The principle of low frictional torque in the Charnley total hip replacement

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The design of the Charnley total hip replacement follows the principle of low frictional torque. It is based on the largest possible difference between the radius of the femoral head and that of the outer aspect of the acetabular component. The aim is to protect the bone-cement interface by movement taking place at the smaller radius, the articulation. This is achieved in clinical practice by a 22.225 mm diameter head articulating with a 40 mm or 43 mm diameter acetabular component of ultra-high molecular weight polyethylene.

We compared the incidence of aseptic loosening of acetabular components with an outer diameter of 40 mm and 43 mm at comparable depths of penetration with a mean follow-up of 17 years (1 to 40).

In cases with no measurable wear none of the acetabular components were loose. With increasing acetabular penetration there was an increased incidence of aseptic loosening which reflected the difference in the external radii, with 1.5% at 1 mm, 8.8% at 2 mm, 9.7% at 3 mm and 9.6% at 4 mm of penetration in favour of the larger 43 mm acetabular component.

Our findings support the Charnley principle of low frictional torque. The level of the benefit is in keeping with the predicted values.

In developing his total hip replacement (THR) Charnley used polytetrafluoroethylene (PTFE) first as 'synthetic cartilage' interposition shells¹ then with a 'standard Moore prosthesis with a head 1-5/8 inches (41.5 mm) in diameter'.² Charnley was persuaded that 'resistance to the movement of the head in the socket is greatly reduced by reducing the radius of the ball and therefore reducing the 'moment' of the frictional force. If at the same time the radius of the exterior of the socket is made as large as possible, the moment of the frictional force between the socket and bone will be increased, and this will lessen the tendency for the socket to rotate against the bone'.² "Since there was no way of estimating the rigours of service in the human hip joint over a period of years we had to proceed by trial and error from the starting size of 41.5 mm the diameter was reduced to 28.5 mm then to 25 mm and finally to 22 mm".² It is that change from low friction, the property of the materials, to low frictional torque, the principle of the design, that marked the turning point in the evolution of the Charnley low frictional torque arthroplasty (LFA).

In an attempt to establish the optimum size of prosthetic metal heads in relation to the wear of plastic acetabular components,

Charnley, Kamangar and Longfield³ examined 100 explanted PTFE acetabular components and concluded that "..... the sphere should have a diameter not greater than half of the external convex diameter of the socket".

Andersson, Freeman and Swanson⁴ questioned the benefit of the low frictional torque in clinical practice. Using Charnley 22.225 mm diameter stainless steel heads with ultra-high molecular weight polyethylene (UHMWPE) and a McKee-Farrar metal-on-metal design cemented into cadaver pelvises, the torsional moments needed to loosen the acetabular components were measured. They concluded that "the torsional moments were found to be from four to more than 20 times higher than the frictional moments measured".⁴ Their suggestion was that "late loosening of the acetabular component, was most likely due to thermal damage to the bone occurring at the time of polymerisation of the cement and the subsequent bone resorption".⁴ No evidence was offered to support this statement. Fatigue fracture of bone, as a factor contributing to late loosening, was suggested to support the use of UHMWPE, although the "importance of this factor could not be estimated".⁴ Charnley⁵ argued that it was because of the low frictional torque that

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the radiographic demarcation of the bone-cement interface of the component did not progress to clinically symptomatic acetabular component loosening.

Ma, Kabo and Amstutz⁶ studied frictional torque both in resurfacing and in conventional hip replacement with cemented UHMWPE acetabular components, and concluded that frictional torque was proportional to the diameter of the head of the femoral component, becoming lower as the thickness of the UHMWPE acetabular component increased.

Ritter et al⁷ compared 67 Müller THRs with a 32 mm prosthetic head and an acetabular component of 50 mm diameter, with 300 Charnley arthroplasties with a 22 mm prosthetic head and acetabular component of 44 mm diameter, at a minimum follow-up of seven years. The acetabular component in the Müller series was found to be loose in 15%, compared to 4% in the Charnley group ($p < 0.032$). The survival at five and seven years was respectively 87% and 70% for the Müller and 94% and 86% for the Charnley ($p < 0.003$). They concluded: "The difference is possibly due to the large Müller femoral head".⁷

Morrey and Ilstrup⁸ assessed the correlation between the size of the head of the femoral component and acetabular revision in 6128 THRs and concluded: "although friction increases with the size of the femoral head, theoretically it remains significantly low so that the bone-cement interface is not at risk".

