Acta Orthop Scand 1995; 66 (3): 234–238

Circulating blood diminishes cement penetration into cancellous bone

In vivo studies of 21 arthrotic femoral heads

Rigmor Juliusson, Gunnar Flivik, Johan Nilsson, Leif Ryd and Rolf Önnerfält

We compared the penetration depth into cancellous bone when pressurizing cement at predetermined pressure levels, and at different times after cement mixing, in 21 arthrotic femoral heads during total hip replacement. To determine the influence of circulating blood on cement penetration, cement was injected into holes drilled into the femoral head before and after osteotomy of the femoral neck. The penetration of cement increased on the average 100 percent in the absence of circulation.

Department of Orthopedics , University Hospital, Lund, Sweden. Correspondence: Dr. Gunnar Flivik , Department of Orthopedics, University Hospital, S-221 85 Lund, Sweden. Tel +46 46-17 15 10. Fax -13 07 32
Submitted 94-03-13. Accepted 95-01-24

Despite improved cementing techniques, there is still an unacceptably high rate of late aseptic loosening of the acetabular component (Mulroy and Harris 1990, Garcia-Cimbrello and Munuera 1992, Morscher 1992, Wroblewski and Siney 1992, Dall et al. 1993, Hodgkinson et al. 1993, Malchau et al. 1993). This may be due to inadequate cement penetration into the cancellous bone. Under laboratory conditions, the minimum penetration of cement needed for good fixation of the prosthesis to bone has been found to be 3–5 mm (Krause et al. 1982, Noble and Swarts 1983, Askew et al. 1984). In a previous study (Juliusson et al. 1994), we found that a pressure level of more than 0.2 MPa is needed for sufficient penetration of cement into the cancellous bone in the absence of circulation. This pressure level is hard to maintain during the 3–4 minutes needed until the start of curing of the cement. In the presence of circulation, the pressure level needed to achieve at least 3 mm of cement penetration in the human arthrotic hip is not known. We determined the influence of circulation on cement penetration into the cancellous bone in arthrotic femoral heads before and after severing of the femoral neck during total hip replacement.

Patients and methods

During 32 total hip arthroplasties because of arthrosis, cementation studies were performed. After dislocation of the femoral head, but before osteotomy of the femoral neck, a hole was drilled 10 mm in diameter and 10 mm in depth in the uppermost sclerotic part. The hole was prepared by thorough lavage and dried out with hydrogen peroxide in a routine manner. Thereafter cementation was performed with precooled vacuum-mixed cement (Palacos®, Schering-Plough), using an ordinary cement gun provided with a special silicon nipple to avoid leakage and ensure adequate pressure transfer. The pressure created in the cement gun during pressurization was recorded by a small balloon catheter (Shiley, Pfizer, Howmedica) filled with saline and inserted through a hole in the delivery pipe at the very tip of the cement gun and positioned approximately 5–10 mm proximal to the tip to avoid squeezing effects between the balloon and the nipple (Juliusson et al. 1994). The balloon catheter was attached to a transducer (Druck, PDCR 75) with a measuring range of 0–5000 mmHg (0–0.66 MPa). The values were read digitally and recorded by a pen writer (Brown Boveri Metrawatt, speed 30 mm/min). The system was calibrated against a gold standard in the range of 0–3000 mmHg for linearity and accuracy (error < 2.5 percent). The holes were cemented with a standardized application time of about 20 sec according to a random schedule at pressure levels of 0.1, 0.2, and 0.3 MPa (1, 2, and 3 atmospheres) and at 1, 2, and 4 min after cement mixing (Table 1). After 4 min, it is generally assumed that no cementation should be done because of the viscosity of the cement. The over-all project, of which this study was a part, was accepted by the local ethics committee.

Table 1. Distribution of 21 femoral heads according to time after mixing and level of cementation pressure

	Pressure (MPa)		
Time (min)	0.1	0.2	0.3
1	3	2	3
2	3	2	3
3	2	2	2

After this first cementation procedure, the femoral head was removed and the procedure was repeated in exactly the same way, at the same pressure levels and the same times after mixing in a drill hole created at least 15 mm apart from the first one, also in the same sclerotic part of the femoral head, to achieve comparable conditions. The holes were meticulously marked in order to ensure identification after complete processing.

