Femoral cement pressurization in hip arthroplasty

A laboratory comparison of three techniques

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Background Several cementing techniques are used for the proximal femur.

Material and methods We evaluated 3 femoral cement pressurization techniques (standard, pressurizer in situ, and thumb pressurization) in 12 plastic femurs, with 4 sets of observations for each technique. Intramedullary pressure readings were obtained using proximal and distal pressure monitoring transducers. The peak pressure and the length of time for which the pressure was above a particular cutoff level (5 KPa and 100 KPa) were compared for the different techniques.

Results We found significant differences between the 3 cementing techniques in the peak pressure and the length of time for which the pressure was above 100 KPa. The pressurizer in situ technique gave higher peak pressure ($p < 0.001$), both proximally (398) and distally (597). The standard technique produced a pressure of 100 KPa for a longer duration, both proximally and distally (mean 67 sec and 45 sec, $p < 0.001$) compared to the other two techniques (less than 5 and 17 sec for the thumb pressurization technique and the pressurizer in situ technique, respectively, both proximally and distally). Although the pressurizer in situ technique produced the highest peak pressure, the standard technique produced an optimum pressure of longer duration.

Interpretation The standard technique appears to be adequate for achievement of optimum pressurization during femoral cementing without increased risk of embolization.

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Increased pressurization of bone cement improves its penetration into trabecular bone (Davies and Harris 1993, McCaskie et al. 1997, Noble et al. 1998), increasing the strength of the cement-bone interface and possibly the longevity and performance of the implant (Panjabi et al. 1983). Bending and axial stiffness of the cement-bone composite are related linearly to penetration, and nonlinearly to cement intrusion pressure. 75% of the maximum bending and axial stiffness values were achieved with a cement intrusion pressure of 550 KPa (Panjabi et al. 1986). The intramedullary pressure during cementing the femoral canal varies between different studies from 100 KPa to 700 KPa (Panjabi et al. 1983, Davies and Harris 1993, McCaskie et al. 1997). 300 KPa cement intrusion pressure is considered to be required to achieve 3–5 mm of cement intrusion into the trabecular bone (Juliusson et al. 1994). High pressures also help to prevent back bleeding and reduce the presence of blood at the cement-bone interface (Heyse-Moore and Ling 1983). Back bleeding can displace the cement dough from bone up to 6 min after the start of mixing (Benjamin et al. 1987).

Although several reports have insisted on the importance of third-generation cementing techniques (Mulroy and Harris 1990, Noble et al. 1998, Morscher and Witz 2002), there are still several variations in the techniques of femoral cementation currently used. Cement pressurization has been assessed in vitro (Davies and Harris 1993, Song et al. 1994, McCaskie et al. 1997, Noble et al. 1998, Rice et al. 1998), as well as in vivo (Davies

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Harris 1993, McCaskie et al. 1997) with the help of appropriately placed pressure transducers. We compared three techniques of femur cementation in a laboratory setting, and assessed the effect on pressures achieved at the cement-bone interface, proximally and distally, on a sawbone femur model.

Materials and methods

We evaluated three femoral cement pressurization techniques in the laboratory using a plastic femur model. 12 femoral bone models were cemented and pressurized using three cement pressurization techniques: the standard technique, the pressurizer in situ technique, and the thumb pressurization technique. 4 sets of observations were taken for each cementing technique. The study was performed with anatomic plastic specimen femurs made up of density-7 polyurethane foam (Sawbones Europe AB, Malmö, Sweden). The femur model had a resected neck and a broached proximal cavity. A midshaft plug of the same material was sited in the medullary canal 23 cm from the tip of the greater trochanter. All models had a pre-broached canal diameter of 16 mm. Two pressure transducers (Kulite Sensors Ltd., Basingstoke, UK) were presited on the lateral surface of the femur, distally opposite the tip of the prosthesis, and proximally at the level of the lesser trochanter. The transducers were designed and calibrated to measure pressures from 0 to 1 500 KPa. The sensitivity of the whole system (transducer and computer software) was around 0.1 KPa. Two mixtures of cement (60 g each, CMW1 cement, De Puy International Ltd., Leeds, UK) were used in each test. The cement was mixed at room temperature (26–27°C) using the technique described in the manufacturer's instruction leaflet and using a Cem-Vac Ultra cementing apparatus (De Puy). The cement was introduced in the pre-reamed femoral canal using a cement gun in a retrograde fashion, 90 sec after the cement was mixed. The Elite-plus pressurizer (De Puy) was used, except for the thumb pressurization technique. The prosthesis was inserted 270 sec after the onset of mixing of cement. The prosthesis used was a plastic replica of size-3 C-stem femoral component (De Puy). The resulting plots of cement pressure (KPa) against time (sec) were obtained from both transducers.