This conclusion must be questioned as friction does not increase with the size of the femoral head but frictional torque does. Furthermore, radiolucent lines were more frequent at the bone-cement interface of the acetabular component with the 32 mm diameter head: 29%, as opposed to 15% with the 22 mm diameter head. 'Multivariate analysis showed that the 32 mm component was associated with a higher incidence of loosening than the 22 mm component'.⁸ The revision rate for aseptic loosening was also higher with the 32 mm, 6.8% as opposed to 2% to 3% for the 22 mm diameter head. The authors also found it "important to emphasise that the use of the 32 mm component was initiated approximately five years after considerable experience had been accumulated with the 22 mm component. This suggests that better results should have been achieved with the larger model: however, the opposite was true".⁸

In a study by Frankel et al,⁹ of the effect of the size of the femoral head on the radiographic demarcation of the acetabular bone-cement interface a comparison was made between 32 mm and 22 mm head sizes at 19 to 24 months' follow-up: "three-zone demarcation of the acetabular bone-cement interface was 56% of the 32 mm group as compared to 5% of the 22 mm group. When a sub-group of women under 60 years of age was examined to control variables, the high grade demarcation rates were 67% and 18% respectively". The conclusion was that "these results emphasize the adverse effects of large femoral head prostheses on bone-cement interface and underline the need for alternative methods of fixation".⁹

The contribution of frictional torque to loosening of the bone-cement interface was examined in Tharies hip replacements.¹⁰ The authors concluded that frictional torque was not the primary factor in loosening of the prostheses with a large bearing surface, and that the higher friction and frictional torque can be tolerated if the generation of wear debris was sufficiently limited.¹⁰ The conclusions were based on 170 Tharies hip arthroplasties with a follow-up to 16 years. The overall revision rate was 47.1%. The revision rate for aseptic loosening of the acetabular component was not dissimilar, irrespective of whether the components were small: (23.5%), medium: (23.5%) or large: (26.5%). The number of hips in each group was just within the acceptable limits for survival analysis¹¹ at the beginning but not at the end of the study. The authors also suggested that "polyethylene wear has a greater effect on the durability of fixation of the implant than does frictional torque".¹⁰ No evidence was offered to support this statement, and measurements of wear were not given.

We set out to investigate to what degree the theoretical advantages of the low frictional torque are reflected in the long-term results of the Charnley LFA, taking radiographic evidence of loosening of the acetabular component as the endpoint.¹²

Theoretical considerations. The diameter of the head of the Charnley stem is 22.225 mm. The frictional torque is inversely proportional to the external radius of the UHMWPE component. With increasing depth of acetabular component penetration the radius of the worn part of the acetabular component will shorten, increasing the frictional torque. This will be reflected in the increasing incidence of aseptic loosening.

With the Charnley design the acetabular component-head radius ratio is 1.8 for the 40 mm and 1.9 for the 43 mm diameter acetabular component. The difference, expressed as a percentage is 7% to 7.5%. It was therefore postulated that the benefit of the larger, 43 mm diameter acetabular component should be reflected in a lower incidence of aseptic acetabular component loosening of 7% to 7.5% at comparable depths of penetration of the cup, irrespective of factors affecting wear.

Materials and Methods

Patients undergoing a Charnley LFA between November 1962 and December 1990 were included in an indefinite follow-up study. They were aged 50 years or less at the time of operation.¹³ Routine follow-up was at three months, then annually and subsequently according to the radiographic appearances, the level of patient activity, or the rate of wear of the acetabular component.¹³ The radiographic appearances of the bone-cement interface were classified according to Hodgkinson et al.¹² Complete demarcation > 1 mm or migration of the acetabular component observed as a change in position on serial radiographs were taken to indicate loosening. Measurements of wear were made from

Table I. Demographic details

Acetabular component size (mm)	40	43
Number of hips	453	879
Gender		
Male	37	369
Female	301	309
Age in yrs		
Mean (range)	40.3 (15 to 50)	41.7 (19 to 50)
Weight in kg		
Mean (range)	59 (32 to 93)	69 (30 to 108)
Number of acetabular component loosening (%)	121 (26.7)	187 (21.3)

