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ORIGINAL STUDY

Comparison of peri-prosthetic bone density in cemented and uncemented total knee arthroplasty

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The aim of our study was to assess the effect of knee replacement with or without bone cement on periprosthetic bone density. Periprosthetic bone density in two comparable groups (30 each) of cemented and uncemented knee replacements was measured with DEXA scanner. Bone loss was more in the area posterior to the anterior femoral flange in the cemented subgroup, nearing statistical significance (p = 0.059). In both groups, the reported bone density at a median of four years postoperatively was reduced at several periprosthetic sites. However, the method of fixation could not be clearly demonstrated to influence the bone loss differentially. This brings into question the use of the more expensive cementless implants. Reduction in bone density in both groups at several periprosthetic sites remains a concern. Whether or not this can be addressed with medical intervention like post arthroplasty bisphosphonate treatment needs further consideration.

Keywords : bone mineral density; dual-energy x-ray absorptiometry; total knee arthroplasty; cemented and cementless; peri-prosthetic bone loss.

INTRODUCTION

Poor bone quality and bone stock are related to failure after total knee arthroplasty, including that due to peri-prosthetic fracture. Bone loss in total knee arthroplasty (TKA) is a common feature and is mainly attributed to three aetiological factors (*25*). Stress shielding causes an "osteopenia" type of bone loss behind the anterior flange and adjacent to the distal aspects of the femoral component. Secondly, polyethylene, cement and metal particles are released by implant wear and may cause the less common "osteolysis" type of bone loss located directly at the anterior and posterior implant bone or cement bone interface. Finally, implant loosening leads to bone loss and results in "hollowing out" of the distal femur in a stemmed TKA.

Stress shielding and bone resorption after total hip and knee arthroplasty are well reported (*13,17,25,27*). Few studies support the contention that the use of a cemented stem reduces proximal

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stresses and may result in proximal bone resorption (20) and this has been supported by the finite element model study (24).

We analyzed the periprosthetic bone density in two comparable groups of patients who had either cemented or cementless knee arthroplasty. The aim, was to study the effect of knee replacement with or without bone cement on periprosthetic bone density.

MATERIALS AND METHOD

The study was approved by the Central Office for Research Ethics Committees (COREC). Two groups of thirty patients each were selected and comparisons at baseline are shown in table I. All operations were performed in an identical manner, using a midline skin incision and medial parapatellar approach, and rehabilitation was as per the standard departmental protocol. The activity level was assessed by the University of California, Los Angeles (UCLA) Scoring system (2). Inclusion criteria included unilateral knee replacement, osteoarthritic knee, informed consent and two to five years post knee replacement. Patients with bilateral knee replacement, knee replacement for a diagnosis other than osteoarthritis and with complications post surgery like infection, fracture or deep vein thrombosis were excluded from the study.

All the patients had a Rotaglide Rotating Platform Knee (Corin, UK). The uncemented group had the uncemented version of the same prosthesis which had a porous coating.

Bone density was measured using dual – energy X-ray Absorptiometry (DEXA) (GE Lunar Prodigy, UK) (21). We used the Prodigy analysis 'Orthopedic' software which incorporates metallic exclusion algorithms, automatically removing prostheses, enabling measurement of peri-prosthetic bone density.

Regions of Interest (ROI) were identified and templates were formulated. We had six ROI's in the anteroposterior view; two femoral (AP-F1 and –F2) and four tibial (AP-T1, -T2, -T3 and –T4) (fig 1). There were four ROI's on lateral scanning; two femoral (LAT-F1 and –F2), one patellar (LAT-P) and one tibial (LAT-PT) (fig 2). The templates were designed to analyze the bone density values in both the cortical and cancellous bones in the periprosthetic areas of tibia and femur. The ROI's were placed at a distance of 3 mm from the prosthesis in the uncemented group and from bone cement in the cemented group. The templates were used to measure the bone density in the regions of interest on the operated knee and to measure the identical area on the opposite unoperated knee in each patient.

