THE CEMENT MANTLE IN FEMORAL IMPACTION ALLOGRAFTING

A COMPARISON OF THREE SYSTEMS FROM FOUR CENTRES

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An analysis of the cement mantle obtained with the Exeter impaction allografting system at one centre showed that it was either deficient or absent in almost 47% of Gruen zones. We therefore examined the mantle obtained using this system at another hospital and compared the results with those from the CPT and Harris Precoat Systems at other centres.

The surgical indications for the procedure and the patient details were broadly similar in all four hospitals. There was some variation in the frequency of use of cortical strut allografts, cerclage wires and wire mesh to supplement the impaction allograft. Analysis of the cement mantles showed that when uncertain Gruen zones were excluded, the incidence of zones with areas of absence or deficiency of the cement was 47% and 50%, respectively, for the two centres using the Exeter system, 21% for the CPT system and 18% for the Harris Precoat system.

We measured the difference in size between the proximal allograft impactors and the definitive prosthesis for each system. The Exeter system impactors are shorter than the definitive prosthesis and taper sharply so that the cavity created is inadequate, especially distally. The CPT proximal impactors are considerably longer than the definitive prosthesis and are designed to give a mantle of approximately 2 mm medially and laterally and 1.5 mm anteriorly and posteriorly. The Harris Precoat proximal impactors allow for a mantle with a circumference of 0.75 mm in the smaller sizes and 1 mm in the larger.

Many reports link the longevity of a cemented implant to the adequacy of the cement mantle. For this reason, femoral impaction systems require careful design to achieve a cement mantle which is uninterrupted in its length and adequate in its thickness. Our results suggest that some current systems require modification.

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In 1993 Gie et al[1] published an 18- to 49-month follow-up of a series of 56 revision arthroplasties of the hip in which the deficient proximal femur had been reconstituted by the creation of a new medullary canal using impacted morsellised allograft. A polished, tapered, femoral component, used for many years for primary hip replacement,[2] was then cemented into this cavity. Early radiological follow-up showed remodelling of the impacted bone and it was apparent that this was an attractive alternative to revision by cemented or uncemented fixation, or the replacement of the proximal femur with bulk allograft or a prosthesis. Since then there has been one further preliminary report of the results of the technique with a minimum two-year follow-up.[3]

The longevity of a cemented hip prosthesis has been related to the production of a circumferential cement mantle that is uninterrupted and of adequate thickness. Second-generation techniques, such as careful preparation and plugging of the femoral canal, retrograde delivery of cement and pressurisation, are associated with improved longevity and a reduced risk of revision.[4-7] Third-generation techniques, which added roughening or precoating of the stem, centralisation in the cement mantle and the reduction of cement voids by centrifugation or vacuum mixing, show some promise.[8]

After use of the Exeter impaction allografting technique, we became concerned about a number of cases in which there was rapid subsidence of the implant within the impacted

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Fig. 1a

Fig. 1b

Examples of impaction allografting procedures using the Exeter (a) and Harris Precoat (b) prostheses.

allograft in association with radiological evidence of fracture and fragmentation of the cement mantle. We therefore studied the mantle and confirmed that it was often deficient or absent, especially around the distal end of the prosthesis.[9]

We have now examined the cement mantle achieved using the same technique at another centre. We aimed to distinguish the difficulties of an individual unit from problems produced by the design of the system. We have also examined the cement mantles attained after the use of two other systems of impaction allografting at two other hospitals. We report the radiological results obtained at the four centres, using the three different systems.

MATERIALS AND METHODS

The four centres had performed almost 200 impaction allografting procedures. The Exeter impaction allografting system (X-change; Howmedica, Rutherford, New Jersey) had been used in Vancouver and Halifax (Fig. 1a) and a customised impaction allografting system for use with the Harris Precoat prosthesis (Zimmer, Warsaw, Indiana) in Chicago. This system is not marketed commercially (Fig. 1b). The CPT impaction allografting system (Zimmer, Warsaw, Indiana) had been used at the Mayo Clinic (Fig. 2).

For each patient the preoperative radiographs and those taken up to three months after the procedure were analysed independently by one of the authors (ELM) who visited each centre. Patients with incomplete or inadequate radiographs were excluded as were a small number in whom non-standard components had been inserted.