Thumb pressurization technique

The technique was similar to the so-called second-generation cementing technique using manual (finger) pressurization (Sanchez-Sotelo et al. 2002). The cement was injected in a retrograde fashion. The gun was extracted once the canal had been fully injected with cement. Sustained pressure was applied to the proximal opening of the femur, pressing on it with the pulp of the distal phalanx of the thumb for 3 min (McCaskie et al. 1997). The prosthesis was then introduced, and manual pressure applied again to the prosthesis to prevent its extrusion due to the raised pressure in the femoral canal.

Standard technique

The standard technique was similar to the third-generation cementing technique using a plastic pressurizer (Eisler et al. 2000). The cement was injected in a retrograde fashion without blocking the proximal opening of the femoral canal with the pressurizer. The nozzle of the gun was cut to the level of the distal end of the cement pressurizer, and pressure was applied with the pressurizer at the proximal opening of the femur, with the gun still in situ. Pressure was applied for 3 min. The prosthesis was then introduced, and the pressure on the prosthesis maintained to prevent its extrusion from the canal.

Pressurizer in situ technique

The pressurizer was slid onto the nozzle of the cement gun. The nozzle was introduced into the canal until the pressurizer sat on the proximal opening of the femur. Cement was introduced in a retrograde fashion with an assistant applying steady pressure on the pressurizer. The pressure was maintained until insertion of the femoral stem, which took place 270 sec after the onset of cement mixing.

4 tests were run using each technique. All procedures were carried out by one of the authors according to the manufacturer's recommendations, and after 3 trial runs for each method.

The pressure readings were obtained from both proximal and distal femoral transducers. They

Peak pressure and duration for different pressurization methods. Mean and standard deviation (SD) are given

	Time (sec)				Peak pressure (KPa)	
	Proximal > 5 KPa	Distal > 5 KPa	Proximal > 100 KPa	Distal > 100 KPa	Proximal	Distal
Thumb pressurization technique	62 (36)	84 (56)	2.9 (1.6)	4.3 (1.8)	148 (110)	211 (117)
Standard technique	149 (13)	135 (27)	67 (30)	45 (16)	227 (65)	290 (36)
Pressurizer in situ technique	143 (69)	114 (66)	15 (3.9)	17 (3.4)	398 (40)	597 (102)
P-values (One-way ANOVA)	0.03	0.07	<0.001	<0.001	0.007	0.008

were taken for 200 sec after cement insertion had started (whereas the stem was inserted 270 sec after cement insertion). Peak pressures during cementing were measured. The lengths of time for which the intramedullary pressure was greater than 5 KPa and greater than 100 KPa were calculated.

Statistics

The data were analyzed using Minitab statistical software. Descriptive statistics were calculated. One-way ANOVA was used. Non-parametric post-hoc tests were also performed.

Results

Peak pressure (Table)

Peak pressure was always greater at the distal end of the femur, irrespective of the technique used. The highest peak pressure at the proximal and distal end was achieved with the pressurizer in situ technique (397 (SD 40) KPa and 597 (SD 102) Kpa, respectively). The lowest peak pressure at the proximal and distal end was seen with the thumb pressurization technique (147 (SD 110) KPa and 210 (SD 116) Kpa, respectively).

Using the pressurizer in situ technique, peak pressures were higher both proximally ($p < 0.05$) and distally ($p < 0.001$) than with the other two techniques.

Pressure duration (Table and Figures 1–3)

The pressurization methods were compared according to the period of time that the pressure remained above 5 KPa and 100 KPa. At the proximal and distal ends, a sustained pressure

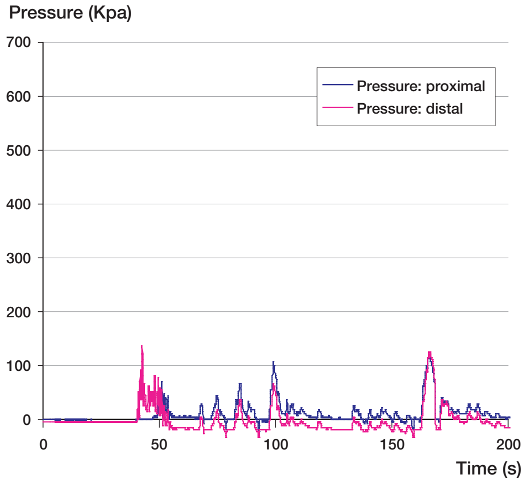

Figure 1. Typical time-pressure plot for the thumb pressurization technique.

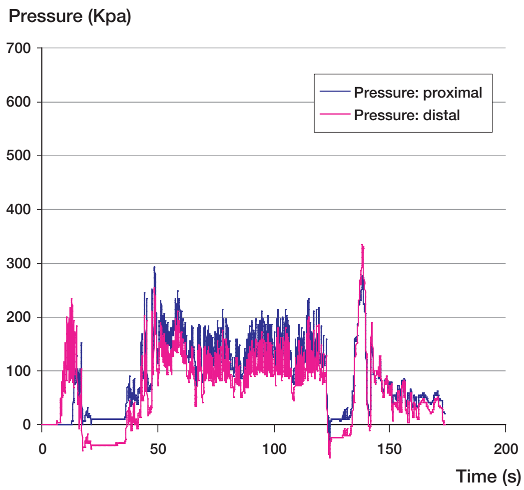

Figure 2. Typical time-pressure plot for the standard technique.

