Acetabular cementing technique in THA—flanged versus unflanged cups, cadaver experiments

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Background There are few studies on the effect of acetabular cup design on cement penetration.

Material and methods We evaluated the effects of an acetabular flange on cement pressurization and cement penetration in 12 cadavers. Flanged or unflanged cups were implanted in paired human acetabula with simulated intraosseous bleeding pressure but without cement pressurization before insertion of the cup. Three pressure transducers were used to record intra-acetabular peak and average pressures during cup insertion. Following implantation, the whole specimens were AP-radiographed and standardized sections through the acetabula were microradiographed to evaluate cement penetration.

Results Flanged cups produced greater intra-acetabular peak pressures than unflanged cups, but did not increase the average intra-acetabular pressure. Cement penetration did not differ significantly between the two groups.

Interpretation Our findings do not support the use of flanged cups as the sole means of cement pressurization in the acetabulum.

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Modern cementing techniques have contributed to improved long-term results in total hip arthroplasty (THA). Meticulous bone preparation, bone lavage and cement pressurization as well as new implant designs improve cement penetration, increase the stability of the bone-cement interface and consequently lengthen the lifetime of femoral (Roberts et al. 1986, Mulroy and Harris 1990, Ballard et al. 1994, Ritter et al. 1999, Alho et al. 2000) and, less evidently, acetabular components (Ranawat et al. 1988, 1995, 1997, Wroblewski and Siney 1993).

Aseptic loosening of the acetabular component is the most common reason for revision surgery (Schulte et al. 1993, Sochart and Porter 1997, Wroblewski et al. 1999, Callaghan et al. 2000). However, most basic research studies regarding cementing technique are focused on the proximal femur and the femoral component of THA (Bean et al. 1988, McDonald et al. 1993, Oates et al. 1995, Breusch et al. 2000, 2001a, b). There have been few basic research studies addressing the effect of cementing technique on cement pressurization and penetration in the acetabulum (Oh and Harris 1982, Oh et al. 1983, 1985, Somville et al. 1987, Shelley and Wroblewski 1988). This is in part understandable since many factors, such as improved cement penetration into the cancellous bone following lavage, would be expected to apply equally in the acetabulum and proximal femur. However, the effects of implant design features, such as the flange of an acetabular cup, need to be evaluated in dedicated studies.

In 1981, Charnley designed the so-called "ogee-flanged" cup. The flange could be trimmed to seal round the acetabular rim and improve the pressurization of the cement during cup insertion. Despite early reports demonstrating positive effects in vitro (Oh et al. 1985, Shelley and Wroblewski 1988), flanged cups have not become widely accepted.

Recently, excellent long-term results using flanged cups were published (Garellick et al. 2000). The purpose of the present study was thus to re-evaluate the efficacy of flanged cups in pressurizing the acetabular cement and increasing penetration of cement into the acetabular bone using a bleeding model with human acetabula. The hypothesis to be tested was that flanged cups increase intra-acetabular pressure and consequently lead to improved cement penetration.

Materials and methods

We used 12 human cadaver pelvises without macroscopic or radiographic signs of osteoarthrosis on either side. The paired acetabula were freed of adherent soft tissue and subsequently reamed with increasing reamer sizes up to the point at which the subchondral plate remained only partially intact. Depending on the acetabular dimensions, 10–15 anchoring holes of 6–7 mm depth were made in the upper two quadrants of the acetabulum using a 4.5-mm drill. The left and right pairs had an equal amount of drill holes and an attempt was made to distribute these evenly. Finally, the acetabula were jet-lavaged (MicroAir, AAP, Germany) with 1 L saline in order to clean the cancellous bone bed.

Dyed saline solution was introduced into the bone marrow cavities via a cannulated screw inserted in the anterior inferior iliac spine. This provided a diffuse flow of saline solution into the acetabulum from the cancellous bone exposed by the reaming. By lifting the saline delivery bag to a height of approximately 1 m above the acetabulum, a bleeding pressure of 25–30 mm Hg was generated in the acetabulum. We determined the intraosseous pressure using the pressure transducers described below after sealing the acetabular cavity with a rubber glove. Three pressure transducers were mounted in standardized positions in DeLee-Charnley zones I, II and III within the acetabulum such that the sensing membrane at the tip of the transducer was level with the surface of the exposed cancellous bone (Figure 1). The transducers were connected to a PC-based data logger, allowing continuous measurement and permanent storage of the pressures generated during implantation of the acetabular component.