The extent of femoral bone deficiency was assessed on the preoperative radiographs and classified using the systems of both the American Academy of Orthopaedic Surgeons and the Endo-Klinik.[10,11] The indication for the revision procedure and the condition of the acetabulum were also determined. Any doubts were discussed with the relevant operating surgeon.

The best available AP and lateral radiographs taken within three months of operation were used for analysis of the cement mantle. On the AP view we divided the mantle into the seven zones of Gruen, McNeice and Amstutz[12] with zone 1 adjacent to the greater trochanter and zone 7 at the calcar. On the lateral view the mantle was divided into another seven zones which were numbered from 8 to 14, with zone 8 anterior and zone 14 posterior, as recommended by Johnston et al.[13] The cement mantle in each zone was examined in detail and assigned to one of the following categories:

Unclear. The cement mantle could not be distinguished with any degree of certainty from the adjacent impacted allograft.

Adequate. It had a minimum thickness of 2 mm throughout that particular zone.

Deficient. It was less than 2 mm in thickness in some or all areas.

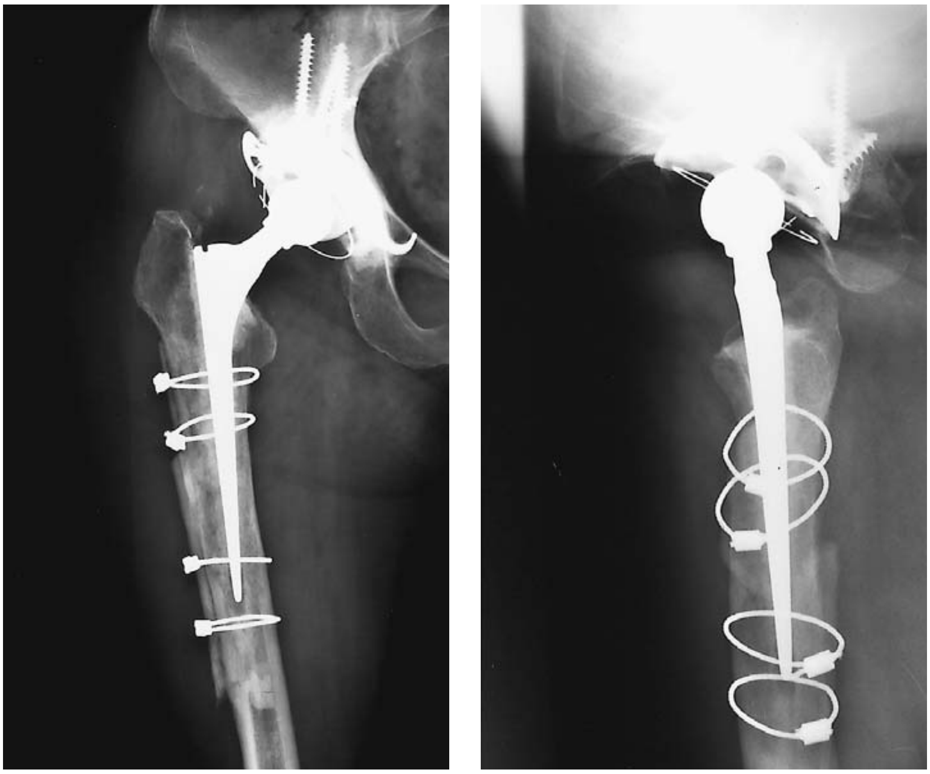

Fig. 2

Anteroposterior and lateral radiographs showing the CPT impaction allografting system.

Absent. There were areas within the zone in which there was no evidence of cement.

We also studied and recorded stem alignment, the use of intramedullary plugs, the management of the acetabular component and the use of cerclage wires, cortical strut allografts and wire mesh to reconstitute the deficient femur.

The percentage of each component, including the femoral head, which was above and below the most proximal bone remaining in the region of the calcar was assessed. Measurements were also taken at the level of the junction between the proximal 75% and distal 25% of the femoral component on the AP film to determine the percentage of the transverse diameter of the femur occupied by the implant at that level.

Finally, we obtained measurements of the length and the mediolateral and anteroposterior diameters of each femoral stem from the three different systems directly from manufacturers' blueprints or by direct measurement of trial implants using callipers. These were compared with the dimensions of the appropriate proximal allograft impactors for each stem to determine the allowance made for a cement mantle with each system (Fig. 3).