After curing, two blocks of bone, each containing one hole and surrounding bone, were prepared from the femoral heads. These bone blocks were cut in 2–3 mm thick slices by a band saw perpendicular to the cemented holes. To determine the mean value of cement penetration in each block, the diameter of the cement mass was measured in a low magnification microscope (5×) on the two slices with the largest penetration area and the calculations were performed according to the formula:

$((D_1+D_1^{90°}+D_2+D_2^{90°}) / 4–10) / 2$, where D_1 and D_2 are the two maximum diameters of the slices and $D_1^{90°}$ and $D_2^{90°}$ are the diameters at 90° angles to the maximum diameters. The 10 in the formula is the diameter of the drill hole; it was subtracted from the mean. The result was divided by 2 to arrive at the penetration on each side of the drill hole. Measurements are given in mm. All slices were measured and counted twice in a blind manner. Accuracy of measurements at 95 percent confidence level was better than 0.3 mm. Because of technical difficulties with the pressure recordings, 11 holes had to be excluded and the results were based on the remaining 21 femoral heads with a complete set of data.

Results

The cement penetration ranged from 0.1 mm to 4.6 mm among those that were cemented in the presence of circulation, and between 0.8 and 8.2 mm among those that were cemented in the absence of circulation (Table 2). The overall results showed less penetration in the holes cemented in the presence of circulation within every pair, at all pressure levels and all mixing times (Figures 1 and 2). The mean difference was 50 percent and ranged from 20 to 80 percent ($p < 0.0001$, paired t-test). There was a strong correlation between the penetrations with or without circulation in the individual heads (Figure 3, r^2 0.7, $p < 0.0001$, regression analysis). The regression line shows that per every unit of penetration with circulation there were 1.2 units of penetration without circulation. At low pressures, i.e., in the low-penetration region of the regression plot, the influence of circulation was higher and the intersection with the ordinate was at 1.4 mm (Figure 3). This tendency for less influence at higher pressures was, however, insignificant (ANOVA). The penetration depth increased with the pressure level, as found in a previous study (Juliusson et al. 1994). No correlation between penetration and time after mixing was found (Figure 2).

Table 2. Observations in 21 femoral heads cemented with and without blood circulation

A	B	C	D	E	F	G	H
1	M	67	1	0.1	0.60	1.00	0.60
2	F	66	1	0.1	0.25	0.80	0.31
3	F	64	1	0.1	2.00	2.40	0.83
4	F	66	1	0.2	1.60	2.00	0.80
5	F	67	1	0.2	1.10	4.10	0.27
6	M	74	1	0.3	0.50	2.60	0.19
7	F	64	1	0.3	2.30	4.00	0.58
8	M	71	2	0.1	0.50	1.00	0.50
9	F	60	2	0.1	0.10	1.70	0.06
10	F	81	2	0.1	0.10	3.20	0.03
11	F	66	2	0.2	4.10	6.30	0.65
12	M	69	2	0.2	0.60	3.00	0.20
13	M	77	2	0.3	3.20	4.60	0.70
14	F	75	2	0.3	4.10	8.20	0.50
15	M	50	2	0.3	2.10	2.60	0.81
16	F	71	4	0.1	0.12	1.20	0.10
17	M	72	4	0.1	1.50	3.40	0.44
18	M	67	4	0.2	1.40	2.00	0.70
19	F	76	4	0.2	1.00	3.80	0.26
20	F	65	4	0.3	4.60	7.20	0.64
21	M	68	4	0.3	0.70	4.00	0.18

A Case
B Gender
C Age
D Mixing time, min
E Pressure, MPa
F Penetration with circulation, mm
G Penetration without circulation, mm
H Quotient: penetration with/without circulation

Discussion

The first cementation was performed on the femoral heads before severing the femoral neck and it was assumed that the circulation to the femoral head was intact. It is, however, conceivable that the circulation was disturbed by dislocating the head out of the ace-

