Cementation pressure in arthroplasty

In vitro study of cement penetration into femoral heads

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We analyzed the pressure needed for adequate cement penetration into the human arthrotic hip. 85 holes in 39 arthrotic femoral heads were cemented under predetermined pressures and times after cement mixing. Cement penetration correlated well to both pressure and time after mixing. No correlation to the degree of sclerosis was found. At 0.2 MPa, the average penetration into bone was 2 mm. However, 3–5 mm is considered the minimum depth for good fixation of an implant. To achieve a consistent adequate interdigitation, a pressure of approximately 0.3 MPa is recommended.

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Even though the cementing techniques in arthroplasty have improved, it has still not been elucidated what pressure level is needed to achieve sufficient cement penetration. Our experiment was aimed at finding the appropriate pressure for adequate cement penetration into arthrotic bone in the acetabulum.

Material and methods

Because of its availability, the femoral head was chosen as an initial model for the human acetabulum under the assumption that the properties of the bones at corresponding sites are similar in the arthrotic hip. During half a year, 39 human arthrotic femoral heads were collected from the operating theater during total hip replacement and prepared for cementation in their fresh state, i.e., within 2 hours, in order to avoid coagulation and protein precipitation due to freezing. Femoral heads from patients with diagnoses other than primary arthrosis were excluded from this study, as well as heads with large cysts.

2–4 holes, 9.3 mm in diameter, were drilled into the upper, most sclerotic and worn part of the head, at least 15 mm apart to avoid penetration interference. After thorough cleaning of the bone by pulsatile lavage and vacuum mixing (Mitab, Sweden) of precooled cement (4 °C, Palacos®, Schering-Plough), cementation was performed (Figure 1). The cement was introduced into the holes with a standard cement gun and a special silicon nozzle to avoid leakage of cement between the cement gun and the bone, ensuring a perfect pressure transfer. The holes were cemented at predetermined pressure levels: 0.1, 0.2, and 0.3 MPa (1, 2, and 3 atm) and at 1, 2, 4, and 6 min after cement mixing in a random fashion. The pressure during cementation was recorded by a balloon catheter (Shiley, Pfizer, Howmedica, U.S.A.), filled with NaCl and placed at the very tip of the cement delivery pipe. The catheter was attached to a pressure transducer (Druck, PDCR 75, Germany) with the measuring range 0–5000 mmHg (0–0.66 MPa). The values were read both digitally and from a pen-writer (Brown Boveri Metrawatt). The time during which the cement was pressurized into the avascularized, thoroughly cleaned bone varied from 20 to 60 sec, as recorded on the pen-writer. The system was calibrated against a gold standard in the measuring range 0–3000 mmHg for accuracy and linearity (error < 2.5 percent). After curing, the bones were cut with a band saw (EMCO, Sweden) perpendicularly to the cemented holes in 2–3 mm thick slices.

Figure 1. Femoral head prepared for cementation.

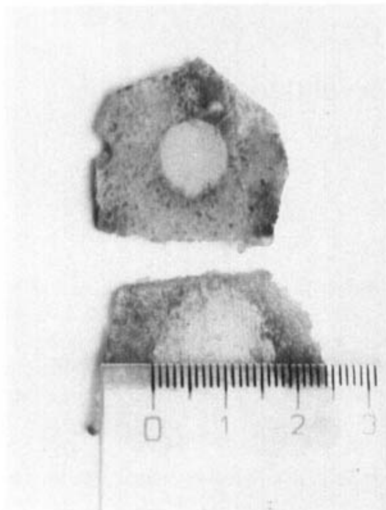

Figure 2. Bone slices showing cement penetration performed at different pressure levels and times. Above: 0.1 MPa, 4 min. Below: 0.3 MPa 2 min.

The largest diameter of the cement area and the diameter perpendicular to the first one were then measured by a Zeiss low magnification microscope (5×) with a ruler on the 2 bone slices with the largest penetration. The known size of the drill hole, 9.3 mm, was subtracted and the mean of the 4 values on each slice thus obtained gave a value for the penetration (Figure 2). All slices were measured and counted twice. Accuracy of the measurements at 95 percent confidence level was less than 0.3 mm. Preoperative radiographs were collected from the patients and the degree of sclerosis was classified on a nominal scale as nil, mild or severe, for both the acetabulum and the femoral head.

Table 1. Distribution of 85 femoral head preparations according to pressure and time after cement mixing

	Pressure (MPa)		
Time (min)	0.1	0.2	0.3
1	6	12	13
2	5	11	10
4	4	6	7
6	2	5	4

Results

The 85 cemented holes were distributed as shown in Table 1. The penetration ranged from zero to 8.1 mm. There was an excellent correlation between pressure and penetration depth ($P < 0.001$, ANOVA), and a good correlation between penetration and time after mixing ($P < 0.02$, ANOVA) (Figures 3 and 4). The mean penetration at 0.2 MPa was 2.0 mm and at 0.3 MPa just below 4 mm with the largest mean values achieved at 1 min after mixing. Best mean penetration was achieved at 0.3 MPa and 1 min (4.5 mm) and the worst at 0.1 MPa and 6 min (0.2 mm). There was no correlation between penetration and the duration of cement delivery. The radiographic classification of sclerosis was obtained for 71 of the 85 cemented holes and compared to penetration depth; no correlation was found.

