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Prediction of Charnley femoral stem aseptic loosening by early post-operative radiological features

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Abstract We describe the association between immediate post-operative radiological appearances and early aseptic failure of total hip replacement. Sixty-three hips were entered into the aseptic failure group and 138 into the control group. Alignment of the femoral stem was not associated with failure (p=0.283). Thickness of the cement mantle was associated with failure in Gruen zones 6 (p=0.040) and 7 (p=0.003). A significant association for the presence of radiolucent lines was found for Gruen zones 3 (p=0.0001) and 5 (p=0.0001). Grade of cementation was associated with failure for Barrack grades C (p=0.001) and D (p=0.001). This study has demonstrated that easily applied radiological criteria can be used to identify 'hip arthroplasties at risk' from the immediate post-operative radiograph.

Résumé Nous décrivons l'association entre l'aspect radiologique postopératoire immédiat et l'échec aseptique précoce de l'arthroplastie totale de la hanche. Soixante-trois hanches sont entrées dans le groupe de l'échec aseptique et 138 dans le groupe témoin. L'alignement de la tige fémorale n'était associé à l› échec (p=0.283). L'épaisseur du manteau de ciment était associé à l› échec dans les zones de Gruen 6 (p=0.040) et 7 (p=0.003). Une association significative a été trouvée avec la présence de liserés dans les zones de Gruen 3 (p=0.0001) et 5 (p=0.0001). Le niveau de cimentation a été associé à l'échec pour les grades C (p=0.001) et D (p=0.001) de Barrack. Cette étude montre que des critères radiologiques simples peuvent être utilisés pour identifier les ‹ arthroplasties à risque› sur les clichés post-opératoires immédiats.

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Introduction

The principal cause of failure of cemented total hip arthroplasty (THA) is aseptic loosening and associated periprosthetic osteolysis. There is evidence that improvements in cementing techniques have increased the longevity of THA [7, 14, 15, 17]. A number of previous studies have attempted to find associations between the femoral and acetabular cement mantles in post-operative radiographs and failure of THA components. These have tended to be retrospective observational cohort studies on a heterogeneous group of patients undergoing THA. As such, the number of failed relative to successful implants that have been studied has been very small [4, 11, 21, 23]. Correlation between initial diagnosis and implant survival has also been described [5, 19] but not searched for in the descriptions of the impact of careful cementing technique on implant survival. A recent case-control study attempted to relate the radiological quality of the immediate post-operative cement mantle to the subsequent development of aseptic loosening of the femoral stem. However, only 22 radiographs of failed stems were analysed and the control group was poorly selected, as the entry criterion was only that aseptic loosening had not developed by 5 years after implant insertion [3].

In this study, we describe the association between the radiological appearances of the immediate post-operative femoral cement mantle and early aseptic failure of THA. The flaws in previous studies have been addressed by only choosing patients with a primary diagnosis of osteoarthritis, including a large number of cases with strictly defined early aseptic loosening and a large number of controls with a minimum clinical and radiological follow-up of 10 years.

Material and methods

We performed a retrospective review of the records and radiographs of all THA patients attending for follow-up at Wrightington Hospital between August 2002 and August 2003. They had undergone THA either at Wrightington Hospital or had been referred for revision surgery from other hospitals. Strict inclusion and exclusion criteria were set for the study group (aseptically loosened THA) and the control group (well-fixed implants) to make them directly comparable. Only Caucasian patients of either gender with a primary diagnosis of osteoarthritis were included. All had a cemented Charnley monoblock femoral stem and either a cemented Charnley or Ogee flanged polyethylene acetabular cup. Radio-opaque cement had been used in all cases.

