BONE SURFACE PREPARATION IN CEMENTED JOINT REPLACEMENT

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We studied the effects of nine techniques of bone surface preparation on cement penetration and shear strength at the cement-bone interface in a standard model of bovine cancellous bone.

In unprepared bone the mean penetration was 0.2 mm and the mean shear strength of the interface was 1.9 MPa, less than that of the underlying bone. Brushing with surface irrigation gave mean penetrations of 0.6 to 1.4 mm and mean shear strengths of 1.5 to 9.9 MPa. In 50% of specimens the interface was weaker than the underlying bone. The use of pressurised lavage resulted in mean penetrations of 4.8 to 7.9 mm and mean shear strengths of 26.5 to 36.1 MPa, which were greater than those of the cancellous bone in all specimens.

Pressurised lavage was equally effective alone or in combination with brushing, and its efficacy was not altered by using pulsed or continuous jets, or by changing the temperature of the solution from 21°C to 37°C.

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Aseptic loosening remains the principal cause of late failure of cemented total hip arthroplasty (Amstutz et al 1976; Stauffer 1982; Fowler et al 1988) although its incidence has decreased since the introduction of modern cementing techniques (Harris and McGann 1986; Rusotti, Coventry and Stauffer 1988). Post-mortem examination has shown that clinical success is associated with osseointegration at the cement-bone interface (Charnley 1979; Linder and Hansson 1983) whereas in failure the cement is separated from the bone by a layer of fibrous tissue of variable thickness (Linder, Lindberg and Carlsson 1983). In the first few months after implantation, the dead bone produced by the operation is replaced; it is thought that osseointegration can occur only if the mechanical environment is sufficiently stable (Albrektsson et al 1981; Johanson et al 1987). This stability depends on the quality of fixation obtained at the time of implantation.

The initial strength of the cement-bone interface can be increased by cement pressurisation (Krause et al 1982), intramedullary plugging (Oh et al 1978) and cleaning the bone by brushing and lavage (Halawa et al 1978; Lange 1979; Krause et al 1982). Brushing removes surface debris, while lavage clears marrow from bone interstices, allowing improved cement penetration (Bean et al 1987). Fat becomes less viscous at higher temperatures and this clearance may therefore be enhanced by lavage with solutions at body temperature as opposed to room temperature. The relative importance of the extent of brushing, the pressure and periodicity of lavage, and the temperature of the lavage solution has not been established. Our aim was to assess the effect of these variables on cement penetration and the shear strength of the cement-bone interface in a standard model of cancellous bone.

MATERIAL AND METHODS

Specimens of fresh cancellous bone were obtained from the distal metaphyses of two pairs of bovine femora. Twenty transverse sections, each 15 mm thick, were warmed to 37°C in an incubator and subjected to one of nine different surface-preparation techniques. Matching paired sections of bone from the right and left femora of the same animal were used to compare one technique with another. The relative efficiency of each method of removing debris and marrow was assessed by weighing each bone section before and after preparation.

The test surfaces were left unprepared or prepared by brushing, pressurised lavage or a combination of the two. Brushing alone involved either 10 or 60 strokes with a stiff nylon brush followed by low-pressure irrigation with 60 ml of saline from a bladder syringe. Pressurised lavage at 50 psi used 1 litre of normal saline at either
21°C or 37°C. It was either continuous (Exeter Bone Lavage System, Howmedica (UK) Ltd, London, UK) or pulsed (Micro-Aire, Surgical Instruments Inc, San Fernando, California). The ten pairs of specimens were treated as shown in Table I.

After surface preparation, Simplex P bone cement (Howmedica (UK) Ltd, London, UK) mixed at 1 Hz for 1 minute was injected onto the surface of the bone, starting 3 minutes 40 seconds from the beginning of mixing, when it was at a doughy stage. It was pressurised at 25 psi for 30 seconds, using a specially designed jig (Fig. 1). This pressure is equivalent to that achieved by finger packing of the femoral canal (Markolf and Amstutz 1976; Oh, Bourne and Harris 1983).