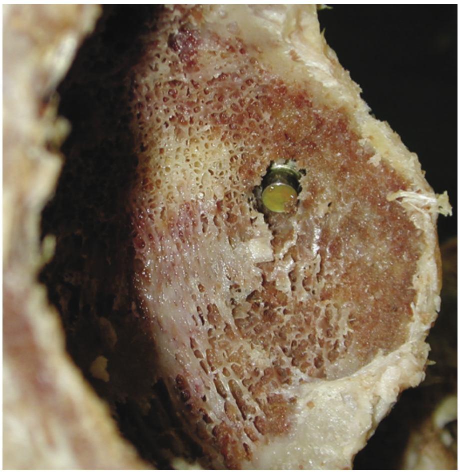
Figure 1. Pressure tansducer tip within the acetabulum in situ.

All specimens were cemented under standardized conditions by the senior author (SJB) using CMW 2000 cement (DePuy, Germany). The left and right acetabula were randomly allocated to receive either a flanged cup (Ogee Cup, DePuy, Germany) or an unflanged cup (standard Exeter Cup, Howmedica, Germany). The cup sizes were selected according to the reamed size of the acetabular cavity.

According to the principle of flanged cups, the flanges were trimmed manually before insertion to fit snugly inside the outer rim of the acetabulum.

CMW 2000 cement was mixed by hand in an open bowl following the recommendations of the manufacturer. At approximately 2.5 min after mixing, the cement was placed in the acetabulum by hand and then the cup was implanted at approximately 3 min after mixing. No additional, preceeding pressurization was performed to allow for standardization and evaluation of cup design as an influential factor. The force applied to the cup was controlled using a calibrated spring-loaded device and varied between 60 and 100 N. Priority was given to ensuring that adequate cement mantle thickness was maintained and that “bottoming-out” of the cup was avoided. The intra-acetabular cement pressures were recorded until the cement was considered cured, approximately 4 min after cup insertion (7 min from mixing). Peak and average pressures were extracted from the raw data after testing. We determined average pressures

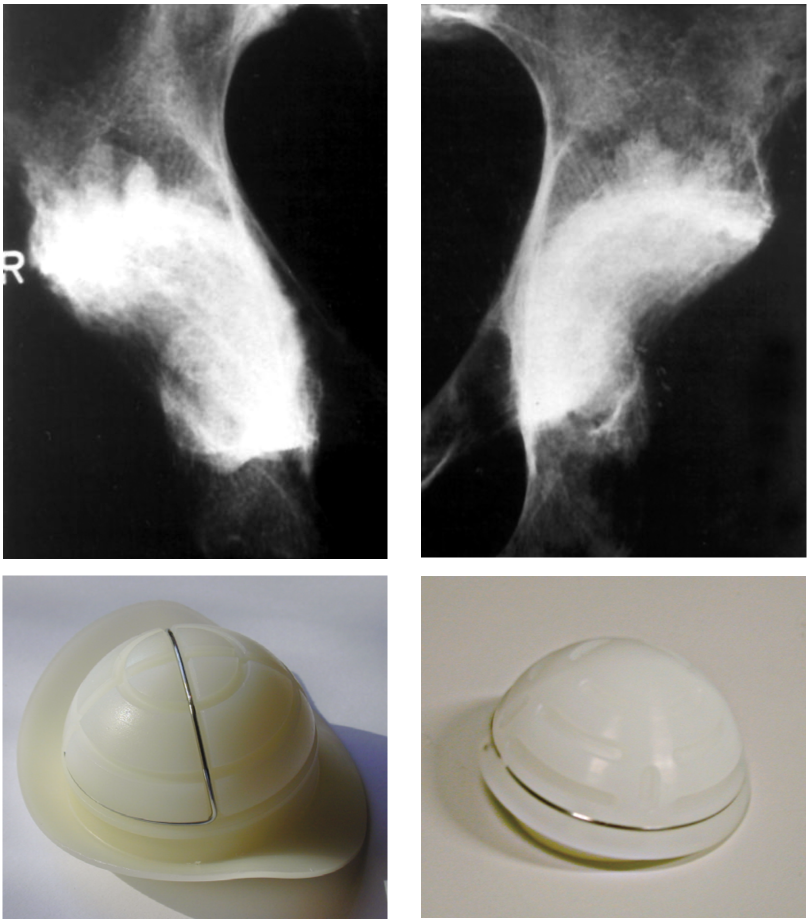

Figure 2. AP radiographs of the paired hemipelvices after cup implantation (right: unflanged cup, left: flanged cup). Note that orientation wires had been removed before insertion.

by computing the area of the pressure versus time curves corresponding to cup implantation by numerical integration and then dividing that area by the time during which the cup was being implanted.

Following cup implantation, AP radiographs were taken to evaluate the thickness of the cement mantle and to obtain evidence of radiolucency in each of the three zones of DeLee and Charnley (1976) (Figure 2). We classified the extent and width of demarcation at the cement bone interface into four grades, as described by Hodgkinson et al. (1993). The specimens were then cut into 3-mm thick sections using a diamond saw. The section plane was parallel to the plane formed by the rim of the acetabulum. Microradiographs of the sections were then taken with a Faxitron machine (Rhode & Schwarz, Germany) (Figure 3).

