

An in-vitro investigation of the CPS-Plus femoral stem

Influence of the proximal centraliser on cement pressurisation during stem insertion

Charles Gozzard², Sabina Gheduzzi¹, Anthony W Miles¹ and Ian D Learmonth²

Departments of ¹Mechanical Engineering, University of Bath, ²Orthopaedic Surgery, University of Bristol, U.K.
Correspondence: Charles Gozzard, 67 Berkeley Road, Bishopston, Bristol BS7 8HQ, U.K. DrsGozzard@compuserve.com
Submitted 01-08-27. Accepted 02-08-09

ABSTRACT The CPS-Plus stem is designed for use with a proximal and distal stem centraliser. This in-vitro study examined the cement pressurisation achieved during insertion of the CPS-Plus femoral stem into a model femur. Cement pressures were measured at proximal, mid and distal stem levels. Pressures were recorded during insertion of the CPS-Plus stem with both proximal and distal centralisers and compared with those achieved when only a distal centraliser was used with digital occlusion of the proximal femur. The CPS-Plus with a proximal centraliser generated significantly greater cement pressures than the CPS-Plus without a proximal centraliser at proximal and mid-stem regions.

The use of a proximal stem centraliser may improve the cement-bone interdigitation and shear strength at the cement-bone interface, particularly in the region of the proximal femur.

Pressurisation of bone cement increases interdigitation of cement into bone (Halawa et al. 1978, Oh et al. 1978, Panjabi et al. 1983, Askew et al. 1984). In-vitro studies suggest that during insertion of the stem, cement pressurisation is greatest distally, with lower pressures achieved proximally (Markolf and Amstutz 1976, Bourne et al. 1984, Song et al. 1994, McCaskie et al. 1997, Reading et al. 2000). Increased interdigitation between cement and bone increases the cement-bone interface strength (Halawa et al. 1978, Oh et al. 1978, Krause et al. 1982, Bean et al. 1987, MacDonald et al. 1993, Reading et al. 2000). Blood lamination

within bone cement has largely been eliminated as cementing techniques have improved. Back-bleeding may prevent cement interdigitation into bone and maintenance of cement pressure above 10KPa is important to prevent displacement of cement by blood (Benjamin et al. 1987). The presence of blood between cement and bone reduces the shear strength of the cement-bone interface (Bannister and Miles 1988, Majkowski et al. 1994).

An inadequate cement mantle around the femoral prosthesis is associated with early loosening (Huddleston 1988, Anthony et al. 1990, Jasty 1991, Ebramzadeh et al. 1994, Ramaniraka et al. 2000). The use of a distal stem centraliser does not prevent malpositioning of the stem in the proximal femur. This may be associated with an inadequate cement mantle proximally. Use of proximal and distal centralisers improves prosthesis alignment and cement mantle thickness (Goldberg et al. 1998). The CPS-Plus stem (Endo Plus) is a cemented, polished, collarless stem, which has been introduced for use with modular methylmethacrylate proximal and distal centralisers (Figure 1). The proximal and distal stem centralisers are reported to ensure that the stem is inserted in the centre of the reamed bone envelope, resulting in an even cement mantle.

This in-vitro study investigated the cement pressurisation achieved during stem insertion. The role of the proximal stem centraliser as a possible cement pressuriser was also determined.



Figure 1. CPS-Plus femoral stems with centralisers.

Material and methods

A femoral mould for the CPS-Plus stem was manufactured using the femoral broach. The broach was covered with filling material, sanded and varnished, such that the tips of the teeth were just visible. This produced a smooth phantom of the broach. The reamed femoral canal was modelled using dental plaster moulds, supported by aluminium tubes. The proximal end of the construct was cut at a 45° angle to mimic the cut of the femoral neck. The distal end of the aluminium tube was sealed with a polyethylene plug. Dental plaster was poured into the aluminium tubes. The filled broach was inserted into the plaster using a specially constructed rig. The rig ensured a central and repeatable positioning of the broach within the plaster. On removal of the broach, a cavity for the prosthesis was formed, allowing for a cement mantle determined by the broach size. 8 pressure transducers (RS Components) were located within each mould (proximally—anterior, posterior, medial and lateral, mid-stem—medial and lateral, distally—medial and lateral). Each aluminium tube had a 3 mm diameter bleed hole drilled distal to the lowest level of pressure transducers. This allowed simulation of the escape of cement around an intra-medullary cement plug.