After polymerisation of the cement each of the 20 resulting cement-bone preparations was cut into 25 rectangular struts, each 6 x 6 mm in cross-section, and perpendicular to the cement-bone interface. This produced a total of 500 struts, which were radiographed at 30 mV for 30 seconds (Faxitron 438 55-A; Vinter Analytical Ltd, Sandy, UK). The penetration of cement into bone was measured directly from the radiographs and the bone porosity was assessed by computerised image analysis. The shear strength of the cement-bone interface, the cement and the cancellous bone was tested at a strain rate of 20 mm/min on a single-face shear jig mounted on a Hounsfield tensometer. The cement-bone interface was tested at the original cut surface of the bone as described by Krause et al (1982). Statistical analysis was performed using Student’s t-test where appropriate.

**RESULTS**

**Preparation and macroscopic appearance.** In specimens prepared by brushing alone the weight loss was 0.84 ± 0.15% compared with 3.6 ± 0.6% when pressurised lavage was used either alone or in combination with brushing. Unprepared specimens had a flat, featureless surface, but after brushing the apices of trabecular bone could be distinguished from the surrounding marrow. The internal trabecular architecture only became clearly visible after pressurised lavage (Figs 2 to 4).

**Penetration** (Table I, Fig. 5). The mean penetration of cement in unprepared specimens was 0.2 mm. This increased to 0.6 to 1.4 mm after brushing and to 4.8 to 7.9 mm after pressurised lavage (p < 0.001). No advantage was conferred by increasing the number of brush strokes. There was no difference between continuous and pulsed pressurised lavage: they both resulted in four to eight times the depth of penetration obtained after

<table>
<thead>
<tr>
<th>Pair</th>
<th>Preparation</th>
<th>Sample size (n)</th>
<th>Shear strength (MPa)</th>
<th>Penetration (mm)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cement interface</td>
<td>Bone</td>
</tr>
<tr>
<td>1</td>
<td>None</td>
<td>25</td>
<td>46.1 ± 2.5</td>
<td>2.0 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>Brush × 60</td>
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<td>45.6 ± 9.6</td>
<td>4.3 ± 3.0</td>
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<tr>
<td>2</td>
<td>None</td>
<td>25</td>
<td>44.1 ± 5.2</td>
<td>1.7 ± 1.5*</td>
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<tr>
<td></td>
<td>Pressurised lavage</td>
<td>25</td>
<td>43.8 ± 7.8</td>
<td>28.0 ± 9.5*</td>
</tr>
<tr>
<td>3</td>
<td>Brush × 10</td>
<td>25</td>
<td>46.5 ± 4.4</td>
<td>9.9 ± 6.8</td>
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<td></td>
<td>Brush × 60</td>
<td>25</td>
<td>45.3 ± 6.2</td>
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</tr>
<tr>
<td>4</td>
<td>Brush × 60</td>
<td>25</td>
<td>46.1 ± 6.4</td>
<td>5.1 ± 2.8*</td>
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<td>Pressurised lavage</td>
<td>25</td>
<td>45.5 ± 6.3</td>
<td>26.9 ± 6.1*</td>
</tr>
<tr>
<td>5</td>
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<td>25</td>
<td>43.4 ± 3.1</td>
<td>34.1 ± 8.9*</td>
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<td></td>
<td>Pulsed lavage</td>
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<td>43.8 ± 5.6</td>
<td>3.6 ± 2.1*</td>
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<td>6</td>
<td>Brush × 60</td>
<td>25</td>
<td>45.9 ± 5.2</td>
<td>29.9 ± 7.3*</td>
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<td></td>
<td>Brush × 60 + pressurised lavage</td>
<td>25</td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>Brush × 60</td>
<td>25</td>
<td>41.4 ± 3.4</td>
<td>5.3 ± 5.2*</td>
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<td>8</td>
<td>Brush × 60 + pressurised lavage</td>
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<tr>
<td></td>
<td>Brush × 60 + pulsed lavage</td>
<td>25</td>
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<tr>
<td>9</td>
<td>Brush + pressurised lavage at 21°C</td>
<td>25</td>
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<tr>
<td></td>
<td>Brush + pressurised lavage at 37°C</td>
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<td></td>
<td>Brush + pulsed lavage at 37°C</td>
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* difference between pairs significant at p < 0.001
brushing alone (p < 0.001). The addition of brushing to pressurised lavage did not improve on pressurised lavage alone. There was a small increase in penetration with warmed continuous pressurised lavage at 37°C as against 21°C but this was not statistically significant.

