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Cement pressurisation in the acetabulum

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Abstract Cement pressurisation is an important step in total hip arthroplasty that determines the long-term integration at the cement-bone interface. Our aim was to evaluate the performance of a new pressuriser designed by us against the standard existing pressurisers in an in vitro experimental set-up using two parameters: cement penetration and cement pressurisation. A polypropylene cup model was designed to represent the acetabulum. DePuy's T-handle, Exeter and our own plunger type pressuriser were each tested for cement pressurisation in this acetabular model. Cement penetration and pressures were measured. The cement intrusion into the capillaries with the DePuy pressuriser was found to vary between 2 and 8 mm (mean: 5 mm at the pole and 4.6 mm at the rim), with the Exeter pressuriser it varied between 3 and 9 mm (mean: 5.8 mm at the pole and 7.8 mm at the rim) and with the plunger type pressuriser it varied between 4 and 6 mm (mean 5.2 mm at the pole and 4.8 mm at the rim). The peak pressure achieved with the DePuy pressuriser was 60 kPa whereas it was 70 kPa with the plunger type pressuriser. The mean penetration with the plunger type pressuriser was found to be better than the other types. The penetration was found to be more uniform with equal penetration at the rim as well as at the pole.

Résumé La pressurisation du ciment est une étape importante dans la prothèse totale de hanche qui peut déterminer une bonne intégration, à long terme, des implants, notamment à l'interface ciment-os. Le but de notre étude est d'évaluer les performances d'un nouvel appareil destiné à pressuriser le ciment, en comparaison avec l'appareil préexistant, cette comparaison étant réalisée au cours d'une étude expérimentale in vitro avec étude de deux paramètres, la pénétration et la pressurisation du ciment. Une cupule en polypropylène a été fabriquée comme modèle d'acétabulum. Nous avons ensuite mesuré la pénétration et la pressurisation du ciment, nous avons utilisé trois appareils, le porte cupule Depuy, l'appareil d'Exeter et notre propre appareillage. *Résultats:* l'intrusion du ciment dans les capillaires avec le porte cupule Depuy a été de 2 à 8 mm, avec l'appareil d'Exeter de 3 à 9 mm et avec notre nouvel appareillage de 4 à 6 mm. Le type de pression avec l'appareil porte cupule Depuy a été de 60 kPa alors qu'il était de 70 kPa avec notre nouvel appareillage. *En conclusion:* la pénétration moyenne avec notre nouvel appareillage a été nettement améliorée si on la compare aux autres types d'appareillage. Cette pénétration a été plus uniforme que se soit au pourtour de la cupule ou au niveau des pôles.

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Introduction

A secure bone-cement interface between the acetabulum and the cement mantle of the hip socket is an important requirement for the long-term success of a cemented hip arthroplasty. Careful cement preparation to maximise fatigue strength, control of bleeding, bone bed cleaning and cement pressurisation before socket introduction can all help to achieve this objective [1, 2].

Reduction of cement porosity has been shown to improve fatigue strength [3] and hence vacuum mixing of cement would appear advantageous. Cement mantle contamination with blood will not only disrupt the bone-cement interface but can also produce laminations that will weaken the cement mantle [4]. Whilst blood flow may be

controlled by the use of hypotensive anaesthesia, there is no completely effective way of preventing it [5]. However, cement pressurisation after bone bed cleaning enables cement to penetrate interstices of cancellous bone forming a superior fixation strength [6].

Cement may be pressurised by a flanged socket, but difficulty may be experienced in applying the necessary force, and inaccurate trimming of the flange may render pressurisation ineffective [7]. Cement pressurisation using a purpose built pressuriser, prior to socket insertion, therefore would appear the most effective method of pressurising cement in the acetabulum. The Exeter pressuriser is a commonly used purpose built pressurisation instrument as is the T-handle manufactured by DePuy International to which is added a disposable flexible pressuriser head. Little objective data exist as to the relative merits of these instruments.

We have designed an experimental model to evaluate the performance of the Exeter pressuriser and the DePuy T-handle. The results of this model have then been used to design a new pressuriser and test its efficacy against the standard existing pressurisers using two parameters: cement penetration and cement pressurisation.