Figure 2. The insertion rig, with prosthesis and model femur in-situ, positioned in the Instron materials testing machine.

Bone cement (Palacos R-40, Schering-Plough Ltd) was vacuum mixed (Summit Medical In-Syringe Mixing System) according to the manufacturer's instructions. Cement insertion was performed retrogradely, using a cement gun, 2.5 min after mixing. The CPS-Plus stem was inserted after 3.5 min. The alignment rig ensured central insertion of the prosthesis into the cement. An Instron materials-testing machine was used to control the depth of the stem insertion and to maintain a constant insertion speed of 500 mm/minute (Figure 2). Laboratory temperature was maintained at 23.5 °C ± 0.5 °C. Continuous pressure recordings were collected using a computerised data acquisition system.

Pressure transducer readings were recorded at a sampling rate of 50 Hz during insertion of the prosthesis. Maximum pressure at each transducer location was recorded for each test. Median maximum pressures and the pressure range were noted.

6 sets of experiments were performed on each of

the following configurations: CPS-Plus with both a proximal and distal centraliser and CPS-Plus with only a distal centraliser combined with digital occlusion of the proximal medial femoral canal.

The statistical analysis was done using the Mann-Whitney U-test.

Results

The CPS-Plus, when used with a proximal centraliser, generated greater pressures in all proximal ($p < 0.002$) and mid-stem ($p < 0.004$) regions than when the CPS-Plus with only a distal centraliser and digital occlusion was used (Table).

Discussion

Current cementing technique involves the pressurisation of cement before insertion of the femoral stem. This prevents back-bleeding (Benjamin et al. 1987) and improves interdigitation between cement and bone (Halawa et al. 1978, Krause et al. 1982, Panjabi et al. 1983). Our study solely investigated the effect of stem insertion on cement pressurisation. Several authors have found that higher pressures are achieved during stem insertion than during cement insertion (Song et al. 1994, McCaskie et al. 1997) and that higher pressures are achieved distally than proximally (Markolf and Amstutz 1976, Bourne et al. 1984, Song et al. 1994, McCaskie et al. 1997, Reading et al. 2000). Use of a proximal stem centraliser has increased the proximal cement pressurisation while maintaining high distal cement pressures. The significance of high proximal cement pressures depends on the viscosity of the cement at the time of pressurisation. High proximal cement pressures may increase the cement-bone interdigitation and subsequent cement-bone interface strength beyond that achieved during cement pressurisation prior to stem insertion.

Previous in-vitro studies of cement pressure during stem insertion have reported pressures higher than would be expected in-vivo (Panjabi et al. 1983, Bourne et al. 1984), some have exceeded the intramedullary hydraulic bursting pressure calculated by Sakkars et al. (1995). The cement pres-

Cement pressures achieved at proximal-, mid- and distal-stem levels during insertion of the CPS-Plus with use of proximal digital occlusion or a proximal centraliser, median (range) KPa

	Proximal digital occlusion	Proximal centraliser
Proximal-stem		
Anterior	251 (127–409)	663 (497–885)
Posterior	231 (191–335)	671 (561–852)
Medial	224 (169–249)	535 (425–604)
Lateral	263 (210–363)	635 (569–785)
Mid-stem		
Medial	484 (456–682)	783 (686–957)
Lateral	502 (391–661)	788 (639–944)
Distal-stem		
Medial	445 (359–700)	520 (354–688)
Lateral	451 (280–511)	546 (368–619)

ures achieved in this study are higher than those recorded in-vivo using first generation techniques (Kallos et al. 1974). Modern cementing techniques are, however, more likely to achieve cement pressures of the same order as those attained in this study.

