Cement penetration in the proximal femur does not depend on broach surface finish

Steffen J Breusch[1], Timothy L Norman[2,3], Ian C Revie[4], Burlehard Lehner[1], Jamie T Caillouette[5], Ulrich Schneider[1], J David Blaha[2] and Martin Lukoschek[1]

Departments of [1]Orthopedic I, University of Heidelberg, Schlierbacher Landstr. 200a, DE-69118 Heidelberg, Germany. Tel/Fax +49 6221 969245. E-mail: Steffen.Breusch@urz.uni-heidelberg.de; [2]Orthopedics and [3]Mechanical and Aerospace Engineering, Musculoskeletal Research Center, West Virginia University, PO Box 9196, Morgantown, WV, 26506-9196, USA, [4]Depuy International, A Johnson & Johnson Co., St. Anthony's Road, Leeds, LS11 8DT, U.K., [5]South Coast Orthopedics and Sports Medicine, 361 Hospital Road, Suite 223, Newport Beach, CA, 92663, USA
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ABSTRACT – In a cadaver study, we prepared 29 paired human cadaver femora using 3 different broaches of identical geometry but different surface characteristics. In one group of 20 pairs, preparation with chipped-toothed broaches was compared to diamond-shaped broaches; in the other group of 9 pairs, polished tamps for compaction of cancellous bone were compared with chipped-tooth broaches. Cancellous bone was irrigated with 1 liter pulsed lavage. The specimens were embedded in specially-designed pots. Palacos R and Simplex bone cements were used. After vacuum mixing, the cement was applied in a retrograde manner and subjected to a standard pressure protocol with a constant force of 3000 N. Radiographs were taken and horizontal sections were obtained at predefined levels using a diamond saw. Microradiographs were taken, digitized and analyzed to assess cement penetration into cancellous bone. In 6 of 9 femora prepared using smooth tamps, femoral fractures occurred despite careful preparation technique. The microradiographic evaluation showed no significant morphometric differences between diamond and chipped-tooth or between polished and chipped-tooth broaches with regard to cement penetration into cancellous bone. Therefore, in the presence of pulsed lavage, one finds no significant effect of broach surface characteristics on cement penetration into cancellous bone of the proximal end of the femur.

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Even in the early days of cemented THA, the correlation between poor packing of cement and radiographic loosening was apparent (Beckenbaugh and Ilstrup 1978). The incidence of radiographic loosening in poorly cemented hips (medially and distally) was as high as 52%, compared to 5% in well seated and cemented femoral components. The introduction of an intramedullary plug allowing for cement containment and application of cement under pressure has reduced loosening (Indong et al. 1978, Harris et al. 1982, Harris and McGann 1986, Britton et al. 1996). Other clinical studies have shown the superiority of modern cementing techniques (Roberts et al. 1986, Russotti et al. 1988, Mulroy and Harris 1990, Barrack et al. 1992, Schmalzried and Harris 1993, Ballard et al. 1994, Oishi et al. 1994, Breusch and Draenert 1997).

The results of the Swedish Hip Register (Malchau et al. 1993, Malchau and Herberts 1998) have furthermore confirmed that modern cementing techniques are important with regard to long-term implant survival. With the use of jet-lavage, proximal seal and distal plug, the risk of stem revision is reduced by approximately 20% each. These modern techniques of cement application aim to improve the interdigitation between bone and cement thus creating a more durable interface. With increased depth of cement penetration, the strength of the cement-bone interface is enhanced (Halawa et al. 1978, Krause et al. 1982, Panjabi et al. 1986, MacDonald et al. 1993, Mann et al. 1997). Pressurization and lavage of cancellous bone have been found to be significant factors