Failure

Early aseptic loosening for both components was defined as that occurring within 6 years of implantation, in line with the yearly incidence of loosening in the evolution of the Charnley low-friction arthroplasty [18]. Femoral stem aseptic loosening was defined either by findings at revision surgery, the definite radiographic loosening criteria of Harris [8] or progressive endosteal cavitation across zones as described by Gruen [6]. All patients were clinically symptomatic due to component failure. Well-fixed control THAs were defined as those that had remained clinically asymptomatic for over 10 years and demonstrated none of the described radiographic features of aseptic loosening or 'at risk' signs as described by Wroblewski et al. [18].

Radiological analysis

A single surgeon blinded to which group the patient had been entered assessed the initial index post-operative antero-posterior pelvis X-ray of every patient entered into the trial. Lateral radiographs were not assessed, as they were not routinely taken. The following parameters were measured:

(1) Alignment: Coronal alignment of the femoral prosthesis was measured as the angle between the central axes of the proximal femoral canal and the Charnley femoral prosthesis. Angles were classified as varus, valgus or neutral.
(2) Grade of cementation: Barrack et al. [2] described a grading system for the quality of femoral cementing in THA, which has been used as a measure of the cement-bone interface.
(3) Cement mantle: The widest width of the cement mantle in millimetres and the presence and width of any radiolucent lines (RLLs) at either the cement–bone or cement–prosthesis interfaces were measured in the seven Gruen zones [6] for the femur.

Table 1 Mean cement mantle thickness in each Gruen zone for both groups, and step-wise logistic regression of cement mantle thickness

Gruen zone	Aseptic failures	Controls	*p* value
1	3.38	3.72	0.104
2	3.06	2.86	0.756
3	2.50	2.84	0.085
4	13.62	14.04	0.368
5	2.10	2.40	0.058
6	2.88	3.18	0.040
7	4.83	6.04	0.003

Twenty-five radiographs were chosen at random and re-assessed by the observer. The findings were the same in 23 cases, giving an intra-observer error of 8%.

Statistical analysis

Independent and step-wise logistic regression analysis was performed using chi-squared and Fisher's exact test to determine whether the radiological variables studied were associated with femoral prosthesis aseptic loosening.

Results

We identified 224 hips in 218 patients suitable for inclusion in the study. Of these hips, 23 did not have their original post-operative radiographs available, leaving 201 hips in 201 patients. Sixty-three hips were entered into the early aseptic loosening group and 138 into the control group. The mean age of all patients was 69.2 years (70.9 in the control group and 66.2 in the aseptic group). There were 114 women and 87 men. Differences in age and gender between the two groups were not statistically significant.

The mean alignment in the failure group was 3.2° valgus (standard deviation: 2.17°) and 2.0° valgus (standard deviation:1.97°) for the control group. Alignment of the femoral stem was not associated with failure (p=0.283). Mean cement thickness in each Gruen zone and the

Table 2 Prevalence of radiolucent lines (RLLs) in each Gruen zone for both groups, and step-wise logistic regression of the presence of RLLs

Gruen zone	Aseptic failures	Controls	*p* value
1	26	48	0.382
2	31	52	0.173
3	36	41	0.001
4	7	14	0.915
5	25	20	0.001
6	26	44	0.127
7	26	44	0.127

Table 3 Barrack grades for femoral cement mantles

Barrack grade	Aseptic failures	Controls
A	9	47
B	14	52
C	28	28
D	12	11

association between cement mantle thickness and failure are shown in Table 1. Thickness of the cement mantle was statistically associated with failure in Gruen zones 6 (p=0.040) and 7 (p=0.003) and approached significance in Gruen zone 5 (p=0.058).

The presence of RLLs and the association between RLLs and failure are shown in Table 2. A significant association was found for Gruen zones 3 (p=0.0001) and 5 (p=0.0001). The width of RLLs was not associated with failure.

The grade of cementation as measured by the Barrack grade was strongly associated with failure (Table 3) for grades C (p=0.001) and D (p=0.001).

