Bone remodelling around a cemented polyethylene cup

A LONGITUDINAL DENSITOMETRY STUDY

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The aims of this study were to examine the repeatability of measurements of bone mineral density (BMD) around a cemented polyethylene Charnley acetabular component using dual-energy x-ray absorptiometry and to determine the longitudinal pattern of change in BMD during the first 24 months after surgery.

The precision of measurements of BMD in 19 subjects ranged from 7.7% to 10.8% between regions, using a four-region-of-interest model. A longitudinal study of 27 patients demonstrated a transient decrease in net pelvic BMD during the first 12 months, which recovered to baseline at 24 months. The BMD in the region medial to the dome of the component reduced by between 7% and 10% during the first three months, but recovered to approximately baseline values by two years.

Changes in BMD in the pelvis around cemented acetabular components may be measured using dual-energy x-ray absorptiometry. Bone loss after insertion of a cemented Charnley acetabular component is small, transient and occurs mainly at the medial wall of the acetabulum. After two years, bone mass returns to baseline values, with a pattern suggesting a uniform transmission of load to the acetabulum.

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The pattern of load transfer between implant and host and the resultant change in peri-prosthetic bone mass are of interest to orthopaedic surgeons undertaking joint replacement. Adequate bone is needed to support the implant, loss of bone mass due to stress shielding may result in peri-prosthetic fracture and a low bone mass presents a reconstructive challenge at revision.

Finite element analysis shows that total hip arthroplasty (THA) changes the pattern of load transmission in the acetabular region compared with the normal hip joint.¹ In the natural acetabulum, the stresses in subchondral and trabecular bone are highest in the superomedial wall. THA using a cemented cup increases the stresses in the cancellous bone immediately superior to it.¹⁻³ With a non-cemented press-fit component the load is transferred at the acetabular rim.⁴ The altered pattern of loading in these circumstances leads to a loss of trabecular bone in the central part of the ilium at the medial wall of the acetabulum. Finite element analysis also indicates that cemented implants may transfer a greater amount of load to the medial wall of the ilium than non-cemented metal-backed components.^{2,3}

Dual-energy x-ray absorptiometry (DEXA) is a sensitive and precise tool for measuring

changes in peri-prosthetic bone mineral density (BMD).⁵⁻⁷ Measurement of the changes in the BMD after operation gives a good indication of the pattern of load transfer between implant and host bone.^{8,9} Several studies have evaluated changes in BMD of the proximal femur after THA and have been useful in evaluating the effect of different implant materials, methods of fixation and the extent and type of porous coating on peri-prosthetic bone mass.^{6,10-13}

Few studies have evaluated the changes in pelvic BMD after THA. We have previously described the pattern of remodelling of the pelvis during the first two years after the insertion of a hemispherical press-fit titanium shell with a polyethylene bearing (Plasmacup, B. Braun Ltd, Tuttlingen, Germany).¹⁴ In this earlier study we found that bone loss was most rapid during the first six months and was greatest at the medial wall, with relative sparing at the superior and inferior margins, indicating a rim-loading pattern of stress transfer, as predicted by finite element analysis. There is little information available on the pattern of change in BMD around cemented polyethylene acetabular components¹⁵ and none for the widely-used Charnley acetabular component (DePuy International Ltd, Leeds, United Kingdom). The

Fig. 1

Mean (95% confidence interval) changes in regional pelvic bone mineral density (BMD; %) over two years as analysed by repeated analysis of variance (ANOVA).

aims of the current study were to determine the repeatability of measurements of peri-prosthetic BMD in patients with a cemented polyethylene Charnley acetabular component and to determine the changes over the two years following surgery.

Patients and Methods

The study group comprised a subset taken from a larger randomised study ($n = 65$) comparing the Exeter (Howmedica Ltd, Staines, United Kingdom) and Ultima TPS (DePuy International Ltd) femoral implants. Patients with uncomplicated primary or secondary osteoarthritis of the hip undergoing unilateral cemented THA were recruited between June 2000 and September 2002. The exclusion criteria were metabolic bone disease, inflammatory arthritis and patients who had taken pharmacological doses of oral

steroids, hormone replacement therapy, tamoxifen, calcium or vitamin D during the previous year, or had ever received bisphosphonate therapy. All patients gave written informed consent prior to inclusion in the study, which was approved by the North Sheffield local research ethics committee and conducted in accordance with the ethical principles stated in the Helsinki declaration.

