BONE REMODELLING IN THE PROXIMAL FEMUR AFTER CHARNLEY TOTAL HIP ARTHROPLASTY

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We measured bone mineral density (BMD) in the proximal femur by dual-energy X-ray absorptiometry (DEXA) in 20 patients after cemented total hip arthroplasty over a period of one year.

We found a statistically significant reduction in periprosthetic BMD after six months on the medial side and on the lateral side adjacent to the mid and distal thirds of the prosthesis. At one year after operation there was a mean 6.7% reduction in BMD in the region of the calcar and a mean 5.3% increase in BMD in the femoral shaft distal to the tip of the implant.

These changes reflect a pattern of reduced stress in the proximal femur and increased stress around the tip of the prosthesis. They support current concepts of bone remodelling in the proximal femur in response to prosthetic implantation.

Received 3 January 1995; Accepted 2 March 1995

Two well-documented changes in the bone of the proximal femur after cemented total hip arthroplasty (THA) are distal cortical hypertrophy and resorption of the medial femoral neck, often called calcar resorption (Charnley, Follacci and Hammond 1968; Carlsson and Gentz 1980; Sarmiento et al 1988).

Charnley and Cupic (1973) reported that 41.5% of hips had radiological evidence of calcar resorption nine to ten years after Charnley THA and this increased to 70% with longer follow-up (Blacker and Charnley 1978). Nicholson (1973) found a 22.8% incidence of calcar resorption at three to four years after operation in 250 Charnley THAs.

Distal cortical hypertrophy has been defined as "a fusiform enlargement of the cortical bone in the region of the tip of the stem of the prosthesis" (Ritter and Fechtman 1988). Blacker and Charnley (1978) had noted two different forms of hypertrophy: one involved thickening of the endosteal cortex without external change, and the other caused an increase in the thickness of the cortex with widening of the external diameter, which may become apparent on radiographs as early as six months after operation. Salvati et al (1976) have suggested that this change usually occurs within the first year after operation.

The relationship between these changes and their significance is uncertain. In a retrospective study of 1683 THAs using eight different prostheses, Ritter and Fechtman (1988) found distal cortical hypertrophy in 3.4% of hips. In addition, 38% of hips with hypertrophy showed calcar resorption, as compared with 13% of hips with no distal hypertrophy. This contrasts with the findings of Blacker and Charnley (1978) who found no such correlation in a series of 133 Charnley THAs. Carlsson and Gentz (1980) found a highly significant correlation between calcar resorption and loosening of the femoral component, which they defined as a radiolucent zone at the cement-bone interface on the lateral side of the prosthesis.

There is also evidence that distal cortical hypertrophy and calcar resorption are affected by the mechanical properties of the prosthesis. Changing the modulus of elasticity of a femoral component alters its loading pattern in the femur (Engh and Bobyn 1988). This may explain the results of Sarmiento et al (1988), who found a lower incidence of both calcar resorption and distal cortical hypertrophy after the use of a titanium-alloy prosthesis with a lower modulus of elasticity than a standard Charnley femoral component.

Our aim was to assess whether dual-energy X-ray absorptiometry (DEXA) could be used prospectively to measure these changes in bone remodelling after cemented THA at up to one year after surgery, that is before they can be detected by conventional radiography.

PATIENTS AND METHODS

We studied 20 patients who had had a THA with a Charnley prosthesis (De Puy, Leeds, UK). There were 7 men and 13 women with a mean age of 70.9 years (40 to 82). There were 15 right and 5 left operated hips. The primary diagnosis was osteoarthritis in all cases and details of the
patients are given in Table 1.

The operations were performed through a lateral approach with a trochanteric osteotomy in 16 patients and an anterolateral approach in four. A Hardinge cement restrictor (De Puy, Leeds, UK) was placed in the femoral canal and the prosthesis cemented with Palacos R polymethylmethacrylate (PMMA) bone cement (Schering Plough, Welwyn Garden City, UK) containing gentamicin. The cement was inserted into the femoral canal in a retrograde fashion with a cement gun. Suction drainage was used for 24 to 48 hours. All operations were performed in a laminar air-flow theatre by one of two surgeons (BC, NR). All patients received a three-dose regime of prophylactic antibiotics, either flucloxacillin (Beecham, Brentford, UK) or cefuroxime (Glaxo, Greenford, UK) if the patient was allergic to penicillin.

