S. J. Mellor · L. G. Ripley · D. M. Ricketts

The femoral cement mantle in three total hip replacements

Accepted: 9 July 2003 / Published online: 8 October 2003
© Springer-Verlag 2003

Abstract We measured the size and volume of the femoral broaches and stems supplied with three commercial total hip replacement (THR) systems (JRI Furlong, Biomet Stanmore, and Howmedica Exeter). Using an in vitro method, we created cement mantles that could be directly measured. The broaches supplied with the Biomet Stanmore and the Howmedica Exeter systems allowed the creation of significantly thicker cement mantles than the JRI broaches and stems (Stanmore mean thickness = 1.7 mm, defects at 3% of measurement sites; Exeter mean thickness = 2.0 mm, no defects; JRI mantles mean thickness = 0.9 mm, cement defects at 29% of measurement sites). We conclude that, in vivo, the broaches supplied with the Stanmore and Exeter systems are significantly larger than the corresponding stems, and will excavate a cavity large enough to accommodate the appropriate femoral stem surrounded by an intact cement mantle.

Résumé Nous avons mesuré la dimension et le volume des alésoirs fémoraux et des tiges fournis avec trois

This research was supported in part by a grant from The Sprint Fund. No benefits of any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

S. J. Mellor

Department of Orthopaedic Surgery,
Austin and Repatriation Medical Centre,
Heidelberg, Melbourne, Victoria, Australia

L. G. Ripley

School of Engineering, University of Sussex,
Falmer, Brighton, East Sussex, BN1 9QT, UK

D. M. Ricketts

Department of Orthopaedics, Princess Royal Hospital,
Lewes Road, Haywards Heath, West Sussex, RH16 4EX, UK

S. J. Mellor (✉)

3 Bethune Street, 3123 West Hawthorn, Melbourne,
Victoria, Australia
e-mail: simonmellor@fsmail.net
Fax: +61-3-94584779

systèmes commerciaux de PTH (Furlong JRI, Biomet Stanmore, Howmedica Exeter). Utilisant une méthode in vitro, nous avons créé des manteaux de ciment qui pouvaient être mesurées directement. Les alésoirs des systèmes Biomet Stanmore et Howmedica Exeter ont autorisé la création de manteaux de ciment considérablement plus épais que dans le système JRI (Stanmore épaisseur moyenne = 1.7 mm, défauts sur 3% d'emplacements de la mesure; Exeter épaisseur moyenne = 2.0 mm, aucuns défauts; JRI épaisseur moyenne = 0.9 mm, défauts du ciment à 29% d'emplacements de la mesure). Nous concluons que, in vivo, les alésoirs fournis avec les systèmes Stanmore et Exeter sont nettement plus grands que les tiges correspondantes, et font une cavité assez grande pour recevoir la tige fémorale appropriée entourée par d'une manteau de ciment intact.

Introduction

We have previously described a method for measuring femoral broaches and stems and the in vitro creation of cement mantles [15]. Using this technique, we have shown that the femoral broaches supplied with the JRI hip system are smaller than the equivalent stems and excavate inadequate cavities. This may predispose to thin or deficient cement mantles in vivo. Earlier reports have recommended this prosthesis, citing satisfactory 5-year survival figures of 97% [21]. We have now applied the same techniques to measure the femoral broaches and stems of two other hip replacements, the Biomet Stanmore and Howmedica Exeter.

Methods

The experimental methods were in three stages, as previously described [15]. In stage one, the JRI, Stanmore and Exeter femoral broaches were measured in the coronal and sagittal planes at 1-cm intervals using dial vernier callipers. Similar measurements were performed on the definitive implant stems. Statistical analysis of the pooled data (all sizes of each type of implant amalgamated) was

by multiple comparisons of the marginal means and presentation of the confidence intervals (SPSS for Windows: SPSS Inc., 2000).