All the patients received an unmodified cemented polyethylene Charnley acetabular component and a double-tapered polished femoral stem (Ultima TPS, or Exeter). Preparation of the acetabulum consisted of bone reaming to, but not through, the subchondral plate using powered instruments; multiple drill holes were keyed, using the Charnley step drill, from positions 11 to 4 o'clock. Pulsed lavage of the bone bed was undertaken with cement pressurisation prior to insertion of the component. Both com-

Table I. Precision of pelvic peri-prosthetic measurements of bone mineral density (n = 19)

Characteristic*	NET	Region of interest			
		1	2	3	4
Mean area in cm ² (SD)	22.15 (3.69)	6.99 (1.05)	4.34 (1.42)	4.93 (1.73)	7.01 (1.23)
Mean BMC in g (SD)	31.20 (11.98)	10.11 (3.97)	7.85 (4.13)	7.07 (4.06)	8.05 (2.64)
Mean BMD in g/cm ² (SD)	1.39 (0.08)	1.44 (0.16)	1.76 (0.25)	1.40 (0.21)	1.13 (0.16)
Coefficient of variation	4.1	7.7	9.8	10.8	9.9

* BMC, bone mineral content; BMD, bone mineral density

ponents were cemented using high-viscosity Palacos R with gentamicin (Schering Plough Ltd, Welwyn Garden City, United Kingdom). The patients were mobilised, fully weight-bearing as tolerated, on the second post-operative day, with crutches for balance support for the first six weeks.

DEXA scans of the hemipelvis were made one week after surgery, and at 3, 12 and 24 months. All scans were acquired using a Hologic QDR 4500-A fan-beam densitometer (Hologic Inc., Waltham, Massachusetts), according to a previously described protocol.¹⁶ The patients lay supine on the scanner with the legs in extension and the foot of the operated side held in a neutral position using the Hologic foot-positioning device. Scans were made using the 'metal-removal hip' scanning mode (point resolution 0.06 mm, line spacing 0.11 mm). The acquisition area extended proximally from 2 cm above the lower limit of the ipsilateral sacroiliac joint and distally for 2 cm below the lower border of the inferior pubic ramus. The width of the scan field was 15 cm, centred on the component. All scans were analysed independently, using Hologic metal-removal software (version 11.2) by the same observer (NRS). Analysis was carried out using a four-region-of-interest model, described previously (Fig. 1).¹⁶ The term 'net' defined a global region of interest encompassing the four individual regions. A DEXA scan of the ipsilateral femoral neck was also made pre-operatively, using standard protocols, in order to evaluate the local BMD prior to surgery so that the relationship between the initial regional bone mass and later bone loss could be compared. Percentage changes in pelvic bone mass during the period of study were calculated using the post-operative measurement of pelvic BMD as the baseline, as previously recommended.⁵

The repeatability of measurements of BMD was evaluated in 19 patients (three men and 16 women, mean age 72 years, SD 6) using two sequential DEXA scans of the hemipelvis, acquired on the same day after a period for repositioning. The result was expressed as the coefficient of variation for each region of interest, according to a formula described previously.¹⁶ The coefficient of variation of the net pelvic peri-prosthetic region was 4.1%. That of the individual sub-regions varied from 7.7% to 10.8%, with regions having a higher bone mineral content tending to have better precision (Table I). Longitudinal change in BMD was analysed using repeated-measures analysis of variance (ANOVA). The influence of age, gender, compo-

Table II. Characteristics of patients in the longitudinal study (n = 27)

Characteristics*	
Mean age in yrs (SD)	71 (6)
Gender	
Male:female	10:17
Mean height in cm (SD)	166 (11)
Mean weight in kg (SD)	78 (14)
Mean BMI in kg/m ² (SD)	29 (5)
Pattern of hip osteoarthritis (superior pole:medial pole:concentric)	14:4:9
Mean pre-operative 'total hip' BMD in g/cm ² (SD)	0.95 (0.18)
Mean pre-operative 'total hip' z-score (SD)	0.91 (1.18)
Implant side (right:left)	14:13
Approach (anterolateral:posterior)	24:3
Femoral implant (Ultima TPS:Exeter)	12:15
Component diameter (40 mm:43 mm)	13:14
Component type (standard:flanged:LPW)	19:6:2
Mean baseline pelvic BMD (g/cm ²)	
NET (SD)	1.54 (0.34)
Region 1	1.65 (0.45)
Region 2	1.94 (0.47)
Region 3	1.62 (0.54)
Region 4	1.20 (0.31)