DEXA scans of the upper femur were performed 10 days, 6 months and 12 months after surgery using a Hologic QDR-1000 densitometer (Hologic Inc, Waltham, Massachusetts). The software was designed to perform bone-mineral analysis in the presence of metal in the scanning field (prosthetic scanning software version 6.0; Hologic Inc, Waltham, Massachusetts).

The protocol for analysis of the results was based on the radiological zones described by Gruen, McNeice and Amstutz (1979). We analysed bone-mineral density (BMD) in seven regions of the upper femur around the femoral prosthesis. Region 1 was from the tip of the greater trochanter to a point on the lateral cortex one-third of the distance to the tip of the prosthesis. Regions 2 and 3 were of the same dimensions covering the middle and distal thirds of the lateral aspect of the femur. Region 4 was the femoral shaft for 19 pixels in length distal to the tip of the prosthesis. Region 5 was of the same dimension as region 3 but on the medial side and region 6 was from the upper border of region 5 to the lower edge of the lesser trochanter. Region 7 extended from the lower border of the lesser trochanter to the level of neck resection (Fig. 1).

PMMA cement attenuates the photon beam of the densitometer in a similar manner to bone and therefore increases the apparent BMD of the region of interest (McCarthy et al 1991). It was not possible to define clearly the cement-bone interface; the inclusion of cement in the analysed region gives an erroneously high measurement of BMD. PMMA cement, however, has a constant DEXA density that does not change with time (Dickob, personal communication). An even cement mantle around the prosthesis and measurements of large regions of interest will give little proportionate variation in attenuation between regions due to small differences in thickness of the cement. The inclusion of the entire cement mantle within the analysed region means that any changes in BMD will reflect actual differences in bone mineralisation. The in vivo precision of DEXA in our unit is 1.1% to 4.5% depending on the region.

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Mean ± so   70.9 ± 10.8     70.1 ± 0.9

Fig. 1
Periprosthetic regions of interest analysed around the Charnley femoral component.
of interest analysed (Cohen and Rushton 1995).

The results were assessed using correlation coefficients and paired t-tests assuming equal variance.

RESULTS

Periprosthetic BMD values at 10 days, 6 months and 12 months after operation are shown in Table II. There were statistically significant reductions in BMD in regions 2 (p < 0.01), 3 (p < 0.05), 5 (p < 0.05), 6 (p < 0.05) and 7 (p < 0.01) between the 10-day and 6-month scans. There were no significant changes in regions 1 and 4. Comparison of the scans at 6 and 12 months showed no significant changes in regions 1, 2, 3, 6 and 7, but in regions 4 and 5 there was a significant increase in BMD (p < 0.01 and p < 0.05, respectively).

Comparison of the 10-day and the 12-month results showed a statistically significant reduction in BMD on the lateral side of the femur in regions 2 (p < 0.01) and 3 (p < 0.05) and in the proximal part of the medial side of the femur, regions 6 (p < 0.05) and 7 (p < 0.01). There was a significant increase in BMD distal to the tip of the prosthesis, region 4 (p < 0.05), but no significant changes in regions 1 and 5. Region 5 therefore showed a reduction in BMD in the first 6 months, but this was followed by an increase between 6 and 12 months, so that comparison of the 10-day and 12-month scans showed no apparent change.

At 12 months, the overall pattern of change in BMD was of resorption increasing from the distal to the proximal part of the femur, with accretion below the tip of the prosthesis (Fig. 2; Table III). Region 2 showed the largest reduction at 12 months (8.4%); the next largest was region 7 at 6.7%.

Six of the 16 patients who had trochanteric osteotomy had nonunion. In these hips BMD analysis of region 1 was difficult to interpret, leading to a wide range of BMD values at 12 months, and a large standard error for the percentage difference in BMD between the postoperative and 12-month results. Another factor is that the stainless-steel wire used to reattach the trochanter probably caused an edge effect and more inaccuracy in region 1. In the four patients who did not have a trochanteric osteotomy, there was a reduction in BMD in region 1 of 6.9% (p < 0.05).