Materials and methods

The DePuy pressuriser (DePuy, UK) consists of a T-handle to which is added a disposable, flexible pressuriser head to seal the rim of the acetabulum. Operator-dependent manual pressure is then applied via the T-handle to pressurise the cement within the acetabulum with the aim of the flexible head preventing cement egress. The DePuy pressuriser may allow cement through the transverse ligament during pressurisation (Fig. 1a). To restrict this cement escape and thereby increase pressurisation, a bulge can be added to a standard head by fixing an extra piece of silastic to a

standard convex head with adhesive which is known as the Bernoski modification [8].

The Exeter pressuriser (Stryker, UK) uses a rubber balloon (Fig. 1b), which is inflated with saline during pressurisation to seal the acetabulum rim [9]. Whilst the degree of balloon inflation can be controlled and monitored, the critical factor in determining the amount of pressurisation is the applied force and as with the DePuy model, this has to be estimated by the operator. The other disadvantage with the Exeter pressuriser is the puncture and occasional breakage of the balloon with premature release of pressure.

The plunger T-handle pressuriser is a novel device which was designed by two of the authors (MLP and DL) to overcome the limitations of the previous two instruments whilst using the same disposable pressure head as the DePuy model (Fig. 1c). The basic design consists of a T-bar incorporating a central plunger, which protrudes from an outer sleeve when force is applied. The aim of the central plunger is to produce a more even cement mantle and allow a polyethylene cup to be adequately medialised within the acetabulum.

Design of the test model to study cement penetration

The acetabular model consisted of a polypropylene cup-shaped model with two 1.3-mm diameter capillary outlets, one at its pole and one at a point close to its rim opposite the cotyloid notch. Water was allowed to flow freely through the capillaries at a pressure of 13.5" WG to represent blood flow. Cement was applied by hand and then pressurised such that when it would set, the mould could be dismantled around the cement leaving spikes of cement representing capillary penetration.

Krause et al. [6] found that the maximum strength of bone-cement interface occurred with a cement intrusion of

Fig. 1 a Representation of the cement mantle produced by the DePuy T-handle pressuriser. b Representation of the cement mantle produced by the Exeter pressuriser. c Representation of the cement mantle produced by the plunger T-handle pressuriser

5–10 mm. As 10 mm of cement intrusion has been reported as likely to give rise to thermal damage of the bone [10], we determined that the optimum cement intrusion into the capillary of the test model would be regarded as being 5 mm.

Design of the test model to demonstrate and record cement pressure

A similar polypropylene acetabular model was used, but with the modification of a piezoelectric force transducer mounted at the pole (Fig. 2). The transducer was connected, via an electronic interface, to a PC. Data logging software recorded the pressure exerted on the transducer during cement pressurisation and cup insertion. Also a transverse ligament notch was cut into the acetabular model to replicate the real acetabulum; 1.5-mm holes were drilled at regular points between the pole and the rim. During cement pressurisation, cement is extruded through these holes which provide an indication of the pressurisation profile.

Equipment calibration for pressure reading

During pressurisation the acetabular model is mounted on a bench at a convenient angle. For calibration, the model is mounted vertically, as shown in Fig. 2, and the force is applied to the transducer. The weight table weighs 70 g and the diameter of its stem is 5 mm. Hence,

$$\begin{aligned} \text{Pressure exerted by weight table} &= \frac{70 \times 10^{-3} \times 9.81}{3.142 \times 2.52 \times 10^{-6}} \\ &= 35 \text{ kPa} \end{aligned}$$

Pressure exerted by table with a 100gms weight

$$= \frac{70 \times 10^{-3} \times 9.81}{3.142 \times 2.52 \times 10^{-6}} = 35 \text{ kPa}$$

With no weight applied, the transducer output is zeroed. The weight table is then placed in position and the range of the interface circuit is adjusted to give an output on the graphical pressure scale of 35 kPa. A 100-g weight is then added to the weight table and the linearity of the interface

Fig. 2 Diagram of equipment calibration

circuit is adjusted to give an output on the pressure scale of 85 kPa.

Experiment set-up

Five sets of polypropylene acetabular models were used to test each of the three different pressurisers. The cement was vacuum mixed under standard conditions and inserted with the hand. A single operator applied the pressure using each one of the pressurisers in turn with the same amount of force. The cement intrusion obtained in the capillaries at the rim and at the pole in each of the mantles was measured and plotted on a graph manually.

