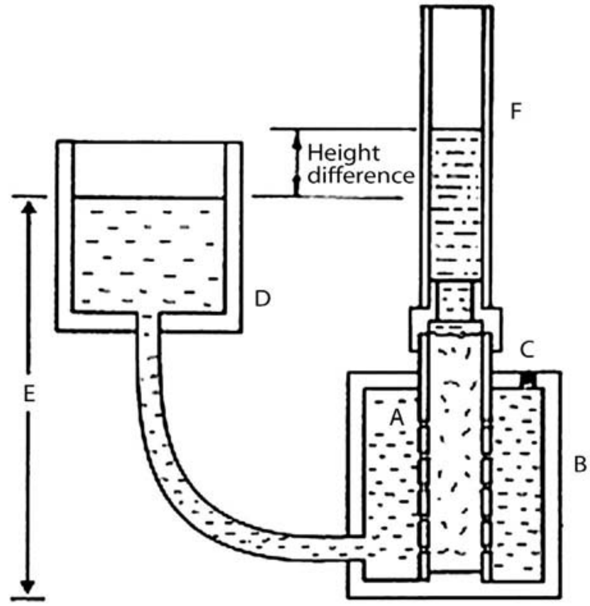
When the pressure exerted by the blood in the reservoir was greater than that exerted by the liquid in the tube (liquid level below blood level) the cement continued to be displaced upwards, out of the tube (Fig. 5.3a). When the pressure exerted by the blood in the reservoir was less than that exerted by the liquid in the tube (liquid level above blood level) the cement was displaced from the tube, through the holes and into the blood (Fig. 5.3b).

These simple experiments demonstrated that the time of pressurisation needed to be extended considerably (to at least 6 minutes after the start of mixing for Simplex bone cement at room temperature) to prevent a lamination of blood forming between the cement and the bone. Pressurisation of cement into bone requires the use of seals and pressurisers, many such instruments have been developed over the years. Lee and Ling [14] describe an acetabular pressuriser that was first used in 1972 and is still in use today. Use of the acetabular pressuriser was shown to be able to maintain raised pressure for several minutes and significantly increase the penetration of cement into bone. Continuous monitoring of arterial blood pressure while using the pressuriser produced no evidence of any unusual effects due to its use [4]. Other pressurisers have been assessed for effectiveness and are reported in Dunne et al. [6].



A Cylinder, containing bone cement
B Annulus around cylinder
C Vent
D Blood reservoir
E Variable height, setting blood pressure

Fig. 5.1. Diagram and picture of bleeding apparatus



A Cylinder, containing bone cement
B Annulus around cylinder
C Vent
D Blood reservoir
E Variable height, setting blood pressure
F Tube, containing water

Fig. 5.2. Bleeding apparatus, modified

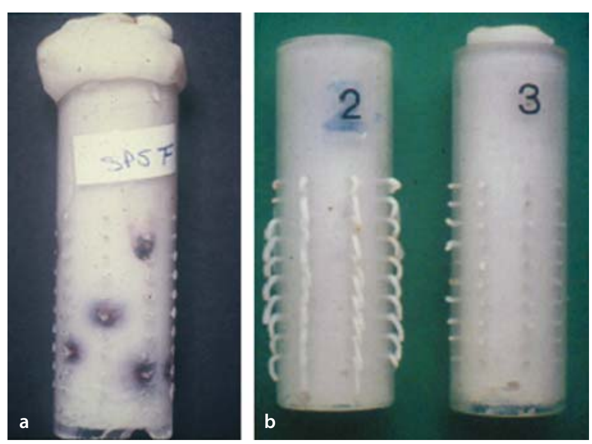
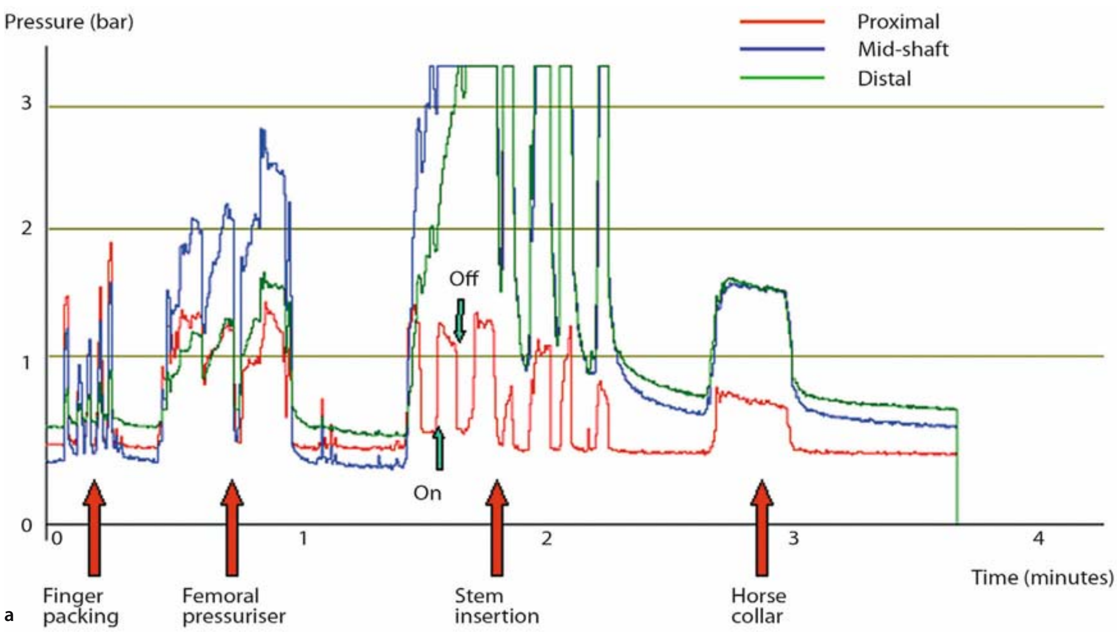