We found no correlation between the age of the patient and the BMD change at 12 months for any of the regions of interest. In our series the women were significantly older than the men (p < 0.05) and significantly lighter (p < 0.05), but despite this there were no significant differences in the BMD changes at 12 months between the males and females.

DISCUSSION

Our study showed a clear pattern of early periprosthetic remodelling of bone. The results for region 1 showed no significant changes over 12 months, because of the confounding factors previously discussed, but patients who did not have trochanteric osteotomy showed a significant reduction in BMD.

During the first six months, all the other regions of interest on either side of the prosthesis showed a reduction in BMD, while the shaft of femur distal to the tip of the
prosthesis did not change. These early changes have not previously been documented, because routine radiography is not sensitive enough to detect such small changes in mineralisation. Several factors may have contributed to this early bone resorption. These include local vascular injury from surgical trauma, thermal injury from the polymerisation of cement, cytotoxicity of the methylmethacrylate monomer, osteolysis from particulate debris and adaptive bone resorption due to the altered pattern of loading.

From six months to 12 months the BMD increased below the tip and medial to the distal third of the prosthesis. These changes were not evident on plain radiographs. The changes which we observed correlate well with present understanding of loading patterns and response in the proximal femur after prosthetic implantation. Oh and Harris (1978) reported that in the intact femur under load, strain decreased from proximal to distal, with the calcar area having the highest strain values. After the insertion of a cemented femoral component this pattern was reversed: maximum strain was around the tip of the prosthesis rather than at the calcar area. They suggested that this change caused resorption in the region of the calcar, and cortical hypertrophy distally. The reduction of stress in the proximal medial cortex after the insertion of a prosthesis has been confirmed in other in vitro studies (Markolf, Amstutz and Hirschowitz 1980; Lewis et al 1984).

Our study showed that some bone resorption occurred around the stem in the first six months, and was more marked proximally. These changes were maintained but did not progress between six and 12 months. The later confirmation of this in region 7 is resorption of the calcar. Bone resorption may occur in other regions, but plain radiographs are not sensitive enough to show these early changes (Sarmiento and Gruen 1985; West, Mayor and Collier 1987).

At one year, we found increased BMD below the tip of the prosthesis, reflecting the reversed pattern of loading described by Oh and Harris (1978). In region 5, medial to the distal third of the prosthesis, we found an initial fall in BMD, but a later increase due to adaptive remodelling.

Our findings are supported by other studies using DEXA. Engh et al (1992a) measured periprosthetic bone-mineral content (BMC) and cortical strain in five specimens of the uncemented AML prosthesis (De Puy, Warsaw, Indiana) studied at up to 7.5 years after surgery. They compared the BMC in six regions around the prosthesis with comparable regions in the contralateral normal femur, and found a gradient of bone loss, highest proximally and lower around the middle third. They associated these remodelling changes with strain shielding of the cortex. Further analysis of the data obtained from the DEXA scans (Engh et al 1992b) showed a mean loss of 45% of BMC around the proximal third and 32% around the middle third. Around the distal third of the implant, three of their five cases showed no loss, one showed some loss, and one had an increase in BMC.

McCarthy et al (1991) in a retrospective study of cemented THAs, using the contralateral femur as a control, showed a substantial reduction in BMC three years after THA. They analysed two small regions in the medial femoral cortex, corresponding to areas within regions 6 and 7 in our study. These showed average losses of 40% and 28% respectively, and the decreases were progressive. This study has been criticised because it included only a small number of patients with several different types of cemented implant and it used small regions of interest around the implant which were difficult to place accurately (Stulberg and Richmond 1992).

Kilgus et al (1993) measured periprosthetic BMD around uncemented AML prostheses using DEXA in 46 patients at up to seven years. They calculated changes by comparing BMD values around the prosthesis with a baseline reference region in the midshaft of the femur. They found a progressive decrease in BMD in all regions around the prosthesis with increasing time.

Our study has shown that DEXA is sensitive enough to demonstrate bone remodelling within six months after a cemented THA, and that the changes reflect the recognised pattern of loading in the proximal femur.

The authors wish to thank the British Orthopaedic Association Wishbone Appeal for funding this project.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES


THE JOURNAL OF BONE AND JOINT SURGERY
BONE REMODELLING IN THE PROXIMAL FEMUR AFTER CHARNLEY TOTAL HIP ARTHROPLASTY