A computerised graphic record of the pressure profile was obtained for the standard DePuy and the plunger type pressuriser in two cement mantles. The standard DePuy convex pressuriser head was used for these tests.

We extended our test further to assess the cement intrusion with full range of head sizes on the plunger type T-handle. DePuy manufactures four sizes of pressuriser head: 52, 55, 60 and 65 mm in diameter. The head used for pressurisation should be about 5 mm larger in diameter than the reamed diameter of the acetabulum. An acetabulum reamed to a diameter of 55 mm would have to have a depth of 27.5 mm (dimension A in Fig. 3). The recommended pressuriser head for this acetabulum would be 60 mm, which has an initial overhang into the acetabulum of 13.5 mm (dimension B in Fig. 3). When pressurised with a plunger extension of 7.5 mm (dimension C in Fig. 3), the resulting cement mantle thickness at the pole is 8 mm minus the inward movement of the handle. This would depend upon the force required to push out the plunger, which in turn would be determined by the resistance offered by the cement and the flexibility of the pressuriser head. Four more acetabular models were made, similar in all respects except for their diameters. These were cut to 47, 50, 55 and 60 mm to facilitate pressuriser head sizes of 52, 55, 60 and 65 mm, respectively. Each model had a single capillary at its pole. Two cement mantles were produced with each head and their thickness and cement intrusion at the pole were measured and averaged.

Five cement mantles, complete with cup introduction, were made with the Bernoski head mounted on the modified T-handle. For comparison purposes, five cement mantles, complete with cup introduction, were made with the modified T-handle with the bulge type pressuriser head mounted. The peak pressures were recorded during pressurisation and during cup introduction.

Results

DePuy pressuriser

When used on the test model, the deformation of the flexible pressure head produced a cement mantle, which is thick at the pole but tapered at its rim (Fig. 1a). This means that during surgery pressurisation would have to be

Fig. 3 Diagram demonstrating dimensions that vary with varying sizes of pressuriser heads

removed with the cement still quite soft so that the cement mantle could be reformed with the socket. This is a disadvantage because cement is viscoelastic and hence early removal of pressure during polymerisation can cause retraction of cement from the bone, thus partly defeating the objective. When cement pressurisation was performed using this pressuriser, similar pressure was generated at the rim as that at the pole as seen in Fig. 4a. However, the cement intrusion into the capillaries was found to vary between 2 and 8 mm for what was judged to be a similar applied force. The mean penetration at the pole was 5 mm (SD 2.24) and at the rim was 4.6 mm (SD 2.70)

Exeter pressuriser

When used on the test model, it was found to produce cement mantles more compatible with a socket (Fig. 1b). However, the test results, recorded in Fig. 4b, show a wide variation in cement penetration occurring for what was estimated for a similar applied force (3–9 mm at the pole and 5–9 mm at the rim). The mean penetration was 5.8 mm (SD 2.59) at the pole and 7.2 mm (SD 1.64) at the rim. It was also shown to have the disadvantage of causing widely dissimilar pressures at the pole and the rim. During one test the cement intrusion was 9 mm at the rim whilst it was only 4 mm at the pole.

Porter/Leonard pressuriser

This was shown to form a cement mantle compatible with the socket, as shown in Fig. 1c, hence allowing pressure to

Fig. 4 a Chart of cement penetrations achieved using DePuy pressuriser. b Chart of cement penetrations achieved using Exeter pressuriser. c Chart of cement penetrations achieved using plunger T-handle pressuriser

be maintained for longer. The plunger protrusion required to produce 5 mm cement protrusion was found to be 7.5 mm. Since this protrusion can be monitored and controlled by the operator, a cement intrusion of 5 ± 1 mm was found to be reproducible (Fig. 4c). The maximum variation in intrusion between rim and pole was 1 mm. The mean penetration was 5.2 mm (SD 0.84) at the pole and 4.8 mm (SD 0.45) at the rim.

Pressure profile

As seen in Fig. 5a and b the pressure using the DePuy T-handle peaks at about 60 kPa whilst with the plunger type handle, it peaks at 70 kPa (Fig. 6a,b). During pressurisation with the plunger type T-handle, pressure was reduced slightly on occasion to demonstrate full plunger protrusion at 7.5 mm. These occasions can be seen in Fig. 6a,b as downward spikes in the pressure.

