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Femoral cementing techniques in total hip replacement

J. Rice[1], **T. Prenderville**[2], **P. Murray**[1], **B. McCormack**[2], **W. Quinlan**[1]

[1] Cappagh Orthopaedic Hospital, Finglas, Dublin 11, Ireland
[2] The Bioengineering Centre, Department of Mechanical Engineering, University College Dublin, Belfield, Dublin

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Summary. *Clinical studies have shown that second-generation femoral cementing techniques at total hip replacement result in a superior fixation of the femoral stem. In an effort to determine what benefits further developments in cementing techniques would provide, we compared the morphology of the cement mantles produced by traditional finger-packing and gun-insertion techniques. The porosity of the cement mantles was quantified using computerised image analysis. The finger-packing technique caused large air inclusions that resulted in large pores in the substance of the cement mantle, whereas the cement-gun technique did not result in any individual pore with an equivalent diameter greater than 3 mm. The mean porosity of cement mantles prepared using the finger-insertion technique was 8.3%, whereas the mean porosity in gun-prepared mantles was 1.7%. The use of a cement gun significantly reduced the porosity of femoral cement mantles (*P*=0.02). Reduction of defects in the substance of the cement mantle may account for the increased survival of femoral prostheses inserted when second-generation techniques were used. Further reduction of the porosity of the cement mantle could not be expected to produce as dramatic a clinical improvement in prosthesis fixation.*

Résumé. *Les études clinique ont montré que la pratique des techniques de cimentation fémorale de deuxième génération au niveau du remplacement total de la hanche aboutissent une meilleure fixation de la tige fémorale. Afin de déterminer quels seraient les avantages préséntes par de nouveaux progrès dans le domaine de ces techniques de cimentation, nous avon compare la morphologie des enveloppes en ciment réalisée par bourrage traditionnel au doigt et par insertion au pistolet. La porosité des enveloppes en ciment a été quantifée par l'analyse d'image informatisées. La technique de bourrage au doigt provoque des ponches d'air plus importantes causant l'apparition de larges pores dans la substance de l'enveloppe en ciment, la technique d'insertion au pistolet ne provoque aucune formation de pores individuals équivalents d'un diametre supérieur a 3 mm. La porosité moyenne des enveloppes en ciment insérées au doigt atteint 8.3%, celle des enveloppes insérées au pistolet s'élevant a 1.7%. L'emploi d'un pistolet à ciment a réduit de manière considérable la porosité des enveloppes fémorales en ciment (*P*=0.02). Il est probable que ce phénomène explique l'accroissement de la survie des prothèses femorales insérées à l'aide des techniques de deuxieme génération. On ne s'attend pas a ce qu'un accroissement supplémentaire de la réduction de la porosité de l'enveloppe en ciment aboutisse à une amélioration clinique aussi radicale au niveau de la fixation des prothèses.*

Reprint requests to: J. Rice, Department of Orthopaedic Surgery, Cappagh Orthopaedic Hospital, Finglas, Dublin 11, Ireland; e-mail jjrice@iol.ie

Introduction

Mechanical failure of the cement mantle is one of a number of factors implicated in the loosening of cemented femoral components of total hip arthroplasties. Carlsson [2] pointed out that deficiencies in the technique of inserting polymethylmetacrylate (PMMA) bone cement into the femur may result in failure of fixation. Charnley [3] initially described a technique of packing cement into the femoral medullary canal using two fingers. Subsequently, "second generation femoral cementing techniques" were described that involved the use of an intramedullary plug [11] and the anterograde insertion of PMMA with a cement gun [5]. Clinical evidence has shown that this technique is associated with improved long-term fixation of the femoral component [1, 10]. Since then, ways to further improve the strength of the cement mantle have been proposed, using vacuum mixing [16] and centrifugation [13]. The issue of whether these developments that involve an increase in operation time and expense will improve the prosthesis survival is a matter for debate [15]. In an attempt to adopt a sensible policy on femoral cementing, the authors examined the morphology of cement mantles produced by finger-packing and gun-insertion techniques in a laboratory model.