**Shear strength of the interface** (Table I, Fig. 6). The cement-bone interface was weakest in the unprepared specimens with mean shear strengths of 1.7 to 2.0 MPa and was never greater than that of the adjacent cancellous bone. Brushing increased the mean shear strengths of the interface to 1.5 to 9.9 MPa, but in 50% of the individual struts this was weaker than the adjacent bone. Pressurised lavage increased the mean shear strengths to 26.5 to 36.1 MPa (p < 0.001), and the interface was always stronger than the adjacent bone. There was no difference between continuous and pulsed pressurised lavage and the temperature of the solution had no effect. The combination of brushing and pressurised lavage was not better than pressurised lavage alone.

**Model.** There were wide variations in the shear strength of the cancellous bone of the specimens (2.7 to 7.4 MPa), and their porosity (30% to 73%) but the differences between paired sections were never significant. The small variation in the mean shear strength of the cement in the specimens (41.5 to 46.5 MPa) was never statistically significant.

**DISCUSSION**

The strength and porosity of bovine cancellous bone are comparable to those of the proximal human femur (Rey et al 1987; Bannister and Miles 1988), but the wide variation in porosity and shear strength of our specimens emphasises the importance of experimental design in comparing bone of similar quality. It is also important that the preparation and pressurisation of cement are standardised.

Penetration depended on the extent of marrow removal from the bone interstices. An increase in penetration beyond a certain level does not give an incremental increase in shear strength (Bugbee et al 1992), but it may be desirable for other reasons. Preparation of the femoral canal causes death of cancellous bone to a depth of 2 to 3 mm (Willert, Ludwig and Semlitsch 1974; Noble and Swarts 1983) and it is theoretically desirable that cement should penetrate beyond this level. Cancellous bone increases in strength towards the corticocancellous junction and the strength of the interface is increased where cement penetrates this region (Halawa et al 1978). Increased cement penetration

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**Fig. 1**

Experimental apparatus used for the pressurisation of bone cement on to prepared specimens of cancellous bone.

**Fig. 2**  
Photographs of cancellous bone surfaces. Figure 2 – No preparation. Figure 3 – After brushing (60 strokes). Figure 4 – After pressurised pulsed lavage.
may also provide more protection against contamination of the interface by bleeding during polymerisation, but penetration beyond 5 mm may increase the risk of thermal damage (Huiskes and Slooff 1981). After pressurised lavage in vitro it usually exceeded 5 mm, but the risk of thermal damage in the proximal femur in vivo could be reduced by removing excess cancellous bone. Our experiments showed that penetration of cement was extremely limited in unprepared bone despite pressurisation.

The shear strengths of the cement-bone interface that we recorded were comparable to those obtained in previous experiments on unprepared or brushed bovine bone (Bannister and Miles 1988) and on human tibial
metaphyses prepared by brushing and pressurised lavage (Krause et al 1982). The latter study tested relatively few specimens and gave no data on the strength of the underlying cancellous bone. Early mechanical failure will occur at the weakest of the cement, cement-bone composite or cancellous bone levels. In unprepared bone there is little cement-bone composite because of the lack of penetration, and this level was always weaker than the adjacent bone. A layer of composite was formed in bone prepared by brushing alone, but this was weaker than the adjacent bone in 50% of the specimens.

Early failure in any weak area will increase the loading at remaining points of contact and lead to more failure with probable loss of mechanical stability at the interface. After pressurised lavage, the cement-bone composite layer was 50% to 75% as strong as the bone cement and always stronger than the adjacent cancellous bone. This situation would seem to offer the best chance of maintaining a stable mechanical environment and allowing osseointegration to take place.

The surgical techniques used to cement total hip replacements still vary considerably (Timperley et al 1991). The routine use of pulsed or pressurised lavage appears to be the single most important factor in preparing the bone bed. It is essential in achieving adequate and uniform penetration of bone cement and a sound cement-bone interface.

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REFERENCES