The microradiographs were digitized with a scanner and analyzed with an image analysis software package (KS 300, Zeiss, Germany). This allowed measurement of the absolute depth of cement penetration and the percentage of cement-penetrated area by generating a defined circle around the reamed acetabular diameter and marking the cement-penetrated area within this circle. Corresponding slices were matched for reamed acetabular diameter and compared between the two groups of implants within three section areas according to their location within the acetabulum (A: outer one-third, B: middle one-third, C: inner one-third; Figure 4).

Statistics

Mean and standard deviation (SD) were calculated for all outcome values. Due to the small sample

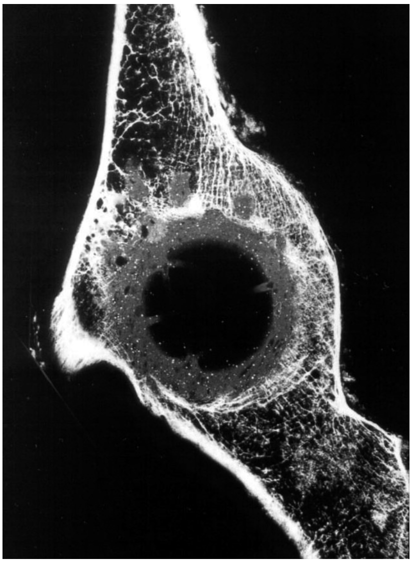

Figure 3. Microradiograph of a section made through the acetabulum.

size in the analysis of the cement penetration, median, inter-quartile range and Wilcoxon signed ranks test were also performed for validation. Paired-sample t-tests were used to determine whether the differences in means between groups were significantly different from zero. A two-tailed p-value equal to or less than 0.05 was considered to be significant. The p-values were adjusted according to the method of Bonferroni and Holm. Data analysis was performed with SPSS for Windows 10.0 (SPSS Inc. Chicago, USA).

Results

Continuous monitoring of the insertion forces applied during cup implantation showed no relevant differences between the two groups.

Intra-acetabular pressure

Implantation of the flanged cup resulted in peak pressures of 49, 79 and 52 kPa and average pressures of 13, 18 and 11 kPa in zones I, II and III, respectively. Implantation of unflanged cups resulted in peak pressures of 20, 39 and 25 kPa and average pressures of 8, 15 and 10 kPa in zones I, II and III, respectively (Table 1).

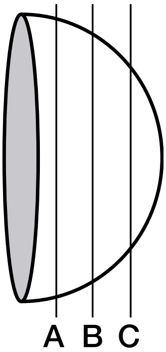

Figure 4. Section zones within the acetabulum.
A. Outer one-third
B. Middle one-third
C. Inner one-third.

Table 1. Peak and average pressures (kPa) during insertion of the cups. Values are mean (SD)

DeLee zone	N	Flanged cups	Unflanged cups	P-value [a]
Peak pressure				
1	12	48.5 (24.7)	20.2 (14.8)	0.001
2	12	78.9 (29.1)	39.4 (11.3)	< 0.001
3	12	52.5 (21.4)	25.0 (7.9)	0.002
Average pressure				
1	12	13.4 (9.5)	8.4 (6.9)	0.09
2	12	17.6 (8.7)	15.5 (8.0)	0.53
3	12	11.5 (7.7)	9.7 (4.4)	0.5

[a] P-value of mean difference, paired-sample t-test, Bonferroni-Holm adjustment

Radiographic evaluation

AP radiographs of the specimens revealed radiolucent lines in 4 of 24 acetabula – 2 within each group (unflanged and flanged cups). The radiolucent lines were all located within DeLee-Charnley zone I, ranging in length from 0.7 to 1.4 cm. They were classified accordingly as grade I (Hodgkinson et al. 1993). The thickness of the cement mantle ranged from 1 to 23 mm (zone I: 2-23 mm, zone II: 3-22 mm, zone III: 1-22 mm). A thin cement mantle of < 2 mm was found in 4 specimens, all within zone III (2 unflanged, 2 flanged cups). A borderline thickness of the penetrated cement of 2 mm was found in 8 specimens; in 3 cases within zone I, and in 6 cases within zone III (one within both). An unflanged cup was used in 5 of these specimens (including the one with involvement of 2 zones) and a flanged cup in 3.