In the next stage, the volumetric assessment of the stems and broaches was performed using a water-displacement method. The results were calculated with 95% confidence intervals. Analysis where necessary was by least significant difference multiple comparisons (SPSS for Windows: SPSS Inc., 2000).

In the last stage, Oasis floral blocks were used as an in vitro substitute for cancellous bone, and the femoral stems were implanted with Palacos cement after cavities were made using the femoral broaches. The Oasis was then broken away, leaving the cement mantle on the femoral stem. The mantle was removed, and was sectioned at 1-cm intervals. Dial vernier callipers were used to measure the thickness of each section on the anterior, posterior, medial and lateral aspects. Results were analysed using multivariate repeated measures analysis of variance (SPSS for Windows: SPSS Inc., 2000).

Results

The JRI femoral broaches appeared to be narrower than the femoral stems for which they were intended. The Stanmore and Exeter broaches appeared to be wider and thicker than their equivalent stems. Linear measurement and calculation of the 95% confidence intervals for the marginal means confirmed this (Table 1). Volumetric analysis (Table 2) revealed that, for each component size, the volumes of the Stanmore and Exeter broaches were significantly greater than the equivalent femoral stems. This was in contrast to the JRI broaches, in which volumes were significantly less than the JRI femoral stems. Least significance difference multiple comparisons confirmed that the femoral broach was significantly bigger than the femoral stem in every size of Stanmore and Exeter implant, and significantly smaller in every size of JRI implant ($p < 0.05$).

The cement mantles produced using the JRI broaches and stems were invariably thin and easily fractured. Large cement defects were present on the anterior and posterior surfaces due to the longitudinal ridges present on the stems but not the broaches. The overall mean mantle thickness was 0.9 mm, and cement-mantle defects (cement thickness = 0 mm) were found at 29% of all

Table 3 Mean cement mantle thickness (mm)

Size	JRI	Stanmore	Exeter
X small or 1	0.7	1.2	2.1
Small or 2	0.8	1.3	1.8
Medium or 3	0.8	1.7	1.8
Large or 4	1.3	2.0	2.2
5	-	2.0	-

measurement sites. The cement mantles created with the Stanmore broaches and stems were thicker, with fewer cement defects. The overall mean mantle thickness was 1.7 mm, and cement-mantle defects were noted at 3% of measurement sites. The cement mantles created with the Exeter broaches and stems were the thickest and most consistent mantles. The overall mean mantle thickness was 2.0 mm and cement-mantle defects were not found.

Statistical analysis showed that the mantles produced with the Stanmore and Exeter systems were significantly thicker than those produced with the JRI system ($p < 0.05$). There was no significant difference between the mantles produced by the Stanmore and the Exeter systems (Table 3).

Discussion

Previous authors have documented the importance of an adequate cement mantle based on the results of finite-element analysis [8, 12], intra-operative observations [2], radiographic studies [7], cadaveric studies [9] and long-term follow-up studies of various designs of THR [3, 11, 16].

As early as 1978, Beckenbaugh and Ilstrup [4] noted that longevity of Charnley THRs was correlated to cement-mantle quality and thickness, with the best results occurring when all loose cancellous bone had been removed and replaced by a 5 mm cement mantle. Other investigators [7, 9, 11] have also provided evidence in favour of an intact and complete cement mantle of at least

Table 1 Estimated marginal means and confidence intervals for linear measurements of broaches and stems

	Femoral broach means and confidence intervals (mm)	Femoral Stem means and confidence intervals (mm)	<i>p</i> value
JRI	11.8 (10.5–13.2)	13.9 (12.4–15.1)	$p > 0.05$
Stanmore	12.1 (11.1–13.0)	11.2 (10.4–11.9)	$p > 0.05$
Exeter	13.1 (11.9–14.3)	10.4 (9.2–11.6)	$p < 0.05$