Table II. Acetabular component penetration and loosening

Acetabular component			Component loosening
Penetration (mm)	Size (mm)	Number	Number (%)
0	40	8	0 (0)
	43	21	0 (0)
≤ 1	40	222	21 (9.5)
	43	438	35 (8.0)
≤ 2	40	90	34 (37.8)
	43	169	49 (29.0)
≤ 3	40	78	35 (44.9)
	43	128	45 (35.2)
≤ 4	40	36	18 (50.0)
	43	52	21 (40.4)
> 4	40	19	13 (68.4)
	43	71	37 (52.1)

Fig. 1

Graph showing penetration and loosening of the acetabular component.

radiographs by an experienced Senior Research Fellow (PDS) by a method previously published,¹⁴ and recorded as penetration. We compared the incidence of aseptic loosening, at comparable depths of penetration, in patients who had received an acetabular component of 40 mm diameter with those in whom one of 43 mm diameter had been used.

Results

In the group of 1092 patients (1434 LFAs) there were 424 men and 668 women. Their mean age at surgery was 41 years (12 to 50). At the latest review in September 2008, 98 patients (9.0%) with 121 LFAs (8.4%) did not have a continuing follow-up, 129 patients (11.8%) with 181 LFAs (12.6%) were known to have died, 263 (24.1%) with 330 LFAs (23.0%) had a revision, and 602 patients (55.1%) with 802 LFAs (55.9%) were attending follow-up and had not had a revision.

The mean duration of follow-up for the whole group was 17 years (1 to 40), and for the patients still attending was 20 years and seven months (10 to 40).

We excluded 102 hips from the study. In 58 an offset-bore acetabular component¹⁵ had been used; this acetabular component has no chamfer and the eccentricity of the bore and the direction of penetration do not allow determination of the external radius of the acetabular component with respect to the head. In 16 others, the quality of the radiographs was unsuitable for the measurements. We also excluded 28 cases where deep infection was present. The remaining 1016 patients with 1332 LFAs were the subject of our study. The results are shown in Tables I and II and Figure 1. The direct correlation between the depth of acetabular penetration and the incidence of acetabular loosening confirms previous findings.^{13,16-20,21} The higher incidence of loosening of the 40 mm diameter component

compared with the 43 mm diameter component, at comparable depths of penetration, supports the low frictional torque concept in the Charnley THR.

Discussion

The long-term benefit of low frictional torque, as reflected in the low incidence of aseptic loosening of the acetabular component, is the fundamental aspect of the design and practice of the Charnley hip replacement. In the original inventory, acetabular components of 43 mm and 40 mm diameter were available. The ratio of the radius of the acetabular component to the head was 1.9:1 and 1.8:1 respectively, close to the 2:1 suggested by Charnley et al.³ Provided this ratio remained, as in cases with no measurable wear, none of the acetabular components showed radiological evidence of loosening with a follow-up of up to 12 years. It is in this context that alumina ceramic and cross-linked polyethylene have proved beneficial.²² With increasing depth of penetration of the acetabular component the increase in frictional torque is reflected in the progressive rise in the incidence of loosening. This was 1.5% at 1 mm, 8.8% at 2 mm, 9.7% at 3 mm and 9.6% at 4 mm of penetration in favour of the 43 mm diameter acetabular component. This is considered close to the predicted percentage difference in the frictional torques between the radii of the acetabular components of 40 mm and 43 mm diameter. With penetration of > 4 mm, restriction of movement and impingement of the neck of the stem on the rim of the acetabular component will become the dominant factor leading to loosening.^{13,16-21} The available acetabular bone stock is the factor limiting the size of the acetabular component. Increasing the size of the acetabular component also increases its projected area and will reduce the pressure and the quality of cement injection.²³ Cement pressurisation before insertion of the acetabular component is recommended. As the benefit of the 22.225 mm diameter head has been shown theoretically and supported by clinical results⁶⁻⁹ and in our long-term study in young patients, it is unclear to us why there is continuing trend to use larger-diameter heads. Increasing the diameter of the head can only be achieved at the expense of thickness of the acetabular component. Other than increasing frictional torque, it will require hard-on-hard articulation. With little or no room for cement, the need for alternative methods of fixation⁹ appears clear, though methods avoiding the use of cement have yet to offer comparable long-term results. The Charnley LFA has now been followed up for more than 40 years. Further improvements will come from a combination of low-wear materials²² while retaining the principle of low frictional torque.

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