Fig. 5.3. **a** Bone cement displaced out of tube by blood. **b** Bone cement displaced through holes in tube by pressure on cement

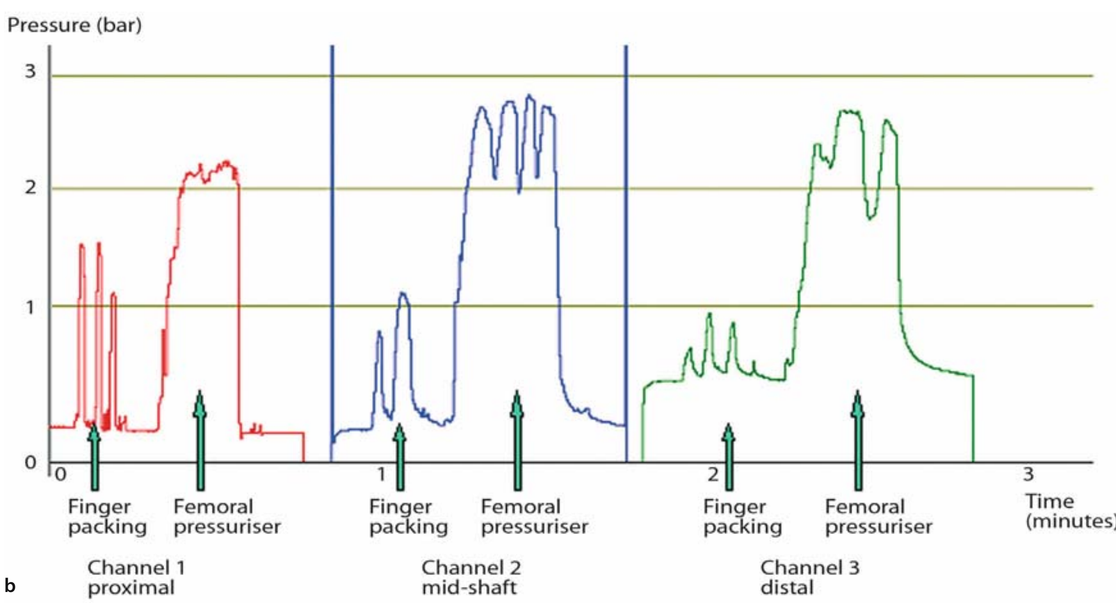
Pressurisation of Cement in the Femur

A simple cement pressuriser has been in use in Exeter and elsewhere for a number of years (Stryker Cement Gun Mk.II, Primary Cement Syringe, Proximal Cement Seal).

The prepared femoral medullary cavity is filled with cement using the cement gun and syringe, the seal is fitted over the syringe nozzle and the nozzle cut to be flush with the end of the seal. The seal is pressed into the cut end of the femur, forming a closed cavity that is full of cement. More cement is injected into the cavity, putting the cement under pressure and forcing it into the bony spaces of the inside of the femoral medullary cavity. As the cement is forced into the bone, so fat is forced out and through the bone, visibly oozing out of the exposed surface of the femur. Pressure is maintained on the cement by periodically injecting more cement into the cavity, until sufficient time has passed for the cement to remain where it is placed. Pressures generated at the proximal end, the mid-diaphysis and the distal end of a Sawbones femur were measured in the laboratory using miniature pressure transducers. Figure 5.4a shows pressures generated dur-