Different head sizes

Table 1 lists the expected dimensions A, B, C and D for each of the pressuriser heads as detailed in the “Methods” section. The experimental cement mantle thickness and the cement intrusion for different head diameters are outlined in Table 2.

Different pressuriser heads

The peak pressures achieved during pressurisation and cup introduction using the bulge type head and the Bernoski head are summarised in Table 3. The peak pressurisation obtained with the bulge type pressuriser head was found to be higher than the flap pressuriser head but the difference was not found to be statistically significant owing to very small sample sizes ($p=0.068$ using the Wilcoxon signed rank test).

Fig. 5 a, b Graph records of pressure generated in the acetabular model using the DePuy T-handle pressuriser

Fig. 6 a, b Graph records of pressure generated in the acetabular model using the plunger T-handle pressuriser

Discussion

Pressurisation had been recognised in the early 1970s to improve the interlock of bone and cement. Numerous techniques have been described to improve the micro and macro-interlock of bone-cement interface. Oh et al. in 1983 [11] described the use of a cement compactor suggesting that it not only achieves better pressure and intrusion, but also reduces cement lamination and the amount of blood in cement enhancing the mechanical properties of cured cement. In vitro and in vivo studies have been performed

Table 1 Expected dimensions A, B, C and D for each of the pressuriser heads as detailed in the “Methods” section

Head diameter (mm)	Diameter of ream (mm)	A (mm)	B (mm)	C (mm)	D (mm) [D=A –(B+C)]
65	60	30	14	7.5	8.5
60	55	27.5	12	7.5	8
55	50	25	10	7.5	7.5
52	47	23.5	8.5	7.5	7.5

Table 2 Experimental cement mantle thickness and the cement intrusion for different head diameters

Head diameter (mm)	Average cement mantle thickness (mm)	Average cement intrusion (mm)
52	6.6	6.0
55	7.5	6.0
60	8.7	5.5
65	8.5	5.0

wherein individual holes in the acetabulum have been packed and pressurised before actually pressurising the whole acetabulum to improve fixation [8, 12].

In our study we have used a pressuriser that obviates the need for packing individual holes by producing a uniform pressure throughout the acetabulum by introducing a plunger—a concept introduced by Bernoski [8]. The cement mantle thickness obtained with our pressuriser was more uniform at the rim as well as at the pole. The uniformity remained consistent throughout the experiment and thus can be reproduced. In particular, the cement mantle produced was of a more even nature than those produced by either of the more commonly used pressurisers. The ability to produce a consistent level of pressurisation by advancing the plunger by 7.5 mm would appear to have great dividends in producing a consistent amount of cement intrusion as opposed to the variable performance of the other systems which depend upon the objective nature of how hard an individual surgeon assesses the need to press on the instrument.

The peak pressure obtained with our pressuriser was consistently higher than the DePuy pressuriser. The increased cement intrusion and reduced cement mantle thickness for the smaller, less flexible heads indicate that they require more force to push out the plunger. Assuming a 4-mm thick cement mantle is required around the cup, the excess cement mantle thickness after pressurisation would

Table 3 The peak pressures achieved during pressurisation and cup introduction using the flap (FS) and bulge (BS) type heads. Pp peak pressure during pressurisation, Cp peak pressure during cup insertion

	Pp (kPa)	Cp (kPa)
FS1	100	120
FS2	90	130
FS3	85	120
FS4	105	130
FS5	105	135
BS1	100	130
BS2	140	150
BS3	115	130
BS4	105	105
BS5	115	125

Average Pp for flap head=97 kPa (SD=8.12)

Average Cp for flap head=127 kPa (SD=6.0)

Average Pp for bulge head=115 kPa (SD=13.78)

Average Cp for bulge head=128 kPa (SD=14.35)

be displaced during cup insertion. The pressuriser introduced by Bernoski had a flap to prevent cement extrusion through the transverse ligament notch. However, the pressure studies would suggest that this may lead to a lower ability to pressurise the cement within the acetabulum as compared to the plunger pressuriser and as such the former modification may be unnecessary.

In conclusion, we have presented experimental evidence that suggests that a plunger type of acetabular cement pressuriser may provide a more consistently reproducible level of pressurisation leading to optimal cement penetration.

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