The inadequacy of standard radiographs in detecting flaws in the cement mantle

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Radiological assessment of the cement mantle is used routinely to determine the outcome of total hip replacement. We performed a simulated replacement arthroplasty on cadaver femora and took standard postoperative radiographs. The femora were then sectioned into 7 mm slices starting at the calcar, and high-resolution faxitron radiographs were taken of these sections.

Analysis of the faxitron images showed that defects in the cement mantle were observed up to 100 times more frequently than on the standard films. We therefore encourage the search for a better technique in assessing the cement mantle.

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If outcome measures are to be an important tool in orthopaedic research, the systems used for assessment must be reliable.^{1,2} Aseptic loosening is commonly assessed by the use of conventional radiographs to identify migration, defects in the cement mantle and radiolucent lines at the implant interfaces. Gruen, McNeice and Amstutz³ described the widely used seven-zone system which allows the localisation of fractures in the cement and radiolucent lines at both the cement-bone and prosthesis-bone interfaces. Johnston et al⁴ used the Gruen system as a basis for a more comprehensive evaluation which included clinical data, observations about the position of the stem and heterotopic ossification. Barrack, Mulroy and Harris⁵ analysed the quality of cementing and described four grades on post-operative radiographs.

These methods have been widely used to measure outcome and to demonstrate the effectiveness of various techniques.³⁻⁶ Concerns have been raised over the reliability of radiographs used for assessment. The three systems outlined above were the subject of a study on interobserver and intraobserver error,⁷ which concluded that the levels of intraobserver error were moderate and that those between observers were poor or fair and, at times, less than would be expected by chance alone. Johnston et al⁴, in describing their system, stated that they did not believe that the true meaning of a radiolucency was known. Our study used a simulated arthroplasty as a model but it was not an experiment on bone cement as an isolated material. A comparison was made of standard postoperative radiographs and high-resolution faxitron images of sections of the implanted specimen. The number of defects seen in the cement mantle was counted for each system and the presence of radiolucent lines assessed.

Materials and Methods

We used six pairs of human femora, obtained by informed consent from relatives at post mortem and stored freshly-frozen. The simulated arthroplasty used the standard Charnley system in a class-one microbiological safety cabinet.

Fig. 1

Faxitron radiograph enlarged to show defects (dark areas).

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Table I. Number of defects in cement seen on faxitron and on standard radiographs for each of the 12 femora

Pair	Gun			Finger		
	Faxitron	Radiograph	Matched	Faxitron	Radiograph	Matched
1	298	3	2	362	0	0
2	294	0	0	169	0	0
3	268	2	2	149	0	0
4	417	2	2	112	1	1
5	693	3	0	482	3	0
6	297	0	0	275	0	0
Median	297.5	2	1	222	0.5	0

All femora were prepared in a standard fashion using powered brushing, pressure lavage, a cement restrictor and 3 ml of blood at the bone interface to simulate bleeding. The cement was hand-mixed, but in one femur of each pair it was inserted digitally and in the other retrograde using a gun.

We took anteroposterior and lateral radiographs after operation. The femora were then sectioned using a high-precision microgrinding system into 7 mm specimens, the first cut starting at the calcar. Faxitron radiographs gave high-definition images of each of the 12 sections obtained.

Fig. 2a

Fig. 2b

Fig. 2c

Figure 2a – A typical postoperative radiograph showing a hazy lucent line medially. Figures 2b and 2c – Faxitron radiographs of sections 2 and 5 from the same femur showing no defect at the cement-bone interface.

Fig. 3a

Fig. 3b

Fig. 3c

Figure 3a – A lateral postoperative radiograph showing a clear lucent line anteriorly. Figures 3b and 3c – Faxitron radiographs of sections 4 and 7 from the same femur showing an obvious defect between the cement and the bone.

Analysis of the standard radiographs and the faxitron images was made to assess the quality of the cement mantle and the position of any defects. The faxitron images were examined visually on a light box (Fig. 1) and two observers, an orthopaedic consultant and a trainee with an interest in hip replacement, reviewed the standard radiographs. Defects on each radiograph were noted in accordance with the Gruen zones to allow them to be matched. Statistical analysis was by the Mann-Whitney U test for non-parametric data with the level of significance taken at $p \leq 0.05$.

Results

The defects observed for each femur are presented in Table I. The total number of defects detected by faxitron exceeded those seen on standard radiographs by 149:1 for the gun and 444:1 for finger-packing. The number of defects seen on the faxitron for finger-packing ($p = 0.005$) and retrograde insertion using a gun ($p = 0.005$) were both significantly greater than those seen on standard postoperative films. The defects which were seen on the stand-

ard radiographs corresponded to those seen on the faxitron, although the numbers are too small for meaningful comparison.

The appearances of radiolucent lines on the standard and faxitron radiographs differed. Figure 2a shows a typical radiolucent line at the medial cement-bone interface which is hazy in outline. Figures 2b and 2c are faxitron radiographs of sections 2 and 5 of the same femur which show that the cement in the trabeculae did not penetrate to the cortex. Figure 3a shows another femur with a radiolucent line with a very distinct and clear outline. Figures 3b and 3c are faxitron radiographs of sections 4 and 7 of the same femur, showing the failure of the cement to penetrate to or even appose the cortex of half of the cement-bone interface. The pressure, however, was adequate to allow penetration to the other areas of cortex. This suggests that there is a fluid layer preventing the penetration of the cortical bone.

Discussion

Defects in the cement mantle which occur at the time of operation can, in part, be controlled by the operative tech-

nique. Those that appear gradually over time, are usually associated with fracture of the cement or loosening of the prosthesis. Primary defects may be due to entrapment of air during mixing, air spaces between the polymer beads, voids due to monomer evaporation, thermal expansion or cavitation voids.

Defects, acting as stress risers, lead to fatigue-failure,⁸ but improved methods of mixing cement have reduced their number.⁹ Centrifugation produces an increase of 54% in the ultimate tensile strength and of 136% in the fatigue-life when compared with a control group.¹⁰ Vacuum mixing can reduce porosity to 0.1% to 0.8%, compared with 7.2% to 9.4% for hand mixing, resulting in a rise in uniaxial tension.⁹ Even better results are obtained with mechanical mixing.¹¹ It must be stated that the observations made in our study relate to hand-mixed cement and that further work is required to compare these results with the more modern mixing techniques.

Our study does not convey clinical relevance with certainty because of its laboratory design. Nevertheless, the different types of radiolucent line are interesting. The first type features a gradual change in radiodensity from cement to cancellous bone and a normal transition to cortical bone. This appears to be associated with a failure of the cement to penetrate to the endosteal surface and may be improved by measures taken to enhance cement ingress. The second type features a distinct change in radiodensity at the edge of the cement mantle and appears to be associated with partial failure of the cement to appose the endosteal surface even although the trabecular structure was well penetrated. This could be the result of an interposed fluid barrier. The importance of surface preparation and control of blood at the interface¹² is particularly relevant to such an appearance.

The most significant finding, however, is the failure of standard postoperative radiographs to show the presence of potentially serious defects in the cement mantle. Routine assessment by standard radiographs and their use in clinical

trials should be viewed with caution. There is clearly a requirement for more reliable methods of assessing the cement mantle, focusing attention on implant migration and bone reaction rather than on the radiological appearance.

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