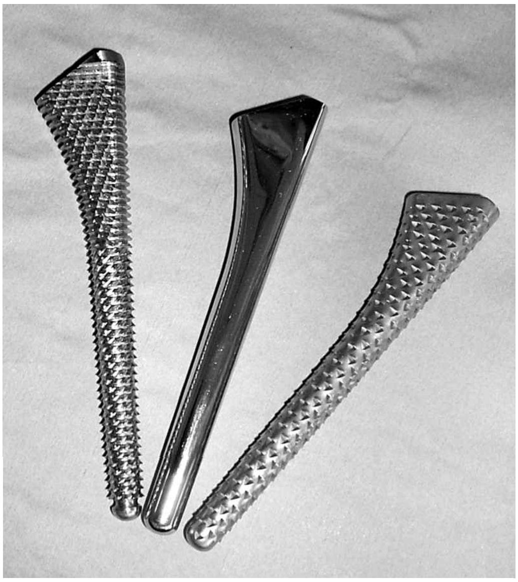

Figure 1. Three different broach configurations used in this study: diamond tooth (left), polished tamp (middle) and chipped tooth (right).

with regard to improved cement penetration and, in consequence, improved shear strength (Markolf and Amstutz 1976, Halawa et al. 1978, Lee and Ling 1981, Krause et al. 1982, Noble and Espley 1982, Askew et al. 1984, Panjabi et al. 1986, Bannister and Miles 1988, MacDonald et al. 1993, Majkowski et al. 1993, Mann et al. 1997).

However, little is known as to how the cement penetration is affected by various bone/canal preparation techniques (DiGiovanni et al. 1999). In Europe, chipped-tooth broaches are widely used whereas in the United States, diamond-tooth broaches are commoner. From the theoretical standpoint, sharp broaches should provide a more cleanly cut bone bed. In contrast, one would expect more debris generation, in particular with diamond-shaped teeth, and a greater degree of bone compaction with the use of less sharp, chipped-tooth broach surfaces. Recently, it has been suggested from in vitro studies (Chareancholvanich et al. 1998a) that in cemented femoral stems, both cement penetration and primary stability are improved by bone compaction techniques, using smooth, polished tamps for canal preparation. However, this seems difficult to imagine as occlusion of the cancellous spaces with debris should limit the depth of cement penetration.

To clarify these questions, we studied the effect of broach surface finish on cement penetration into human bone in a standardized model using jet-lavage.

Material and methods

This was a joint study with the University of Heidelberg (UH), Heidelberg, Germany and West Virginia University (WVU), Morgantown, WV, USA. Three broach surface characteristics were investigated (Figure 1): diamond tooth, chipped tooth and polished tamps. All broaches were manufactured from 316 stainless steel and were identical with respect to geometry. Three sizes were used. The polished broach blank had a surface finish of 0.1 micrometers Ra. The chipped-tooth broach had teeth at a spacing of 4 mm across the surface with the tooth formed as a raised burr on the surface of 0.5 mm. The diamond-tooth pattern was a ground-tooth pattern, cut into the broach surface with a zero degree cutting face relieved at 60 degrees on its back face. These teeth were cut perpendicular to the longitudinal direction of the broach and had a 45 degree channel cut on the surface to generate the diamond-tooth pattern.

In total, 29 paired human cadaver femora were retrieved for this study (Table 1). 5 pairs were fresh frozen and 24 formalin-fixed. Radiographs were taken of all pairs and the Cortical Index (CI)

Table 1. Test matrix of experimental configurations

Pairs	Specimens	Broach surface	Mixing sytem	Bone cement
1–10 (Heidelberg)	Formalin fixed	Chipped versus diamond	Optivac	Palacos R
11–19 (Heidelberg)	Formalin fixed	Chipped versus polished tamps	Optivac	Palacos R
20–24 (Heidelberg)	Fresh frozen	Chipped versus diamond	Optivac	Palacos R
25–29 (Morgantown)	Formalin fixed	Chipped versus diamond	Cemvac	Simplex

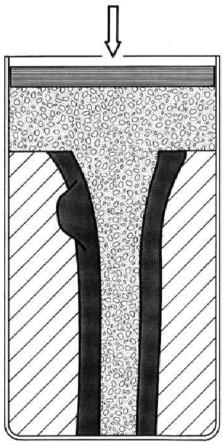

Figure 2. Experimental configuration of a femur embedded in a canister using plaster of Paris. Bone cement is placed in the femoral canal and up to the top of the canister. A 3000 N load is applied to the canister lid, pressurizing the femoral canal in a controlled manner and allowing for standardized cement pressurization.