RESULTS

We assessed 187 femoral impaction allografting procedures in 185 patients. Table I gives the details of the patients, the implant used, and the dates of operation. The gender and age distribution, and the dates and the side of the operation were generally comparable.

Indications. Aseptic loosening of cemented or uncemented femoral components was the commonest indication for surgery (Table II). A few operations were performed for damage which occurred during the removal of solidly fixed uncemented components for intractable thigh pain or for reconstruction in the second part of a two-stage revision for infection.

Acetabulum. Nine hemiarthroplasties had been treated; all had primary replacement of the acetabulum with a prosthesis. The acetabular component had also been revised during 135 operations and in 43 the original acetabular shell or cemented component had been retained. Table III shows the management of the acetabulum at each of the four centres.

Femur. The preoperative radiological assessment of the deficiency of femoral bone stock is summarised in Table IV. No femur showed purely segmental deficiencies since these are not usually managed by impaction allografting. It is likely, however, that a number of cases which had been recorded as having cavitary defects would have been better classified as combined defects since some segmental deficiencies which were found at operation would not have been obvious on the preoperative films.

There was considerable variation in the use of supplementary cortical onlay allograft to reinforce the femur. All the surgeons commonly used cerclage wires or cables to

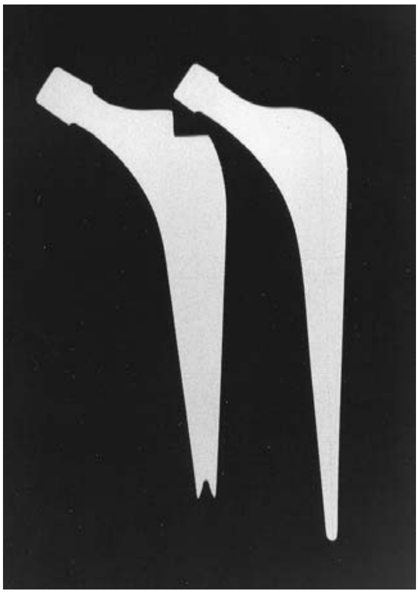

Fig. 3a

Fig. 3b

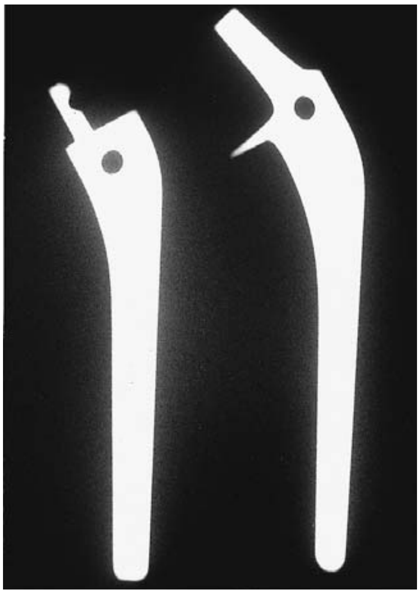

Fig. 3c

Comparison of the mediolateral size differential between the proximal graft impactors and the definitive implant for the Exeter (a), the CPT (b), and the Harris Precoat prostheses (c). For the Exeter prosthesis the recommended proximal impactor is shorter than the definitive implant.

Table I. Details of the patients and implants from the four centres

	Vancouver	Halifax	Rochester	Chicago
Implant used	Exeter	Exeter	CPT	Harris Precoat
Number of surgeons	1	1	2	3
Dates of operation	Feb 94 to Jan 96	Sep 93 to July 96	Feb 93 to July 96	Aug 91 to July 96
Number of patients	35	58	48	44
Number of procedures	35	59	49	44
Male:female	16:19	32:26	23:25	22:22
Right:left	21:14	28:31	29:20	20:24
Mean age in years	62.0	64.6	60.5	58.8
Age range in years	27 to 80	36 to 88	37 to 80	28 to 80

Table II. Indications for femoral impaction allografting

	Vancouver (n = 35)	Halifax (n = 59)	Rochester (n = 49)	Chicago (n = 44)
Loose cemented	22	27	23	33
Loose uncemented	8	23	26	10
Solid uncemented, thigh pain	1	5	0	0
Two-stage exchange for sepsis	4	4	0	1

Table III. Management of the acetabulum

	Vancouver (n = 35)	Halifax (n = 59)	Rochester (n = 49)	Chicago (n = 44)
Primary replacement	1	2	1	5
Not revised	9	6	14	14
Revised	25	51	34	25

protect the femur from the hoop stresses generated during impaction of morsellised bone. Wire mesh was used rarely (Table V).