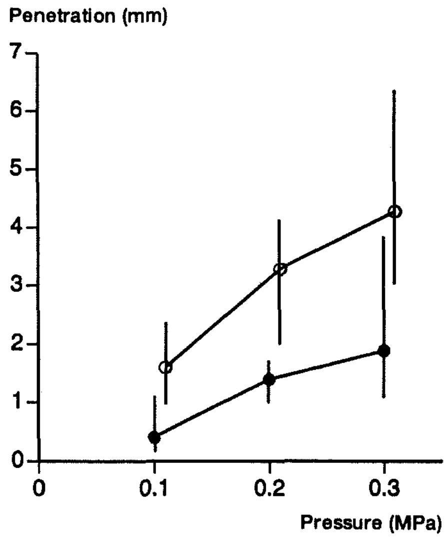

Figure 1. Diagram showing the relation between pressure and cement penetration for 21 femoral heads cemented with or without circulation. Bars represent 25–75 percentiles (● with circulation, ○ without circulation).

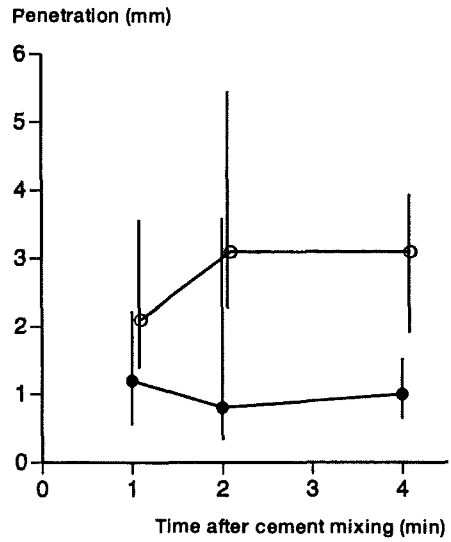

Figure 2. Diagram showing the relation between time after cement mixing and cement penetration for 21 femoral heads cemented with or without circulation. Bars represent 25–75 percentiles (● with circulation, ○ without circulation).

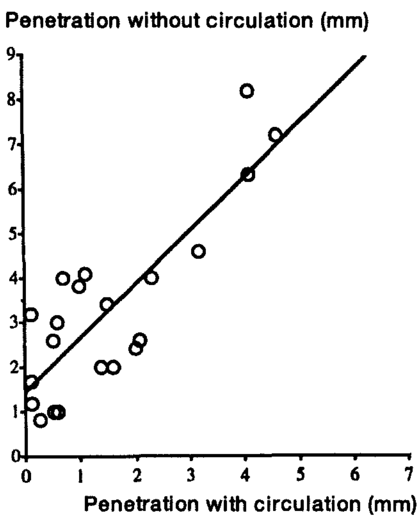

Figure 3. Diagram showing the regression line of cement penetration for 21 femoral heads cemented with and without circulation ($y = 1.4 + 1.2x$; $r^2 = 0.70$).

tabulum either by arterial compression or by venous congestion. No attempt was made to assess this factor. Moreover, because of the arthrosis with the development of sclerotic bone and cysts, the circulation was probably not normal. There was, however, a slow oozing of blood from most holes in much the same way as bleeding from the acetabular bone occurs.

It has been shown that it is extremely important to prepare the bone surfaces thoroughly prior to pressurizing the cement to achieve sufficient cement penetration (Krause et al. 1982, Russotti et al. 1988, Shelley and Wroblewski 1988, Pearse et al. 1992, Majkowski et al. 1993). These maneuvers were also performed in this study; the drill holes were thoroughly rinsed with pulsatile lavage and also treated with hydrogen peroxide to reduce the bleeding to a minimum before cementation (Hankin et al. 1984). Despite these facts, the penetration depth of the cement into the cancellous bone was substantially affected in comparison to the avascularized condition.

We have previously suggested (Juliusson et al. 1994) that adequate cement pressurizing in the acetabulum is hard to achieve in the clinical situation and suggested that the systems presently in use are less than optimal. Yet, it has been shown that attempts at pressurizing the cement reduce the revision rate (Malchau et al. 1993). These findings indicate that adequate pressurization is an important factor for the longevity of hip implants and that even better results can be achieved with further improvement of the technique.