(Gruen 1997) determined to ensure equal femoral configuration. Templates were used to measure the broach size prior to canal preparation. In each pair, a broach size was chosen to preserve a minimum mantle of cancellous bone of 3 mm.

Bone cements commonly utilized in the US and Germany were used in this study including Simplex P (Howmedica-Stryker) and Palacos R (Biomet-Merck) (Table 1). Optivac vacuum mixing systems (Scandimed) were used at UH and Cemvac systems (Depuy/Johnson & Johnson) were used at WVU. Palacos R was prechilled at 4 °C prior to mixing. The mixing protocols followed the manufacturers' recommendations.

On all specimens, experienced orthopedic surgeons (SJB and JDB) performed a femoral neck osteotomy with use of an oscillating saw. Care was taken to ensure identical levels of resection of left and right specimens. The femoral canal was then opened using a T-handled starting hand reamer and the canal was broached to the selected size. Care was taken to align the broach correctly so as to achieve identical stereometric cavities within the paired groups. To minimize the risk of fracture, the smallest chipped-tooth broach was used as a starting broach in the polished tamp group. Again care was taken to align the broach correctly so as to achieve identical cavities within the paired groups. 6 proximal fissures occurred during broaching in the polished tamp group. After visualization of the fissures, the broach was removed and cerclage wires were used in 3 femora to avoid worsening the fracture. In the remaining 3, the fissures were minor. Broaching was carefully completed to the preselected broach size. The cerclage wires were left in place for the embedding process of the specimens.

After broaching, the femoral specimens were divided at the midshaft level. In a paired comparison, all bone beds were irrigated using 1 liter jet-lavage (Pulse lavage, Model L 31, Tava Surgical Instruments (UH) and a Pulse-A-Vac System, Zimmer, Inc. (WVU)) after randomized allocation in the groups. The specimens were placed in specially designed plastic pots and embedded in plaster of Paris so the proximal osteotomy was level with the plaster (Figure 2). After the plaster had set, the vacuum-mixed bone cement was applied at 2 minutes in a retrograde manner using a cement gun. No pressure was applied during the cement insertion. Hand-mixed acrylic cement was used to fill the remaining space in the pot and served as a reservoir for compression. The lid was placed manually until cement protruded from a central hole in the lid. After occluding the hole, the pots were placed in a compression device (Universalprüfmaschine Frank 81816/B No. 28742 (UH) and an MTS machine (Minneapolis, MN (WVU)) and 3000 N, corresponding to an intrafemoral pressure of 370kPa, were applied at 4 minutes after mixing. The force was maintained for 7 minutes. The force applied had been calculated and chosen according to intrafemoral pressures published previously (Engela et al. 1993, Savage et al. 1993, Song et al. 1994, McCaskie et al. 1997).

After storaging the pots for 48 hours at room temperature, the specimens were retrieved and radiographs taken. Standardized horizontal sections were then obtained from the proximal femora using a diamond saw (Figure 3). A reference section was first taken at the level of the lesser trochanter. At UH, one section proximal (+10 mm) and two sections distal (–10 mm and –20 mm) to the reference were taken. At WVU, sections were taken more proximally where trabecular bone density was greater: two sections proximal to the lesser trochanter (+5 mm and +7.5 mm) and two sections

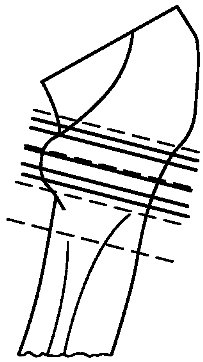

Figure 3. Locations of bone sections from harvested femora (WVU – solid line, UH – dashed line).

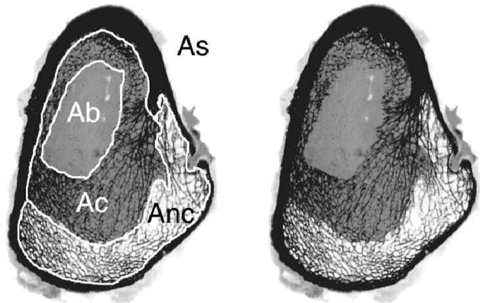

Figure 4. Microradiograph of femoral cross-section with regional definitions used in image analysis.

distal (–5 mm and –7.5 mm). Microradiographs were taken with a Faxitron machine (Model 43855C, Rhode & Schwarz (UH) and a Hewlett-Packard model 43805 (WVU)) (Figure 4).