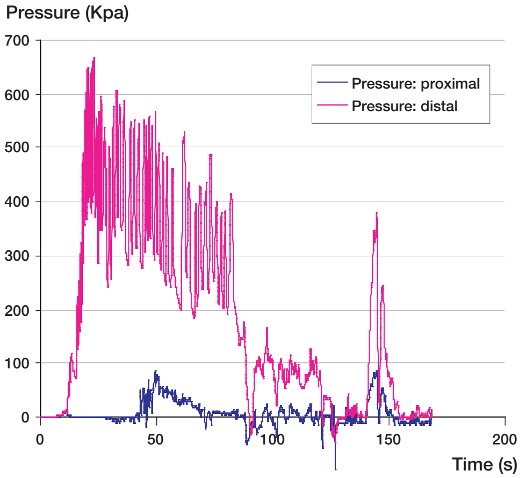

Figure 3. Typical time-pressure plot for the pressurizer in situ technique.

of 100 KPa was maintained for an average of 67 (SD 30) and 45 (SD 16) sec, respectively, using the standard technique. The thumb pressurization technique provided the least sustained pressures proximally and distally (2.9 (SD 1.6) sec and 4.3 (SD 1.8) sec). The sustained elevation of pressures produced by the standard technique was higher than the other two techniques ($p < 0.001$). The difference between the pressurizer in situ technique and the thumb pressurization technique was not significant.

Similarly, a sustained pressure greater than 5 KPa was achieved by the standard technique for 149 (SD 13) sec proximally, and for 135 (SD 27) sec distally. The thumb pressurization technique provided the least consistent pressures proximally and distally, 62 (SD 36) sec and 84 (SD 56) sec, respectively. At the proximal end, there was significant variation between the groups ($p < 0.05$). This variation resulted from the difference between the thumb pressurization technique and the pressurizer in situ technique.

Discussion

The pressurizer in situ method produced intramedullary pressures higher than 390 KPa. Such pressures are likely to increase the risk of embolism (Orsini et al. 1987) and dislodge most of the commercially available distal plugs (Noble et al. 1998). This probably makes the pressurizer in situ technique less desirable. The thumb pressurization technique produced the optimum cement pressure of 100 KPa proximally and distally, but these values were not sustained for long. Also, the time for which the pressure was maintained at 5 KPa or more was shorter than in the other two methods. The thumb pressurization technique may therefore fail to prevent adequate penetration of the cement and back bleeding.

We used 5 KPa and 100 KPa as cutoff pressures, since 5 KPa is thought to be the pressure needed to prevent back bleeding (Heyse-Moore and Ling 1983). The lower range of peak pressures described by various studies is approximately 100 KPa (Panjabi et al. 1983, Davies and Harris 1993, McCaskie et al. 1997).

Of the 3 techniques used, the standard technique with pressurizer and sustained release of cement provides the most satisfactory sustained rise of intramedullary pressure. This technique, when employed with adequate femoral canal preparation, should improve the cement-bone interface without increasing the risk of emboli.

Maltry et al. (1995) reported peak pressures of between 321 KPa and 500 KPa using different pressurization systems. Probably, between 6% and 76% of distal intramedullary plugs would fail to resist cement pressures of 340 KPa in clinical practice (Noble et al. 1998). Davies and Harris (1993) compared three pressurization systems which produced average peak cement intrusion pressures in vitro of over 204 KPa throughout the cement mantle. The average peak pressures we found using the standard and pressurizer in situ technique were similar to those reported by these authors. Peak pressures developed during cement pressurization using the thumb pressurization were lower than in these studies. Dozier et al. (2000) showed that higher pressures and longer duration of pressure during femoral cement pressurization tended to show higher levels of failure when the cut sections of these specimens were subjected to push-out testing (not statistically proven on 10 specimens). From these results, it seems that the standard technique, which produced the greatest sustained pressurization, should provide optimal fixation at the cement-bone interface.

Plastic femurs for the study of intramedullary pressures (Song et al. 1994, Noble et al. 1998, Heisel et al. 2003) have limitations. The absolute pressures and time figures may well be different in human bone (McCaskie et al. 1997). We did not measure the pressure changes after insertion of the prosthesis, as we used a plastic femoral stem replica instead of the actual metal prosthesis. Also, insertion of the stem into late cure stage cement resulted in significantly higher intramedullary pressures (as much as 187% higher) (Song et al. 1994). One of the strengths of laboratory studies is the ability to keep the effect of confounding factors to a minimum, which can be difficult in an in vivo setting. This study therefore provides a baseline comparison of three techniques commonly employed in femoral cement pressurization, and should form the basis of further investigations for measurement of cement penetration and mechanical strength of the cement-bone interface.

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