In the acetabulum, there is some continuous bleeding during the whole procedure. It is known that the circulation of blood exerts a counter-pressure on the cement and, because of this fact, the cement can be displaced by the circulating blood. In an in vitro study Benjamin et al. (1987) found that blood under a pressure corresponding to 28 mmHg (0.004 MPa) could displace cement in a cylinder up to 7 min after mixing. They used Simplex (Howmedica) cement which has a lower viscosity during the first 3 min after mixing, but has a shorter curing time than the Palacos® used in our study. Because of this fact, the pressurization of the cement has to be maintained during its early low viscous phase, the precise period depends on the viscosity and curing time for the cement. In this experiment, we used Palacos®, which is a cement of comparably high viscosity. This fact was, however, somewhat compensated for by our use of the cement in a pre-cooled state. It is expected that the lower the viscosity the better the penetration depth at the same cementing pressures and mixing times, but also that the blood pressure more easily can reject the cement (Markolf et al. 1984, Rey et al. 1987). Interestingly, no difference was shown in the survival of the components in the hip joint whether low- or high-viscosity cement had been used (Mjöberg et al. 1990, Carlsson et al. 1993).

It has been shown that a cement penetration of 3–5 mm is necessary to achieve proper three-dimensional interlocking (Krause et al 1982, Noble and Swarts 1983, Askew et al. 1984). We have previously shown that a pressure of 0.2–0.3 MPa (1500–2300 mmHg) is needed to achieve such penetration in the avascular human arthrotic femoral head and these results were corroborated in this study. Our study shows that in the presence of circulation, the penetration decreases by approximately 50 percent. This is extraordinary, considering the fact that the intraosseous pressure is 25–30 mmHg (Wisbech-Pedersen et al. 1989), or is less than 5 percent of the cementation pressure used in this study. Even though it has been shown that blood perfusion decreases or disappears endosteally close to the cement-penetrated area after the introduction of cement (Stürup et al. 1990), there are still blood and bone marrow products oozing through the cancellous bone while we inject the cement through the drilled anchoring holes. Our results indicate that it is not the blood pressure in itself but rather the presence of fluid which is important. The finding that the influence of the circulation was larger the lower the pressure applied supports this view. It is thus the volume of fluid which is trapped between the bony trabecula with patent circulation and has to be displaced by the intruding cement which is the culprit. The finding thus corresponds to the accepted view that lavage of a bone bed yields better penetration and fixation. With circulation, the bone bed is again filled with blood. The pressure at which this occurs is of less importance. This trapped fluid probably accounts for most of the effects of circulation in the present study. The results of this study concern arthrotic bone, which is harder and more resistant to pressurization of the cement than, for instance, bone in rheumatoid patients (Önsten et al. 1993), where the pressure needed for sufficient penetration is expected to be lower.

In conclusion, we have found that cement penetration increases by approximately 100 percent in the absence of circulation. We believe that the influence of circulation is due to incompressibility of fluid and lack of escape routes rather than to the blood pressure itself. The influence of circulating blood is thus an important factor that affects the possibility of obtaining an adequate penetration of cement into cancellous bone,and a higher cementation pressure is therefore probably desirable.

Acknowledgements

This study was performed with support from Alfred Österlunds Stiftelse, Greta och Johan Kocks Stiftelse, Konung Gustav V 80-year Foundation, Stiftelsen Bistånd åt Vanföra i Skåne, Lund University Medical Faculty and the Medical Research Council 09509-01. We also thank Bohuslandstinget and Mölndals sjukhus for support.

References

Askew M J, Steege J W, Lewis J L, Ranieri J R, Wixson R L. Effect of cement pressure and bone strength on polymethylmethacrylate fixation. J Orthop Res 1984; 1: 412-20.

Benjamin J B, Gie G A, Lee A J C, Ling R S M, Volz R G. Cementing technique and the effects of bleeding. J Bone Joint Surg (Br) 1987; 69: 620–4.