* BMI, body mass index; BMD, bone mineral density

nent size and type and stem type on change in BMD at two years was examined using linear regression analysis. The relationship between the pre-operative pattern of osteoarthritis, the BMD of the femoral neck and the change in BMD at two years was also evaluated using linear regression analysis. All analyses were two-tailed, using a critical p value of 0.05, and undertaken using SPSS statistical software, version 12 (SPSS Ltd, Chertsey, United Kingdom).

Results

There were 17 women (mean age 72 years, SD 5) and ten men (69 years, SD 7) included in the longitudinal study (Table II). All the men received a 43 mm acetabular component. Four women had a 43 mm component and 13 a 40 mm implant. A total of 15 patients (nine women) received the Exeter femoral implant, and 12 (eight women) received the Ultima-TPS component (chi-squared p > 0.05). There were no differences in age, gender or the baseline pelvic BMD in subjects receiving the Exeter rather than the Ultima-TPS implant (p > 0.05, all comparisons). The pre-operative 'total hip' BMD measured at the ipsilateral proximal femur was 0.95 g/cm², SD 0.18, with a z-score (BMD standard deviation compared with age- and gender-

Fig. 2

Mean (95% confidence interval) change in net pelvic bone mineral density (BMD; g/cm²) in men versus women over two years. Analysis is by repeated analysis of variance (ANOVA).

matched controls) of 0.91, indicating that the patients had a bone density similar to that of an age- and gender-matched general population (Table II). The predominant patterns of osteoarthritis were at the superior pole or were concentric (Table II).

At the baseline assessment, the pelvic BMD was highest in the region of the medial wall and lowest in the ischium, with a net pelvic BMD of 1.54 g/cm² (Table II). During the first year after operation there was a fall of -5.4% in the net BMD (Fig. 1, net region of interest, ANOVA $p = 0.007$). By two years, the BMD had recovered to the baseline level (+0.1%). For the individual peri-prosthetic regions, significant bone loss was seen only at the inferomedial wall (region 3, ANOVA $p = 0.01$), but at two years this had recovered to the baseline level. A similar trend was seen for bone loss at the superomedial wall, but this was not statistically significant (region 2, ANOVA $p = 0.08$). In regions 1 and 4, at the superior and inferior margins of the component, respectively, no significant changes in BMD were seen (ANOVA $p > 0.05$).

Women had a lower net peri-prosthetic BMD than men (Fig. 2, ANOVA $p = 0.004$); however, there was no difference in the magnitude of change in BMD between the genders over the two-year period (ANOVA $p > 0.05$). The degree of net regional change in BMD observed was not affected by age, body mass index, component size (40 or 43 mm), type of component (standard, flanged or LPW), number of drill holes (none, < 3 or 3+) or the type of femoral implant (linear regression $p > 0.05$, all analyses). The pre-operative proximal femoral BMD (expressed as 'total hip' BMD using Hologic analysis software), the pre-operative 'total hip' BMD z-score and the pattern of osteoarthritis (superior pole, medial pole or concentric) were not predictors of the net change in BMD at two years (linear regression $p > 0.05$, all analyses).

Discussion

In this study we found that the changes in pelvic peri-prosthetic BMD around the cemented Charnley acetabular component were small and transient. Bone loss occurring within the first year principally affected the medial and inferomedial walls, but had recovered to baseline levels by two years. The regions at the rim of the component showed no significant changes in BMD over this period. Women had a lower pelvic BMD than men, but lost a similar amount of bone post-operatively. Bone loss was not influenced by the initial BMD, age, body mass index, or the type or size of the component.