It is suggested that an increase in cementation pressure in-vivo increases the risk of fat emboli during cementation of the femoral stem (Kallos et al. 1974, Christie et al. 1994, Pitto et al. 1999). This risk is reduced if the femoral canal is adequately prepared, using pulsed lavage and drying, before insertion of cement (Byrick et al. 1989, Wheelwright et al. 1993).

The proximal and distal stem centralisers designed for use with the CPS-Plus are manufactured from polymethylmethacrylate. They are of a modular design. The size of the proximal centraliser varies with that of the femoral stem. The design of the proximal centraliser is such that it allows a thin film of cement to lie between the stem and the centraliser when the stem is inserted into the femur. The proximal centraliser is thus completely embedded within the cement mantle. Should the proximal centraliser be flush with the stem, it is possible that polymethylmethacrylate debris could be generated if there is motion between the centraliser and stem. This situation is similar to the debonding that occurs between polished, tapered stems and cement. Finite element analysis suggests that motion between a polished stem and cement produces less abrasive wear and

subsequent damage to the stem-cement interface than that between a roughened stem and cement (Verdonschot and Huiskes 1998). The good long-term results with polished, tapered stems (Malchau et al. 2002) suggests that such centraliser-stem contact should not lead to short-term clinical problems.

Bulky straight stems have been associated with inadequate cement mantles due to the posterior position of the stem within the femoral canal. A posterolateral point of entry in the femur is recommended for this type of stem. This may require removal of the posterolateral cortex at the point of entry of the stem. Use of only a distal stem centraliser does not prevent malalignment of the stem proximally, with the risk of an inadequate cement mantle. Use of a proximal and distal centraliser ensures central positioning of the prosthesis within the reamed bony envelope and a subsequent even cement mantle. The positioning of the stem in the anatomically curved femur is beyond the scope of this study. Current data from ongoing multi-centre clinical trials do not indicate difficulties with posterior stem positioning and inadequate cement mantles.

The results of these trials are pending; they will determine whether the increased pressurisation achieved with the proximal centraliser is translated into improved stem fixation in-vivo.

We would like to thank Mr R. Weston for his technical contribution to this study and Mr C. Foy for his advice regarding the statistical analysis. We also thank Endo Plus for supplying the femoral stems and broaches, Schering-Plough for providing the bone cement and Summit Medical for the cement mixing systems.

This project was supported by funds from the OSCOR-Lillie research fellowship.

Anthony P P, Gie G A, Howie C R, Ling R S. Localised endosteal bone lysis in relation to the femoral components of cemented total hip arthroplasties. *J Bone Joint Surg (Br)* 1990; 72: 971-9.

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.

Bannister G C, Miles A W. The influence of cementing technique and blood on the strength of the bone-cement interface. *Eng Med* 1988; 17: 131-3.

Bean D J, Convery F R, Woo S L, Lieber R L. Regional variation in shear strength of the bone-polymethylmethacrylate interface. *J Arthroplasty* 1987; 2: 293-8.

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

Bourne R B, Oh I, Harris W H. Femoral cement pressurization during total hip arthroplasty. The role of different femoral stems with reference to stem size and shape. *Clin Orthop* 1984; 183: 12-6.

Byrick R J, Bell R S, Kay J C, Waddell J P, Mullen J B. High-volume, high-pressure pulsatile lavage during cemented arthroplasty. *J Bone Joint Surg (Am)* 1989; 71:1331-6.

Christie J, Burnett R, Potts H R, Pell A C. Echocardiography of transatrial embolism during cemented and uncemented hemiarthroplasty of the hip. *J Bone Joint Surg (Br)* 1994; 76: 409-12.

Ebramzadeh E, Sarmiento A, McKellop H A, Llinas A, Gogan W. The cement mantle in total hip arthroplasty. Analysis of long-term radiographic results. *J Bone Joint Surg (Am)* 1994; 76: 77-87.

Goldberg B A, al Habbal G, Noble P C, Paravic M, Liebs T R, Tullos H S. Proximal and distal femoral centralizers in modern cemented hip arthroplasty. *Clin Orthop* 1998; 349:163-73.