Table 2. Comparison of the percentage of cement-penetrated areas. Values are mean (SD) and (median ± interquartile range)

Section zone	N	Flanged cups		Unflanged cups		P-value [a]
A (outer zone)	11	30 (8.8)	(30 ± 13)	30 (7.4)	(29 ± 6.1)	0.9
B (middle zone)	10	36 (8.5)	(35 ± 8.8)	33 (8.4)	(34 ± 9.7)	0.5
C (inner zone)	5	48 (22)	(46 ± 36)	41 (12)	(36 ± 22)	0.6

[a] P-value of mean difference, paired-sample t-test, Bonferroni-Holm adjustment.

Table 3. Comparison of the absolute depth of cement penetration in mm. Values are mean (SD) and (median ± interquartile range)

Section zone	N	Flanged cups		Unflanged cups		P-value [a]
A (outer zone)	11	2.5 (0.7)	(2.6 ± 1.1)	2.5 (0.6)	(2.4 ± 0.5)	0.9
B (middle zone)	10	3.0 (0.7)	(2.9 ± 1.0)	2.7 (0.6)	(2.7 ± 0.9)	0.3
C (inner zone)	5	3.9 (1.7)	(3.5 ± 2.7)	3.3 (0.9)	(3.1 ± 1.7)	0.6

[a] P-value of mean difference, paired-sample t-test, Bonferroni-Holm adjustment.

Cement penetration

The percentage of the cement-penetrated area and also the absolute depth of cement penetration were similar in all three section zones (A, B and C) using flanged or unflanged cups (Tables 2 and 3).

Discussion

The theoretical advantage of a flanged cup is obvious. The continuous flange restricts the size of the region through which cement can escape during cup insertion, thus increasing pressure in the cement. Early in vitro studies confirmed the efficacy of the flange and the authors recommended its use. Oh et al. (1985) used a “simulated acetabulum” which allowed the cup flange to be inserted flush with the surface. These authors concluded that a cup with a continuous flange generated significantly higher cement pressures and greater intrusion depths as compared to other cups. However, very large forces were generated by the testing machine used to insert the cup, probably ten times the force a surgeon would be capable of sustaining for the period of cement polymerization. In addition, intra-acetabular bleeding was not simulated. Shelley et al. (1988) used “acetabulum-shaped cavities with simulated cancellous bone”. The cup was inserted with a continuous force of approximately 80 N. Constant back-pressure of 25 mm Hg was applied to simulate the intraosseous blood pressure. Flanged cups were found to produce higher peak pressures and also higher intruded cement volumes compared to unflanged cups.

Our study did not reveal a significant effect on cement penetration of a flanged compared to an unflanged cup, however. We can only speculate on the reasons for this discrepancy. One possibility is that we used paired human acetabula, which, unlike the previous studies (Oh et al. 1985, Shelley and Wroblewski 1988), do not exclude the possible effects of the irregularities in the acetabular rim, which may have a detrimental effect on the theoretically convincing sealing action of the flange. Secondly, we used a “realistic” insertion force of approximately 80 N and decided against a robotic insertion set-up, as used by Oh et al. (1985) and Shelley and Wroblewski (1988). This is because in the operative situation, the surgeon must control the position of the cup as well as the pressurization of the cement to avoid “bottoming-out”, which in some circumstances may necessitate reduction of the force applied to the cup. Bottoming-out and also friction of the cup flange on the sides of the acetabular cavities may have an important influence on the pressure measurements (Shelley and Wroblewski 1988). On the other hand, the variability of the insertion force induced by the surgeon within the above-mentioned ranges may provide a bias. This must be taken into consideration when interpreting our results.

In addition, simulation of an intraosseous blood flow is now viewed as being mandatory when evaluating cementing techniques (Benjamin et al. 1987, Bannister and Miles 1988, Majkowski et al. 1994), since it has been shown that intramedullary bleeding pressure of only 27 mm Hg is enough to force blood between cement and bone and to reduce cement penetration (Shelley and Wroblewski 1988).

Finally, to our knowledge, this is the first study to simultaneously evaluate both intra-acetabular pressures and the clinically more important cement penetration in cadaveric acetabula. While it was possible to demonstrate that flanged cups increase the peak intra-acetabular pressure, as previously reported (Oh et al. 1985), in this more realistic simulation of surgical practice they do not improve sustained pressurization over the whole cup implantation process. Sustained pressurization, however, has been reported to be much more effective in causing intrusion of the visco-elastic cement into the small cancellous pores (Oh et al. 1983, Markolf et al. 1984). We can only speculate about the results if we also had used pressurization prior to cup insertion. We refrained from this measure (step) to faciliate comparison of cup design. However, we do regard prior sustained pressurization to be mandatory; the surgeon should not rely on the implant to achieve adequate cement interlock.

The results of our study do not, therefore, support the use of flanged cups as the sole means of cement pressurization to achieve cement penetration into the cancellous bone of the acetabulum.

No competing interests declared.

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