Alignment of the femoral component. At revision no femoral component was inserted in more than 4° of valgus; 16 were placed in 5 to 8° of varus. The remaining stems were all inserted within 4° of neutral.

Cement mantle. The incidence of zones where the

Table IV. Deficiency of femoral bone stock as defined by the American Academy of Orthopaedic Surgeons (AAOS)[10] and the Endo-Klinik classification[11]

	Vancouver (n = 35)	Halifax (n = 59)	Rochester (n = 49)*	Chicago (n = 44)
AAOS				
Cavitary	16	34	22	21
Segmental	0	0	0	0
Combined	10	8	10	13
Ectasia	9	17	17	10
Malignment	0	0	2	0
Stenosis	0	0	0	0
Endo-Klinik				
Grade 1	0	3	0	0
2	6	36	16	19
3	22	9	18	16
4	7	11	15	9

* two cases at the Rochester centre had femoral alignment in addition to proximal bone loss

Table V. Use of supplementary femoral fixation

	Vancouver (n = 35)	Halifax (n = 59)	Rochester (n = 49)	Chicago (n = 44)
Cortical onlay allograft	9	0	32	9
Cerclage wires or cables*	17	28	37	22
Wire mesh	0	5	2	1

* this includes cerclage wire or cables used to secure cortical onlay allografts

cement mantle could not be distinguished with confidence from the impacted allograft was 18.9% for Vancouver, 14.3% for Halifax, 15.9% for Rochester and 10.6% for Chicago. The lateral radiograph was more likely to contain zones which could not be interpreted although definition was greatly improved when a Lauenstein view had been requested rather than a shoot-through film. When the zones which were uncertain were excluded, the incidence of those with either deficient (<2 mm) or absent cement was 46.1% and 50.4% for the Exeter system (both centres), 20.7% for the CPT system and 18.3% for the Harris Precoat system (Table VI). Cement was most commonly absent from around the Exeter components in zones 3 and 5, but in the other systems there was no obvious zonal distribution of cement deficiency.

Component sizing. There was no significant difference between the different designs in the percentage of the vertical height of the femoral component which was proximal to the bone remaining on the medial side of the femur. There was a wide variation, however, from 18.4% to 46.4%, of the amount of the prosthesis left unsupported (Table VII).

The percentage of the transverse diameter of the femur occupied by the prosthesis at the junction of the proximal 75% and distal 25% of its vertical height ranged from a mean of 26.6% for the CPT stem to 35.4% for the Harris Precoat stem. The range for individual cases was from 17.2% to 43.3% (Table VII).

Examination of the proximal allograft impactors (Fig. 3)**.** We compared the differences between the size of the final allograft impactor or trial stem in each system and the definitive prosthesis appropriate to that impactor. We used the manufacturers' blueprints for the CPT and Precoat systems and sample prostheses and proximal impactors for the Exeter system.

In the Exeter system, the instructions recommend that the proximal impactors or provisional trials, which are the same size, should be inserted an extra 5 mm to make room for the cement mantle. They were found, however, to be 15 ± 1 mm *shorter* than the actual implants for all sizes. Thus, even when the impactors are advanced for the extra 5 mm, the space for the distal 1 cm of the stem and its surrounding cement mantle is created only by the guide wire.

Measurements of the space available for cement with the Exeter system were made at an arbitrary 2.5 and 7.5 cm from the distal tip of the prosthesis for each of the four sizes, again allowing for the additional 5 mm advancement of the impactors. The room for cement medially and laterally ranged from 0.9 to 1.75 mm distally to 2.15 to 2.8 mm proximally, and anteriorly and posteriorly from 0.29 to 0.69 mm distally to 0.3 to 0.8 mm proximally.