a



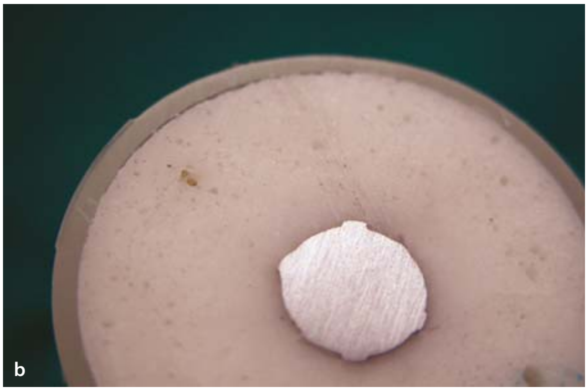
b

Fig. 5.4. a Pressurisation during cementation and stem insertion. **b** Pressure in cement at measured points

ing the whole pressurisation to implant insertion cycle; ◘ Fig. 5.4b shows pressures generated at the three measuring points during cement pressurisation. It can be seen that pressures exceeding 2 bar (202,65 kPa) can be obtained using the pressuriser, ensuring excellent penetration of bone by cement. Pressures generated during stem insertion are even higher, but this is primarily caused by the cement being very viscous, leading to high pressures; the cement is stable within the bone spaces following pressurisation.

The way in which cement is mixed has changed over the years, currently most modern cementing techniques recommend the use of a vacuum mixing system – in the 1st Annual Report of the National Joint Register for England and Wales, 89.5% of cases used vacuum mixing for the femoral cement and 88.8% of cases used vacuum mixing for the acetabular cement [18]. Vacuum mixing of cement decreases the porosity of the cement but also increases the shrinkage of the cement on polymerisation (the effects of vacuum mixing and porosity in cement are also discussed elsewhere in this book: ▶ chapters 3.6, 4.1, 4.2). Gilbert et al. [7] showed that Simplex shrinks by 5.09% when hand mixed and by 6.67% when vacuum mixed; Endurance cement shrinks by 6.50% when vacuum mixed. The shrinkage typically occured between 400 and 600 seconds after start of mixing – this is after pressurisation of cement had been completed, therefore pressurisation should have little effect on countering shrinkage. Haas et al. [8] report different results – they report cement shrinkage of 2.3% with a specimen of 9.0% porosity, and 5.3% shrinkage and 0.8% porosity with a specimen polymerised in a mould at constant pressure. They state the theoretical shrinkage of cement as a result of polymerisation of the monomer to be between 7.6 and 8%.

It is also becoming more common to heat the femoral stem before insertion. Li et al. [15] showed that heating the stem changes the direction of polymerisation of the cement – with a pre-heated stem the cement polymerises first around the stem and the wave of polymerisation progresses from the stem to the bone. The effect of the pre-heating is stated to be unlikely to produce significant thermal necrosis of the bone. Iesaka et al. [12] showed that heating a stem to 37 °C decreased the porosity of the cement at the stem-cement interface by 99%, decreased the setting time by 12% and increased the bone-cement interface temperature by 6 °C. Similar effects were observed when heating a stem to 44 °C and 50 °C. Bishop et al. [3] showed that porosity was dramatically reduced at the stem cement interface when a stem was heated above 44 °C. Heating of the stem caused a negligible increase in the temperature generated in the bone. Shrinkage of the bone cement caused it to try to pull away from the cement-bone interface (it polymerises around the stem first) but shrinkage displacements were reported to be small compared with the macro interlock into bone – the load bearing capacity of this interface was unlikely to be compromised. Bone cement shrinkage and porosity around a pre-heated implant is easily seen in a simple laboratory experiment as described by Draenert [5] (▶ chapter 3.6) and repeated by the author for this chapter. ◘ Fig. 5.5a shows a specimen of cement.



◘ **Fig. 5.5. a** Implant and cement in syringe. **b** Shrinkage gap between cement and syringe; porosity in cement forced away from implant towards syringe

Take Home Messages

- The interface between cement and bone must be as strong as possible.
- The strongest interface is formed by forcing cement into the spaces in trabecular bone and holding it there until the cement polymerises, forming a composite of bone and cement.
- A number of factors can affect the interface, including cleaning and haemostasis, cement mixing, pressurisation and component heating.
- The surgeon must be aware of the effect of all these variables in order that the strongest possible cement-bone interface is obtained at the primary procedure.
- It is the duty of the surgeon at the time of the initial operation to ensure that the mechanical interlock between cement and bone is as good as it is possible to achieve.

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