Carlsson Å S, Nilsson J-Å, Blomgren G, Josefsson G, Lindberg L T, Önnerfält R. Low- vs high-viscosity cement in hip arthroplasty. Acta Orthop Scand 1993; 64: 257–62.

Dall D M, Learmonth I D, Solomon M, Davenport J M. 811 Charnley hips followed for 3–17 years. Acta Orthop Scand 1993; 64: 252–6.

Garcia-Cimbrello G, Munuera L. Early and late loosening of the acetabular cup after low-friction arthroplasty. J Bone Joint Surg (Am) 1992; 74: 1119–29.

Hankin F M, Campbell S E, Goldstein S A, Matthews L S. Hydrogen peroxide as a topical hemostatic agent. Clin Orthop 1984; 186: 244–8.

Hodgkinson J P, Maskell A P, Ashok P, Wroblewski B M. Flanged acetabular components in cemented Charnley hip arthroplasty. J Bone Joint Surg (Br) 1993; 75: 464–7.

Juliusson R, Ryd L, Arve J. Cementation pressure in arthroplasty. In vitro study of cement penetration into femoral heads. Acta Orthop Scand 1994; 65 (2): 131–4.

Krause W R, Krug W, Miller J. Strength of the cement-bone interface. Clin Orthop 1982; 163: 290–9.

Majkowski R S, Miles A W, Bannister G C, Perkins J, Taylor G J S. Bonesurface preparation in cemented joint replacement. J Bone Joint Surg (Br) 1993; 75: 459–63.

Malchau H, Herberts P, Ahnfelt L. Prognosis of total hip replacement in Sweden: Follow-up of 92,675 operations performed 1978–1990. Acta Orthop Scand 1993; 64 (5): 497–506.

Markolf K L, Kabo J M, Stoller D W, Zager S A, Amstutz H C. Flow characteristics of acrylic bone cements. Clin Orthop 1984; 183: 246–54.

Mjöberg B, Franzen H, Selvik G. Early detection of prosthetic-hip loosening. Comparison of low- and high-viscosity bone cement. Acta Orthop Scand 1990; 61: 273–4.

Morscher E W. Current status of acetabular fixation in primary total hip arthroplasty. Clin. Orthop 1992; 274: 172–93.

Mulroy R D, Harris W H. The effect of improved cementing techniques on component loosening in total hip replacement. J Bone Joint Surg (Br) 1990; 72: 757–60.

Noble P C, Swarts E. Penetration of acrylic bone cements into cancellous bone. Acta Orthop Scand 1983; 54: 566–73.

Pearse M F, Ward T J, Smith E J. Cementing techniques in total hip replacement. Surgery 1992; 10: 278–80.

Rey R M J, Paiement G D, McGann W M, Jasty M, Harrigan T P, Burke D W, Harris W H. A study of intrusion characteristics of low-viscosity cement Simplex-P and Palacos cements in a bovine cancellous bone model. Clin Orthop 1987; 215: 272–8.

Russotti G M, Coventry M B, Stauffer R N. Cemented total hip arthroplasty with contemporary techniques. A five-year minimum follow-up study. Clin Orthop 1988; 235: 141–7.

Shelley P, Wroblewski B M. Socket design and cement pressurisation in the Charnley low-friction arthroplasty. J Bone Joint Surg (Br) 1988; 70: 358–63.

Stürup J, Madsen J, Tøndevold E, Jensen J S. Decreased blood perfusion in canine tibial diaphysis after filling with acrylic bone cement compared with inert bone wax. Acta Orthop Scand 1990; 61: 143–7.

Wisbech-Pedersen N, Kiær T, Damgaard Kristensen K, Starklint H. Intraosseous pressure, oxygenation and histology in arthrosis and osteonecrosis of the hip. Acta Orthop Scand 1989; 60 (4): 415–7.

Wroblewski B M, Siney P D. Charnley low-friction arthroplasty in the young patient. Clin Orthop 1992; 285: 45–7.

Önsten I, Bengnér U, Besjakov J. Socket migration after Charnley arthroplasty in rheumatoid arthritis and osteoarthritis. J Bone Joint Surg (Br) 1993; 75: 677–80.