Materials and methods

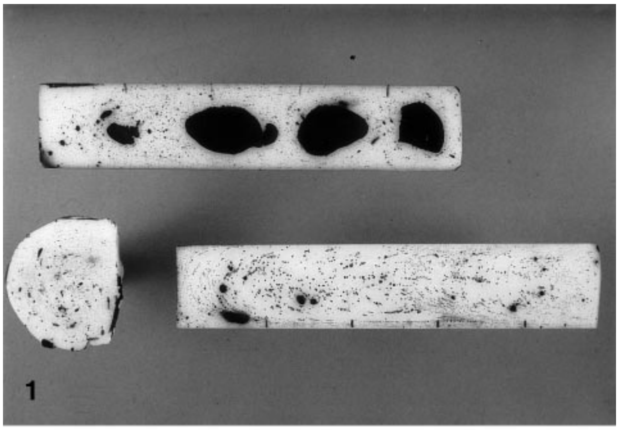
The model of a reamed and plugged human proximal femur consisted of a cylindrical nylon tube, 10 cm long and 2 cm in diameter. There was a screw on-off cap at the distal end. Individual mixes of Simplex AKZ (Howmedica International) bone cement were used for the experiment. This cement was mixed in a glass bowl with a metal spatula at room temperature for 1 min. The cement was allowed to cure for a further 3 min to facilitate ease of handling and was then introduced into the model femurs using one of two techniques.

Finger packing of cement was carried out in the manner described by Charnley [3]. This was achieved by holding the bolus of PMMA against the open end of the nylon tube and packing it in by pushing an introducing finger into the lumen of the tube six times per specimen. Retrograde gun injection of cement was achieved by rolling a cement bolus into an oblong shape to load it into a cement gun insert (Howmedica International) and injecting the cement into the model femur using a cement gun. The cement surplus to what was required to fill the model femurs was rolled into a spherical shape in the mixing bowl and kept as a control specimen.

Two types of specimens were produced for each cementing technique. Ten cement cylinders were produced for each of these techniques by filling the model femurs with bone cement and allowing it cure.

Twenty further model femurs had PMMA similarly introduced, before a steel model of a femoral stem was inserted into the cement-filled tube. All specimens were allowed to cure overnight in a water bath at 35° C. The cured cement was then extracted from the nylon tubes using a mechanical press, and the femoral stems were removed using a mallet and punch. The bone cement specimens and controls were sectioned along a longitudinal diameter using a bench saw. The cut surfaces were polished in a standard fashion using a metallurgical polishing machine (200- and 800-grit size). A black cellulose spray paint (Simoniz International, England) was applied to the polished surfaces. This spray paint stained the solid surfaces and filled the voids opening onto this surface. When the paint had dried, the cut surfaces were again polished to remove spray paint from the solid surfaces. The spray paint remained in the pores and thus represented them as black areas against the white surface of the bone cement (Figs. 1, 2).

The area of pores on the cut surfaces was measured using computerised image analysis (NIH Image). The surface was scanned using a Umax T630 vista scanner with the detection level of pixels for the pores set at 70 (in a full black-and-white range of 0–265 levels). The resolution of the scanning was measured to be 10 μm. The analysis was carried out using macros within NIH Image, and this returned the number of pores, the individual pore diameter, and the area of the individual pores. The total porosity (area of pores/area of cut surface) and the pore density (number of pores/area of cut surface) were calculated from this data.



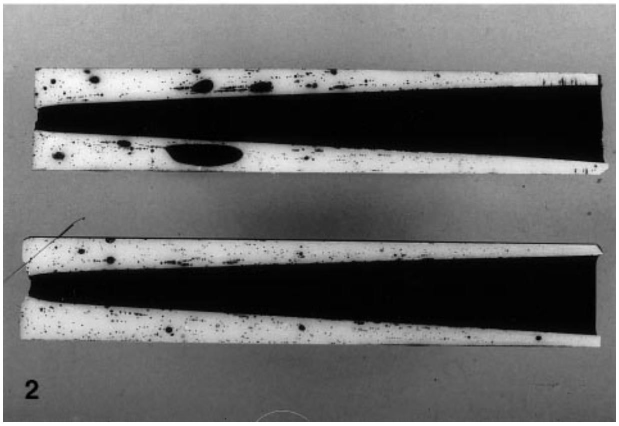


Fig. 1. This photograph shows longitudinal sections through cement cylinders and a control specimen with pores represented as dark areas using the staining technique. This shows large pores in the finger-prepared specimen and a uniform distribution of smaller pores in the gun-prepared and control specimens

Fig. 2. The cement mantle from the finger-packing technique is on top and shows large pores in its substance. The gun-prepared mantle has much smaller defects within its substance

Results

Controls

Sections through 16 control specimens (Fig. 1) showed small pores scattered uniformly throughout the cut surface. The mean equivalent diameter of these pores was 0.2 mm, and the largest was 2.5 mm. The average density of the pores was 35 pores per cm^2. The total surface area of void associated with these specimens had a mean value of 2.8% (range 0.9–3.8%).