Discussion

The quality and thickness of the femoral cement mantle has been the subject of much debate based around clinical, laboratory and post-mortem retrieval studies. It is often stated that cement mantles should be complete and of 2–4 mm in thickness with the inference that otherwise stem subsidence, cement mantle fracture and osteolysis are likely to follow [12]. onversely, a recent article has highlighted the 'French Paradox' of canal-filling stems, which have thin and often incomplete cement mantles but undeniably good medium- and long-term survivorship [22].

Most clinical studies have identified a cohort of patients with medium- to long-term follow up. By the very nature of these retrospective studies, from a heterogeneous cohort, only relatively small numbers of failed THAs are identified and compared against much larger numbers of successful THAs. We have attempted to improve upon the only previous case-control study by matching our groups according to gender, age and quality of surgery and by differentiating between early failure, which is much more likely to be due to mechanical factors as opposed to biological response to wear debris, [1] and long-term survival.

The effect of an uneven cement mantle has been reported by a number of groups. Ebramzadeh et al. noted that femoral stems that had a 2- to 5-mm cement mantle in the proximal medial region had a better outcome than stems with a thicker or thinner mantle [4]. Star et al. reported on 100 Zimmer DF-80 prostheses in a 2–5 year follow-up and related loosening to a thin cement mantle in Gruen zones 5 and 6 or to excessive varus or valgus stem alignment [23]. Ritter et al. reported on 185 Charnley THAs with a mean follow-up of 11.7 years, of which only 15 stems developed aseptic loosening. Defects in Gruen zone 5 were associated with failure [21]. Our study confirmed that it is the medial cement mantle that determines the development of early aseptic loosening in Charnley femoral stems. No such association was found with stem alignment, but this may be due to the fact that there were few stems in marked valgus or varus [4, 23]. It has not escaped our notice that stems in varus tend to have a decrease in medial cement mantle thickness and may explain the above findings.

In our study, we tried to correlate this finding with the presence of RLLs and the grade of cementation. Iwaki et al. [8] reported on the natural history and significance of RLLs at the cement–prosthesis interface of 185 Freeman THAs. They proposed that progressive RLLs as assessed at 2 years post-operatively determined outcome. However, this was based on a total of only six radiological failures. Other groups found no association [3, 21], but the presence of RLLs has been associated with poorer prognosis [10, 24]. Our study demonstrated a strong association between RLLs in Gruen zones 3 and 5 and early failure. This mirrors the development of lytic lesions in these zones and the relative non-progressive nature of Gruen zone 1 and 7 RLLs in the study by Iwaki et al. [8]. They suggest that this represents failure of cement to interlock with the bone at the time of prosthetic implantation, which in the former situation leads to progressive loosening and stem migration. Zones 3 and 5 may be predisposed to this due to the higher stresses in the cement mantle near the tip of the stem [16].

The Barrack system for grading cementation has been shown to be strongly associated with failure for grades C and D. This ties in with the radiological findings already presented, as these grades suggest either an incomplete mantle or at least 50% radiolucency at the cement–bone interface. The validity of radiological evaluation of the interfaces after cemented total hip replacement (THR) has been questioned because of errors in interpretation and difficulties in accurately quantifying cement mantles [9, 13, 20]. The lack of sensitivity in observing cement mantle defects can only have resulted in an underestimate of the associations reported. The system of Chambers et al. [3] of grouping grades A and B together as 'adequate' and grades C and D as 'inadequate' would appear to be an attractive method of quickly assessing in the clinical setting which THAs may require close follow-up. Those with a poor medial mantle or with distal RLLs in either Gruen zone 3 or 5 would require particularly close follow-up. These radiological criteria also provide a useful guide for the training of surgeons in the technique of THA.

The cemented Charnley THR continues to be the 'gold standard' by which the performance of other THRs are judged. This study demonstrated that easily applied radiological criteria can be used to identify 'at risk' Charnley THAs from the immediate post-operative AP radiograph. This has direct implications regarding surgical technique, training and proposed follow-up regimes of individual Charnley THAs. Our study suggests the predictive value of early radiographs, and we intend to confirm this by the prospective analysis of Charnley stems at our unit.

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