Taken alone, the regional changes in BMD at one year may suggest a rim-loading pattern of stress transfer. However, the bimodal nature of the bone loss, with recovery at two years, resembles the remodelling seen with cemented femoral components.¹⁴ The recovery of bone mass in all regions at two years with this implant contrasts with our previous findings with a non-cemented Plasma acetabular component,¹⁴ where the bone loss seen in the first year in regions 1 to 3 still persisted at two years, with recovery limited to region 4. One possible explanation for the preservation of bone mass in the current study may be the similarity in elastic modulus between the polyethylene component, the cement and the bony pelvis. This may result in a more uniform pattern of load transmission, limiting stress shielding.

Direct comparison of the results of this study with those of other investigations of pelvic remodelling after THA are limited by differences in placement of the regions of analysis and the technologies used for measurement. Sabo et al,¹⁷ in a two-year study of 53 uncemented acetabular components, found bone loss of between 6% and 17% in DeLee zones I to III,¹⁸ with the greatest loss inferiorly. Koroivessis, Piperos and Michael¹⁹ applied a non-contiguous three-region-of-interest model (approximating to the DeLee zones) in a retrospective study of changes in BMD around uncemented and cemented acetabular components, using the non-operated hip as a control. They found significant bone loss in zones II and III for uncemented components, and in zone I for the cemented implants. Digas et al,¹⁵ using a five-region-of-interest model, found no significant bone loss in any peri-acetabular region over two years using a conventional polyethylene cemented component.

Rahmy et al¹² have previously shown that femoral peri-prosthetic bone loss may be predicted by the pre-operative bone density in the spine, the contralateral 'total hip' and the forearm. Subjects with a lower BMD at these sites had greater net femoral bone loss at three years after non-cemented THA. Kerner et al⁸ and Sychterz and Engh²⁰ have also found that femoral peri-prosthetic bone loss was greatest in subjects with a low initial bone mass. In neither study was gender an independent predictor of bone loss, after correcting for the initial bone mass. In this study we found no relationship between the changes in BMD and several covariates, including gender and pre-operative BMD. The

probable reason for our findings is that the magnitude of bone loss was very small and the intersubject variability in change in BMD at two years was also relatively small (mean change 0.1%; 95% confidence interval 5.5 (-5.7 to +5.8)). This study does not therefore, exclude a possible relationship between the described co-variables and pelvic bone loss in situations where the amount of loss is greater. We did not examine the effect of thickness of the cement mantle on change in BMD, as cement distribution is typically non-uniform and estimates based on a mean thickness were felt to be unreliable.

CT has been suggested as an alternative to DEXA for measuring peri-prosthetic changes in BMD.^{21,22} A recent study by Schmidt et al²² found good inter- and intra-observer repeatability of this method, as judged by repeat analysis of single scan acquisitions from a number of subjects. However, the precision in the clinical setting of repeated examinations of patients remains unquantified. Although CT has better spatial resolution than plain radiography for measuring regions of focal pelvic osteolysis and may aid in making clinical decisions, it has not been shown to be superior to DEXA for measuring BMD around cemented or non-cemented implants in the pelvis. Owing to the dose of ionising radiation, CT is not suitable for repeated longitudinal measurements in research studies. The effective dose of radiation received during a single pelvic CT examination is 10 mSv, approximately 500 times greater than the dose from a single chest radiograph. In contrast, the effective radiation dose from a DEXA scan of the pelvis is approximately 10 µSv, the equivalent of half a day of normal background exposure to radiation.

The precision of BMD measurements of the pelvis reported in this study was less than that which we had previously reported for measurements around uncemented acetabular components,¹⁶ but was similar to that around cemented implants as noted by Digas et al.¹⁵ The poorer precision compared with that for uncemented components is probably due to the limited difference in visual contrast between polyethylene, cement and bone when analysing the scans. This resulted in some inconsistency in marking the edge of the cup between sequential scans. In these studies, we did not aim specifically to exclude areas of cement from analysis of regions, as we have previously shown that attempting cement exclusion results in poorer precision.¹⁶

DEXA may be reliably used to measure changes in BMD in the pelvis after the insertion of a cemented acetabular component. The use of a cemented Charnley acetabular component is associated with preservation of the peri-prosthetic bone mass over a period of two years after THA. The uniform pattern of preservation of bone mass in contrast to that with uncemented acetabular components, suggests a more even pattern of load transmission to the acetabulum, although longer term studies are required to determine whether this early preservation of bone mass remains.

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