The proximal impactor or final trial stem from the CPT system is more than 3 cm *longer* than the real implant and allows space for 2 mm of cement medially and laterally for the full length of the prosthesis except in the calcar where the mantle is thicker. The space for cement anteriorly and posteriorly is 1.57 mm.

The allograft impactors manufactured for use with the Harris Precoat Plus femoral components allow for a circumferential mantle of 0.75 mm in the small and medium sizes and 1 mm in the large along the full length of the prosthesis, and are of the same length as the definitive implants.

DISCUSSION

The evidence for the need for an adequate cement mantle comes from a number of sources including finite-element analysis,[14,15] studies of cadaver retrieval,[16] observations at operation,[17] radiological studies[18,19] and long-term follow-up of the results of techniques which improve the mantle.[4-7]

Cement should allow a smooth transition of forces from the femoral component to the adjacent bone, especially at

Table VI. Analysis of the cement mantle by the number of Gruen zones with adequate, deficient or absent cement. Uncertain zones have been excluded

Cement mantle	Vancouver (Exeter)	Halifax (Exeter)	Rochester (CPT)	Chicago (Harris Precoat)
>2 mm	208 (53.9%)	351 (49.6%)	453 (79.3%)	450 (81.7%)
<2 mm	24 (6.2%)	53 (7.5%)	84 (6.0%)	26 (4.7%)
Absent	154 (39.9%)	304 (42.9%)	34 (14.7%)	75 (13.6%)

Table VII. Measurements of component size (percentage; range) relative to the femur

	Vancouver (Exeter)	Halifax (Exeter)	Rochester (CPT)	Chicago (Harris Precoat)
Femoral prosthesis above remaining calcar	34.9 (23.0 to 43.3)	29.3 (18.4 to 38.6)	30.4 (24.5 to 38.1)	33.1 (24.7 to 46.4)
Transverse diameter of femur at junction of proximal 75% and distal 25% of prosthesis which was occupied by the component	31.3 (22.9 to 37.5)	31.2 (23.1 to 43.3)	26.6 (17.2 to 33.3)	35.4 (21.3 to 43.3)

the proximal and distal ends of the prosthesis where the stresses on weight-bearing are greatest,[20,21] and it should provide a complete circumferential seal which will reduce access to the endosteal surfaces by wear debris.[17,19,22]

There is controversy as to the importance of a rigid bond between cement and the metal prosthesis. Many implants have surfaces which are designed to form such a bond using precoating with methylmethacrylate, porous coating or a variety of surface lines, grooves or other finishes. Other authors stress the importance of continuous loading of the cement by a polished prosthesis with a double-tapered geometry, which allows the mantle to flow at a very slow rate.[2]

With femoral impaction allografting, the Exeter and CPT systems aim to maintain compression of the allograft by cold flow of the cement during the gradual subsidence of the prosthesis. The other stem is designed to remain rigidly bonded to the surrounding cement. The relative advantages of one system over the other remain uncertain.

The success of the double-taper stem configuration in primary hip arthroplasty has been attributed partly to proximal loading of the femur[2] which is achieved by careful cement pressurisation and by the relative bulk of the proximal part of the prosthesis. Fracture of the distal stem of these prostheses is rare. When reconstituting the deficient proximal femur with impaction allografting, however, the ability to transmit proximal loading is limited by the enlarged dimensions of the medullary cavity, the presence of morsellised bone, and commonly, a deficient calcar which must be reconstituted with mesh. It may be then more important to ensure that the cement mantle is adequate around the entire prosthesis.

Other factors may also be important in determining the clinical results of femoral impaction allografting. These include the size of the component relative to the femur, the quality of the allograft bone and whether or not it has been irradiated, the use of cortical onlay allografts, cerclage wires or mesh and the density to which the morsellised bone is impacted, which will be influenced considerably by the extent of bone deficiency.

We have shown that the cement mantle produced by the Exeter system is often deficient, partly because of an inadequate difference in size between the impactors and the definitive prostheses. Radiological assessment of the other systems showed a more consistent cement mantle. Since this is not a clinical study, we cannot report whether one system functions better than another, but numerous publications have expressed concern about the survival of primary prostheses which do not have an adequate cement mantle.

The concept of impaction allografting remains attractive, but refinements of the technique to help to improve the predictability of the radiological appearance of the cement mantle may give better clinical results.

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