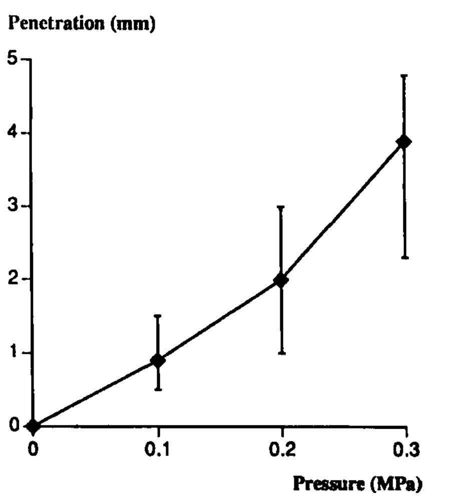

Figure 3. Relationship between penetration and pressure in 85 cancellous bone preparations. Bars indicate 25th–75th percentiles.

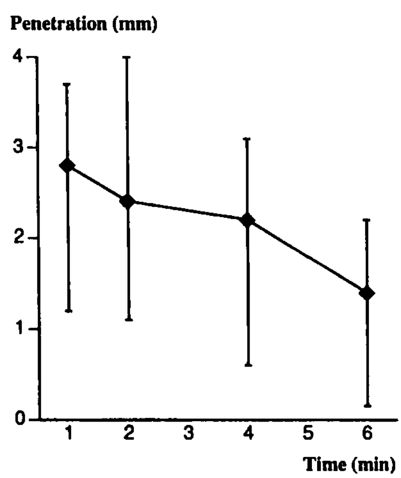

Figure 4. Relationship between penetration and time in 85 cancellous bone preparations. Bars indicate 25th–75th percentiles.

Discussion

Little is known about the mechanical properties of acetabular bone. Recently, Dalstra et al. (1993) reported that the pelvic cancellous bone is weaker than the cancellous bone from femur or tibia but their report concerned bone from normal healthy individuals. Furthermore, without the influence of circulating blood a simplification is made that does not correspond to the clinical situation (Halawa et al. 1978, Benjamin et al. 1987). The importance of time and pressure on penetration of cement into human arthrotic bone in the hip are still not understood. In our study we used Palacos® cement, which is commonly employed, and rather viscous in comparison to other cements, although the precooling makes it readily usable for injection technique (Markolf et al. 1976, Lidgren et al. 1987). A penetration of 3–5 mm is needed for good fixation of the cement into the bone trabecula in normal cancellous human bone (Krause et al. 1982, Noble and Swarts 1983). Further cement penetration is irrelevant to the mechanical stability since the trabecula under overloaded circumstances will fracture immediately outside the bone cement composite (Walker 1984). Whether this also applies to cemented anchoring-holes is unclear (Andersson et al. 1972, Eftekhar and Pawluk 1980, Finlay et al. 1986). In the acetabulum, the concept of cement penetration pertains only to the anchoring-holes and very little cement penetration will occur into the preserved subchondral bone plate. In order to achieve sufficient pressure, the acetabulum raises a special problem, since it is difficult to seal and create a closed space (Charnley 1979). Lee and Ling (1974) presented a cement compactor device with an expandable balloon, by which they managed to create a pressure level of 0.3 MPa, measured at the bottom of a prepared cadaver acetabulum. A pressurization of 1–2 min increased the cement extrusion into the trabecular bone, but they did not measure the penetration depth. To find the appropriate cement bone interdigitation, several investigators have made in vitro studies on normal cancellous bone from distal femur and proximal tibia or even on bovine bone. Krause et al. (1982) found cement penetration ranging from 1 to 3 mm into cleaned bone from the proximal tibia by finger packing. By applying a pressure of 0.17 MPa, the cement penetration increased to more than 10 mm. In agreement with our study, they found variations depending on the quality of the trabecular bone, but considerably lower pressure levels were necessary for the same cement penetration, possibly due to the softer cancellous bone in their studies. Tensile and shear strength tests showed that the deeper the penetration, the stronger the cement bone bond. Similar results were reported by Noble et al. (1983), Walker et al. (1984) and Askew et al. (1984), who applied cement under pressures varying from 0.008–0.52 MPa on prepared cancellous bone specimens from human proximal tibia and found penetration depths varying from 0.5 to more than 10 mm, with optimal strength at 3–4 mm. Oh et al. (1983) compared pressure and intrusion depth during cementation in normal, human cadaver acetabula, using finger-packing and special cement compactors for keying-holes (anchoring-holes) and found that higher pressure levels were created, using the compactor for the entire acetabulum. Since finger-packing can only elevate the cementation pressure momentarily and the duration of pressure is almost as important as the pressure level itself, a compactor was used, by which the intrusion depth for the cement into artificial drill holes was improved. This was credited to the compactors sealing off the acetabulum, thus preventing the cement from escaping. Askew et al. (1984) also found that the shorter the cement delivery duration the more the cement penetration was correlated to pressure, instead of to viscosity as tested on avascular cancellous bone. In that study the cement delivery duration varied from 5 to 30 sec. In our study the duration of cement delivery varied from 20 to 60 sec and, as expected, this time aspect had no influence. In this study we found a pressure level of at least 0.2–0.3 MPa (20–30 N/cm^2) to be necessary to achieve consistently adequate cement penetration into cancellous bone of the femoral head in the arthrotic hip. No studies have been found on human arthrotic bone, which is sclerotic and should thus be more resistant to cement penetration. This is borne out by the fact that the pressure needed per unit cement penetration was found to be considerably higher than in previous reports. The findings in this study are consistent with the hypothesis that the pressure is more important than the viscosity. Extrapolated to the clinical situation in the acetabulum, where the cement is pressurized over the entire area of 20 cm^2 of the acetabular entrance, this would create a counter-force of 400–600 N or 40–60 kg. In the operating situation this might be difficult to counteract during a time period ranging from 20–60 sec, using only muscle power and ordinary cement guns. Thus, it may not be possible to consistently achieve adequate cement penetration.

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