Using the above data, a value for the relative periprosthetic bone mineral density for each ROI was calculated using the formula :

$$\textit{Relative BMD difference (RBMDD)} = \frac{(\textit{Non-operated ROI} - \textit{operated ROI}) \times 100}{\textit{Non-operated knee ROI}}$$

Statistical methods

Comparisons between the cemented and uncemented groups were done using two-sample methods. Where data were normally distributed, two-sample t-tests were used; otherwise Mann-Whitney tests were used. Results are displayed as means (standard deviation) or medians (IQR) corresponding to t-tests and Mann-Whitney tests

Table I. — Comparison of clinical data and scores between the two groups using Student's t-test

Variable	Cemented	Uncemented	95% CI	p-value
Age (years)	67.20 (5.57)	67.33 (5.23)	(-2.93 to 2.66)	0.924
Gender (M :F)	13:17	13:17	–	–
[1] BMI	30.95 (4.89)	29.90 (4.77)	(-1.44 to 3.55)	0.402
[2] F/U (Years)	4.00 (2.85 to 4.00)	3.25 (2.38 to 5.03)	(-0.7 to 0.8)	0.912
[3] UCLA	6.0 (4-8)	4.0 (4-8)	(-0.001 to 2.000)	0.465
[4] T-Score	-0.51 (1.93)	-0.62 (1.88)	(-0.875 to 1.095)	0.824

[1] BMI, Body mass index.
[2] F/U, follow-up period in years.
[3] UCLA, University of California, Los Angeles, scoring system for activity level.
[4] T-score, The *T-score* is the number of standard deviations below the average for a young adult at peak bone density.

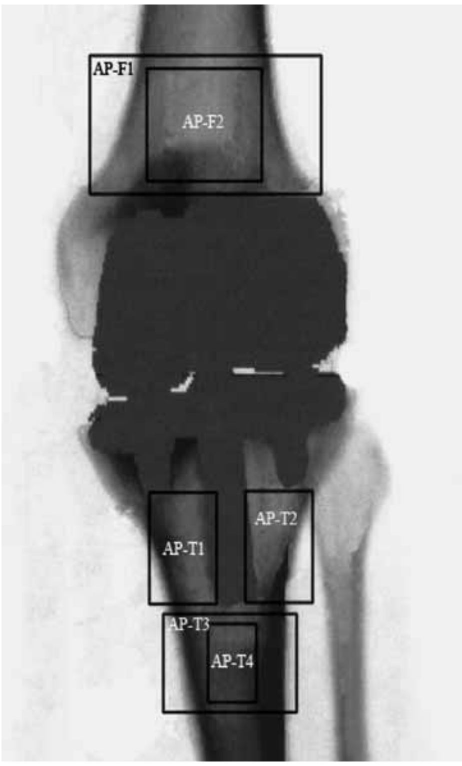

Fig. 1. — Dual energy x-ray absorptiometry scan showing regions of interest in the anterior posterior (AP) view for the replaced knee. AP-F1, anteroposterior distal femur; AP-F2, anteroposterior distal femur cancellous; AP-T1, anteroposterior medial tibial plateau; AP-T2, anteroposterior lateral tibial plateau, AP-T3, anteroposterior distal tibia cortical; AP-T4, anteroposterior distal tibia cancellous.

respectively, along with 95% confidence intervals and p-values. All analyses were done using Minitab (version 13) at a significance level of 5%.

RESULTS

Patients within the cemented and uncemented groups were matched for their age, gender, body mass index (BMI), follow-up, UCLA scores and osteoporotic indices (t-score). This is summarized in table I. Data are expressed as mean (standard deviation) or median (range) according to the distribution.