Table 2 Volumetric data mean values and 95% confidence intervals

Size	JRI (cm ³)		Stanmore (cm ³)		Exeter (cm ³)	
	Broach	Stem	Broach	Stem	Broach	Stem
X small or 1	13.1±0.3	14.8±0.4	9.6±0.4	6.3±0.4	18.2±0.4	11.3±0.2
Small or 2	15.6±0.2	16.7±0.3	14.6±0.5	11.2±0.3	19.6±0.3	13.7±0.3
Medium or 3	18.9±0.4	20.2±0.2	21.8±0.4	17.9±0.2	21.4±0.2	15.6±0.4
Large or 4	21.9±0.3	23.2±0.3	30.7±0.5	27.0±0.4	23.8±0.3	18.2±0.4
5	-	-	41.6±0.3	37.5±0.3	-	-

2 mm thickness. The achievement of a satisfactory cement mantle has been thought to rely on good cementing technique [18, 19, 20]. However, it appears that the correlation between cement-mantle thickness and stem longevity may be more complex than was previously thought. Recently, medium-term results of the cemented Freeman hip replacement have been reported [17]. Paradoxically, a lower rate of focal osteolysis was identified in those stems that were implanted with no regard to thickness of mantle. Cementing techniques that tended to improve cement-mantle thickness resulted in a higher osteolysis rate. This tends to contradict the studies discussed above, and serves to show that femoral stem design (stem material, shape and surface finish) may be more important than cement-mantle thickness in some circumstances.

There are few published results for the Furlong cemented arthroplasty [21]. Alho et al. [1] have reported an 85% survival at 12 years for this prosthesis, but this is based on a very small cohort of 30 patients. Warren et al. [21] have documented the medium-term results of 148 JRI Furlong THRs, and highlighted that aseptic loosening exceeds 11% at year 5–6. There are, however, published series showing, paradoxically, excellent long-term results for stems inserted with thin and incomplete cement mantles [13]. Both the Exeter and Stanmore have excellent long-term results reported from several institutions [8, 15]. How can these conflicting experimental and clinical results be explained?

The results of the present study highlight significant differences between the design rationale of the JRI femoral broaches and the Stanmore and Exeter femoral broaches. The JRI Furlong femoral broaches are smaller than the femoral stems for which they are intended, and this may lead to the creation of an inadequate cement mantle. The Stanmore and Exeter broaches are larger than the equivalent femoral stems, with predictable effects on the cement mantles. The effect of these differences on in vivo performance and femoral-stem longevity cannot be predicted.

We have previously shown that with the JRI broaches and stems, the majority of the cement mantle defects occur on the anterior and posterior surfaces of the stems [15]. In this study, the mantles on the Stanmore and Exeter stems were mostly circumferentially complete. This is highly significant, since the assessment of cement-mantle quality is routinely based on a single AP radiograph, which will not visualise the mantle in the coronal plane, and the importance of an adequate femoral cement mantle in both AP and lateral planes has only recently been appreciated [5, 6].

We would like to point out one limitation to this in vitro study. The use of third-generation cementing techniques in vivo tends to increase cement-mantle thickness because pressurisation results in cement intrusion into cancellous bone (micro-lock). We have not attempted to reproduce this effect using Oasis floral blocks because the foam structure of the blocks would not withstand such high pressures.

In summary, the role of cement-mantle thickness in femoral stem survivorship is poorly understood. If an intact and complete cement mantle is one pre-requisite for long-term survival, then this may be assisted by using femoral broaches that are larger than the equivalent stem. The Stanmore and Exeter THR systems provide such a facility.

Acknowledgement We would like to thank Mr. D. Hitchin at The University of Sussex, and Mr. R. Newson at King's College, London, for statistical advice. We are also indebted to Joint Replacement Instrumentation Ltd., Biomet, and Stryker Howmedica for providing femoral stems and broaches.