Finger-packing technique

The cut surfaces of cement cylinders prepared using the finger-packing technique (Fig. 1) had an average of 30.1% of the surface occupied by pores (range 24.5 to 36.2). The bulk of this porosity was accounted for by three to four large pores per specimen which

Table 1. Summary of experimental results

	Total porosity mean (range)/%	Pore size (equivalent diameter) mean (range)/mm	Pore density (pores/cm²) mean (range)
Controls	2.8 (0.9–3.8)	0.2 (0.05–2.5)	35.0 (24.6–43.4)
Finger-prepared cylinders	30.1 (24.5–36.2)	2.2 (0.05–22.0)	26.4 (22.1–34.4)
Finger-prepared mantles	8.3 (4.2–12.8)	0.5 (0.05–7.9)	48.4 (29.3–59.0)
Gun-prepared cylinders	3.4 (2.8–4.0)	0.3 (0.07–4.1)	35.9 (28.3–43.2)
Gun-prepared mantles	1.7 (1.3–3.5)	0.2 (0.06–2.3)	39.7 (27.1–47.7)

measured up to 315 mm^2. Large pores were also observed when a stem was introduced into the model femurs that were prepared by the finger-packing technique (Fig. 2). The mean total surface porosity of these cement mantles was 8.3% (range 4.2–12.8%).

Cement-gun introduction technique

A longitudinal section through the ten cement cylinders which were prepared using the cement-gun introduction technique had a surface with an even distribution of pores with a mean equivalent diameter of 0.3 mm throughout the length of the specimens. The cement mantles which resulted from this technique had a similar even distribution of pores of similar size throughout their lengths. The total porosity on the cut mantle surface had a mean value of 1.7%. This was significantly less than the porosity of the mantles associated with the finger-introduction technique (P=0.02) when a two-sample Student t-test assuming unequal variance was applied. The mean pore size was not different between the two groups and the control specimens. There were no pores with an equivalent diameter greater than 3.0 mm in the cement gun mantels, whereas pores of this size and greater accounted for 6% of the total porosity in the finger-prepared mantles.

Discussion

This laboratory study shows that a finger-packing technique results in substantial pores in the femoral cement mantle. Air appears to be trapped between the folds of bone cement and thrust into the medullary canal during this technique for cement insertion. Much of the air trapped within the cement column in the femoral canal is dispersed when the cement is compressed during the introduction of the femoral stem, but significant air pockets persist within the resulting cement mantle. Pores within a column of radio-opaque cement would not be obvious on two-dimensional radiographs. A study of cemented femoral components retrieved post mortem by Jasty et al. [8] showed that on average, 29% of the cross-sectional area of the cement mantle was occupied by pores. Our study shows that the use of a cement gun results in a cement mantle with a mean porosity of 1.7% of the cut surface area. The density of pores and the total pore area is not significantly different in the gun-prepared mantles and the control specimens, which suggests that this residual porosity occurs during mixing and polymerisation of PMMA.

Pores in the substance of PMMA have been shown to significantly increase crack formation and mechanical failure under cyclical loading in the laboratory. Mechanical studies by James et al. [6] and Topoleski et al. [14] showed that cracks radiated out from pores when PMMA was cyclically loaded and that larger pores were a more significant source of cracking. It is easily appreciated that large pores as demonstrated in the finger-packed specimens in this study would cause significant weakness under cyclical physiological loading. The reduction of such large pores in the cement mantle may account for the improvement in survival of the femoral stem as observed by Mulroy et al. [10] and Barrack et al. [1]. Further innovations in femoral cementing techniques that seek to further reduce porosity cannot be expected to produce such dramatic clinical results.

The use of a staining and milling technique to quantify porosity in bone cement has previously been described by Wixon [16]. This method provides a two-dimensional representation of porosity through a random section of PMMA. James et al. [7] relates the fatigue behaviour of PMMA to the two-dimensional porosity that was measured using a similar technique. The early experimentation in this study that the quantification of porosity using computerised image analysis depends on the magnification of the surface being analysed and on the level of greyscale detection. In this study the magnification problem was overcome by calibrating the scanned images against a calibrated steel block and using these settings for the bone cement specimens. The greyscale setting was selected based on a comparison with pore measurements made under a light microscope for a 1-cm^2 area of bone cement [12]. The interpretation and comparison of porosity of bone cement in other studies using this type of analysis should take account of these variables.

The traditional finger-packing technique for introducing bone cement is still practised by a minority of surgeons for total hip replacement [9]. This study suggests that this technique results in the inclusion of large air pockets within the cement mantle. The technique must be further criticised for introducing blood and bone particles into the cement in a similar manner during the operation. We therefore recommend the use of a cement gun for PMMA introduction into the femoral intramedullary canal.

Conclusion

The use of a cement gun results in a dramatic reduction in pores within the substance of the cement mantle when compared to finger-packing techniques. This factor may provide a significant contribution to the observed clinical difference in the long-term survival of femoral components where cement was inserted using a cement gun rather than by finger-packing. Further efforts to reduce porosity cannot be expected to have such profound clinical results.

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