At UH, the radiographs were digitized with a scanner and analyzed with an image analysis software (Kontron KS 300, Kontron Elektronik GmbH). At WVU, the radiographs were analyzed using a light table and image analysis software (Optimus, Edmonds, WA). The entire section area (As), the cement area without cancellous bone (Ab) (reflecting the broach cavity), the cross-sectioned area of the region of cancellous bone filled with cement (Ac) and the cross-sectioned area of the region of cancellous bone not containing cement (Anc) were measured from each image. The area of cancellous bone in the cement (Abd) was also measured as an indicator of bone quality. From the above measurements, the following parameters were determined and statistically analyzed:

$$\mathrm{CP}(\%) = \frac{\mathrm{Ac}+\mathrm{Ab}}{\mathrm{As}} \times 100 \qquad (1)$$

$$\mathrm{Rcb}(\%) = \frac{\mathrm{Ac}}{\mathrm{Anc}} \times 100 \qquad (2)$$

$$\rho\,(\%) = \frac{\mathrm{Abd}}{\mathrm{Ac}} \times 100 \qquad (3)$$

where CP is defined as cement penetration into cancellous bone, Rcb is the ratio of supported cancellous bone to unsupported cancellous bone and ρ is the trabecular bone areal density.

The statistical analysis was that of a modified split plot design in which the 2 studies (UH or WVU) were whole plots and the 2 preparations under consideration were the split plots. For the chipped-tooth versus diamond-tooth broach study, replicates were the 15 pairs of specimens used at UH and the additional five pairs of specimens used at WVU; hence, it was a modified split plot in that replicates were nested within whole plots rather than factorial to them. By taking measurements of the different sections in each specimen, we also could compare variances within specimens as well as those among specimens. There was no statistically significant evidence of heterogeneity among variances. The statistical analysis package JMP (Cary, NC) was used in the analysis.

Results

An analysis of all sections showed no significant difference in the cross-sectional areas of left or right femurs, indicating that horizontal cuts were made from the same location on femoral pairs with no consistent difference or bias (Tables 1 and 2). There were also no significant differences in bone quality as indicated by trabecular bone density, ρ, between any of the groups.

Statistical analysis revealed no significant differences between diamond and chipped-tooth broaches for the cross-sectional variables investigated (CP and Rcb) (Table 2). A pairwise comparison of sections taken at the level of the lesser trochanter shows that CP does not depend on broach type (Figure 5). There were also no significant differences in the cross-sectional variables examined

Table 2. Cross-sectional variables for chipped-tooth vs. diamond-tooth broached specimens. Results are reported as mean and *SD* with confidence interval in parentheses

Cross-sectioned variable	Chipped-tooth broach (n 20)			Diamond-tooth broach (n 20)		
ρ (%)	43	*25*	(12)	42	*21*	(9.7)
Rcb (%)	77	*69*	(32)	80	*66*	(31)
CP (%)	40	*19*	(9.0)	41	*0*	(4.8)
Cross-sectioned area (mm^2)	1415	*444*	(207)	1411	*427*	(199)

Table 3. Cross-sectioned variables for chipped-tooth vs. polished tamp broached specimens. Results are reported as mean and *SD* with confidence interval in parentheses

Cross-sectioned variable	Chipped-tooth broach (n 20)			Diamond-tooth broach (n 20)		
ρ (%)	35	*25*	(19)	39	*33*	(25)
Rcb (%)	65	*47*	(36)	67	*40*	(31)
CP (%)	34	*9.0*	(6.9)	36	*19*	(15)
Cross-sectioned area (mm^2)	1588	*330*	(254)	1591	*404*	(311)