Halawa M, Lee A J, Ling R S, Vangala S S. The shear strength of trabecular bone from the femur, and some factors affecting the shear strength of the cement-bone interface. *Arch Orthop Trauma Surg* 1978; 92: 19-30.

Huddleston H D. Femoral lysis after cemented hip arthroplasty. *J Arthroplasty* 1988; 3: 285-97.

Jasty M. Why cemented femoral components become loose. *Instructional Course Lectures (American Academy of Orthopaedic Surgeons)* 1991; 40: 151-9.

Kallos T, Enis J E, Gollan F, Davis J H. Intramedullary pressure and pulmonary embolism of femoral medullary contents in dogs during insertion of bone cement and a prosthesis. *J Bone Joint Surg (Am)* 1974; 56: 1363-7.

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

MacDonald W, Swarts E, Beaver R. Penetration and shear strength of cement-bone interfaces in vivo. *Clin Orthop* 1993; 286: 283-8.

Majkowski R S, Bannister G C, Miles A W. The effect of bleeding on the cement-bone interface. An experimental study. *Clin Orthop* 1994; 299: 293-7.

Malchau H, Herberts P, Eisler T, Garellick G, Söderman P. The Swedish Total Hip Replacement Register. *J Bone Joint Surg (Am) (Suppl 2)* 2002; 84: 2-20.

Markolf K L, Amstutz H C. In vitro measurement of bone-acrylic interface pressure during femoral component insertion. *Clin Orthop* 1976; 121: 60-6.

McCaskie A W, Barnes M R, Lin E, Harper W M, Gregg P J. Cement pressurisation during hip replacement. *J Bone Joint Surg (Br)* 1997; 79: 379-84.

- Oh I, Carlson C E, Tomford W W, Harris W H. Improved fixation of the femoral component after total hip replacement using a methacrylate intramedullary plug. *J Bone Joint Surg (Am)* 1978; 60: 608-13.
- Panjabi M M, Goel V, Drinkler H, Wong J, Kamire G, Walter S D. Effect of pressurization on methylmethacrylate-bone interdigitation: an in vitro study of canine femora. *J Biomech* 1983; 16: 473-80.
- Pitto R P, Koessler M, Kuehle J W. Comparison of fixation of the femoral component without cement and fixation with use of a bone-vacuum cementing technique for the prevention of fat embolism during total hip arthroplasty. A prospective, randomized clinical trial. *J Bone Joint Surg (Am)* 1999; 81: 831-43.
- Ramaniraka N A, Rakotomanana L R, Leyvraz P F. The fixation of the cemented femoral component. Effects of stem stiffness, cement thickness and roughness of the cement-bone surface. *J Bone Joint Surg (Br)* 2000; 82: 297-303.
- Reading A D, McCaskie A W, Barnes M R, Gregg P J. A comparison of 2 modern femoral cementing techniques: analysis by cement-bone interface pressure measurements, computerized image analysis, and static mechanical testing. *J Arthroplasty* 2000; 15: 479-87.
- Sakkers R J, Valkema R, de Wijn J R, Lentjes E G, van Blitterswijk C A, Rozing P M. The intramedullary hydraulic pressure tolerance of the human femur. *Clin Orthop* 1995; 311: 183-9.
- Song Y, Goodman S B, Jaffe R A. An in vitro study of femoral intramedullary pressures during hip replacement using modern cement technique. *Clin Orthop* 1994; 302: 297-304.
- Verdonschot N, Huiskes R. Surface roughness of debonded straight tapered stems in cemented THA reduces subsidence but not cement damage. *Biomaterials* 1998; 19 (19): 1773-9.
- Wheelwright E F, Byrick R J, Wigglesworth D F, Kay J C, Wong P Y, Mullen J B, Waddell J P. Hypotension during cemented arthroplasty. Relationship to cardiac output and fat embolism. *J Bone Joint Surg (Br)* 1993; 75: 715-23.