References

1. Alho A, Lepisto J, Ylinen P, Paavilainen T (2000) Cemented Lubinus and Furlong total hip endoprosthesis: a 12-year follow-up study of 175 hips comparing the cementing technique. *Arch Orthop Trauma Surg* 120:276–280
2. Anthony PP, Gie GA, Howie CR, Ling RSM (1990) Localised endosteal bone lysis in relation to the femoral components of cemented total hip arthroplasties. *J Bone Joint Surg [Br]* 72:971–979
3. Barrack RL, Mulroy RD, Harris WH (1992) Improved cementing techniques and femoral component loosening in young patients with hip arthroplasty. *J Bone Joint Surg [Br]* 74:385–389
4. Beckenbaugh RD, Ilstrup DM (1978) Total hip arthroplasty. A review of three hundred and thirty-three cases with long follow-up. *J Bone Joint Surg [Am]* 60:306–313
5. Crawford RW, Gie G, Ling RSM et al (1997) Periprosthetic femoral osteolysis: an anatomical explanation. *Proc Br Orth Res Soc* :41
6. Crawford RW, Murray D (1998) Early failure of cemented designs. *Current Orthopaedics* 12:244–250
7. Ebramzadeh E, Sarmiento A, McKellop HA, Llinas A, Gogan W (1994) The cement mantle in total hip arthroplasty. *J Bone Joint Surg [Am]* 76:77–87
8. Gerritsma-Bleeker CLE, Deutman R, Mulder ThJ and Steinberg JDJ (2000) The Stanmore total hip replacement. A 22-year follow-up. *J Bone Joint Surg [Br]* 82:97–102
9. Huiskes R (1980) Some fundamental aspects of human joint replacement: analysis of stress and heat conduction in bone-prosthesis structures. *Acta Orthop Scand [Suppl]* 185: 1–208
10. Jasty M, Maloney WJ, Bragdon CR, O'Connor DO, Haire T, Harris WH (1991) The initiation of failure in cemented femoral components of hip arthroplasties. *J Bone Joint Surg [Br]* 73:551–558
11. Joshi RP, Eftekhari NS, McMahon DJ, Nercissian OA (1998) Osteolysis after Charnley primary low friction arthroplasty. *J Bone Joint Surg [Br]* 80:585–590
12. Kwak BM, Lim OK, Kim YY, Rim K (1979) An investigation of the effect of cement thickness on an implant by finite element stress analysis. *Int Orthop* 2:315–319
13. Langlais F, Kerboull M, Sedel L and Ling RSM (2003) The 'French Paradox'. *J Bone Joint Surg [Br]* 85:17–20
14. Malchau H, Herberts P (1998) Prognosis of total hip replacement. Revision and re-revision rate in total hip replacement: a revision-risk study of 148,359 primary operations, 65th annual meeting of the American Academy of Orthopaedic Surgeons
15. Mellor SJ, Ripley LG and Ricketts DM (2001) The femoral cement mantle in JRI Furlong total hip replacements. *Hip International* 11:191–200
16. Mulroy RD, Harris WH (1990) The effect of improved cementing techniques on component loosening in total hip replacement: an 11-year radiographic review. *J Bone Joint Surg [Br]* 72:757–760

17. Skinner JA, Todo S, Taylor M, Wang JS, Pinskerova V, Scott G (2003) Should the cement mantle around the femoral component be thick or thin? *J Bone Joint Surg [Br]* 85:45–51
18. Smith SW, Estok DM, Harris WH (1998) Total hip arthroplasty with use of second-generation cementing techniques. An eighteen-year average follow-up study. *J Bone Joint Surg [Am]* 80:1632–1640
19. Stauffer RN (1982) Ten-year follow-up study of total hip replacement: with particular reference to roentgenographic loosening of the components. *J Bone Joint Surg [Am]* 64:983–990
20. Sutherland CJ, Wilde AH, Borden LS, Marks KE (1982) A ten-year follow-up of one hundred consecutive Muller curved-stem total hip replacement arthroplasties. *J Bone Joint Surg [Am]* 64:970–982
21. Warren PJ, O'Doherty D, Scott G, Greenough CG (1993) The Furlong total hip: satisfactory interim results of a new cemented arthroplasty. *J Orth Rheumatol* 6:33–36