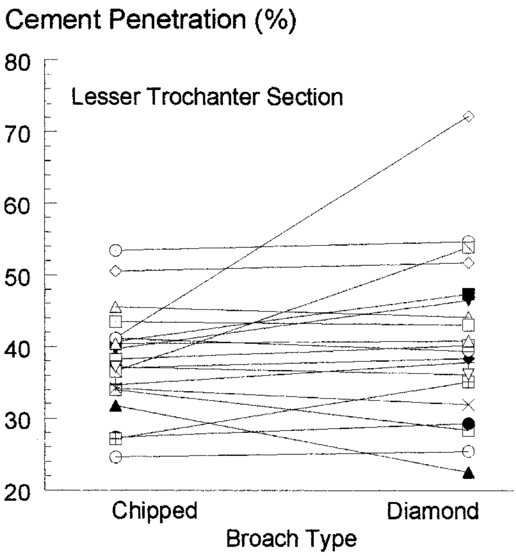

Figure 5. Cement penetration (CP) for matched femoral pairs broached using a chipped or diamond-tooth broach taken at the level of the lesser trochanter. There was no significant difference between broach type with regard to CP.

when comparing the polished tamp broached specimens with the chipped-tooth broached specimens (Table 3). A power calculation on the variables examined indicated that the power was very low, on the order of 0.05. Therefore, an experimental size of 2000 observations of each broach type would result in a power of only 0.30. Hence, there may be a real difference between the two types of broaches, but it is so small and the variability is so great that it is almost impossible to detect it.

Discussion

Interestingly, limited research has been done on the role of broach surface characterisitics with regard to cement penetration. It has been suggested from in vitro studies (Chareancholvanich et al. 1998a) that in cemented femoral stems both cement penetration and primary stability are improved with bone compaction techniques using smooth tamps for canal preparation. However, it remains unclear whether jet-lavage was used in that study. If no bone lavage was used, it is difficult to imagine why better cement penetration should occur in the presence of debris within the cancellous spaces. The sections provided in that study were also not taken at the same level. Thus direct comparison of cement penetration in the compacted and broach groups is subject to debate. Furthermore, it is of critical importance that bone cement is applied under identical conditions, in particular with equal pressure.

The pressures used in this study correspond well to the values given in the literature (Engela et al. 1993, Savage et al. 1993, Song et al. 1994, McCaskie et al. 1997). A constant load of 3000 N was applied to the lids of the pots, corresponding to an internal pressure of 370 kPa. This applied pressure was within the range reported in studies that implanted stems in cadaveric and plastic femurs and monitored pressures using transducers located at the proximal, midpoint and distal locations of the stem. In previous studies, pressures were found to vary between 30 kPa and 1080 kPa, depending on location (distal vs proximal), stem type (Charnley type versus custom stems) or time (during or postinsertion).

Our model eliminates the variable stem insertion thus allowing standardized conditions for comparison of one single factor, here broach surface characteristics. We could not confirm the findings of Chareancholvanich et al. (1998a) who suggested from in vitro studies that in cemented femoral stems cement penetration is better with bone compaction techniques using tamps for canal preparation. However, we were limited to 9 pairs of specimens to base our conclusions. Despite careful broaching, we produced 6 femoral shaft fractures of fissures which raises concern. We can only speculate as to the reason why all fractures have occurred in the polished group. Both chipped-tooth and diamond-tooth broaches remove bone, thus creating a cavity. In contrast, polished tamps have a significant compaction element to them.

We are not aware of any other study comparing chipped-tooth and diamond-tooth broach designs (Breusch et al. 2000a). With regard to cement penetration, it is important to note that in the presence of jet-lavage there is no significant difference between the two designs. Both jet-lavage systems used effectively removed remaining debris from the cancellous spaces. The lavage volume used may appear high, but it is our (UH) practice to use copious lavage for canal preparation and again immediately before cement insertion. One might expect different findings in the absence of jet-lavage, but we did not consider such an investigation as jet-lavage should be regarded important for achieving cement interdigitation with cancellous bone in cemented THA (Breusch et al. 2000b).

In contrast, for cementless femoral components, it has been shown in cadaver and animal experiments that the primary stability of stems is significantly improved in compacted bone (Chareancholvanich et al. 1998b, Green et al. 1999). Thus, theoretically, chipped-tooth broaches should be beneficial with regard to compaction of bone chips generated during broaching of the femoral canal. Further anatomical studies are required to clarify this question. Our results suggest that the broach surface is not of critical importance with regard to cement penetration if jet-lavage is used.

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