The mean RBMDD was calculated for the ten regions of interest in each of the two groups. This showed a decrease in BMD in all ten peri-prosthetic regions of interest. This decrease was noted to be

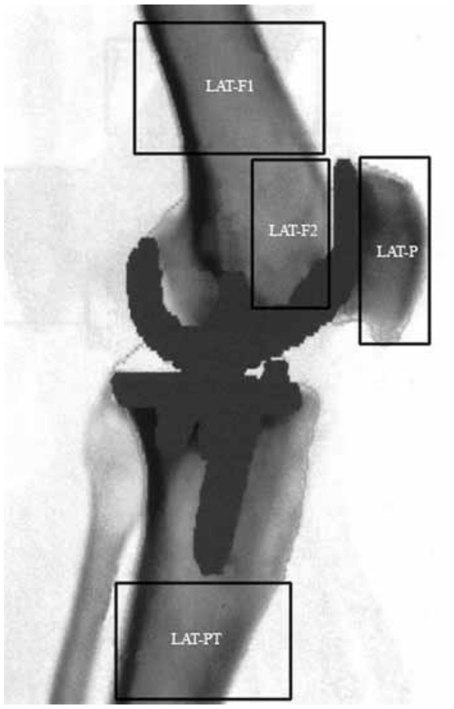

Fig. 2. — Dual energy x-ray absorptiometry scan showing regions of interest in the lateral (LAT) view of the same knee. LAT-F1, lateral distal femur; LAT-F2, lateral distal femur behind flange; LAT-P, lateral patella; LAT-PT, lateral proximal tibia.

greatest in the region posterior to the anterior femoral flange of the prosthesis (LAT-F2) particularly in cemented compared with uncemented prostheses, nearing statistical significance ($p = 0.059$). (tables II & III).

DISCUSSION

The mechanical properties of any bone determine its bone mineral density pattern (*10*). Patients with longstanding knee arthrosis develop altered gait patterns (*7*) and mechanical loading of the knee joint due to pain, altered proprioception (*4*) and ultimately deformity. When such patients undergo total knee arthroplasty, they also undergo an immediate and significant change in the biomechanical stresses to the bone surrounding the knee joint (*11,23*). The mechanical axis of the knee is usually significantly altered and according to Wolffs' law, the bones react with adaptive remodelling, thus

Table II. — Relative Bone Mineral Density Difference (RBMDD) values for the replaced knee in the femur and patella

Region of Interest	Cemented (RBMDD%)	Uncemented (RBMDD%)	95% CI	p-value
AP-F1	10.6 (13.8)	6.4 (14.0)	(-3.02 to11.40)	0.249
AP-F2	9.0 (19.1)	9.6 (16.5)	(-9.88 to 8.61)	0.892
LAT-F1	14.78 (-1.42 to 25.72)	13.17 (-0.29 to 20.61)	(-8.65 to 8.95)	0.971
LAT-F2	21.99 (9.43 to 35.54)	13.35 (6.31 to 23.80)	(-0.34 to 16.82)	0.059
LAT-P	13.0 (19.2)	12.5 (19.6)	(-9.59 to 10.46)	0.931

Table III. — Relative Bone Mineral Density Difference (RBMDD) values for the replaced knee in the tibia

Region of Interest	Cemented (RBMDD%)	Uncemented (RBMDD%)	95% CI	p-value
AP-T1	3.88 (-16.69 to 11.43)	3.63 (-6.99 to 10.97)	(-11.37 to 5.58)	0.751
AP-T2	7.3 (10.8)	5.7 (14.6)	(-5.08 to 8.21)	0.639
AP-T3	2.54 (-2.80 to 10.32)	7.65 (1.26 to 13.98)	(-9.883 to 0.695)	0.075
AP-T4	3.0 (15.9)	7.3 (17.6)	(-13.01, 4.30)	0.318
LAT-PT	6.04 (-2.50 to 21.53)	5.86 (2.55 to 16.78)	(-6.15 to 9.13)	0.941

adjusting their density to the altered mechanical demands (*10*). This is a special type of adaptive remodelling which leads to the local bone loss that is seen in close relation to orthopaedic implants for example hip arthroplasty (*5,9*), knee arthroplasty (*6,15*) and spinal fixation devices (*8,14*). This implant related osteopenia is considered to be a result of stress shielding of the neighbouring bone.

Finite element models of the distal femur have shown that placement of a femoral component leads to a reduction in mechanical stress in the anterior distal femur (*3,22,26*). In addition to this, Van Lenthe *et al* predicted that an equilibrium situation is not reached after two years contrary to earlier clinical findings by Cameron *et al*, but instead bone resorption may continue (*24*). Furthermore, maximum stress shielding was to be expected if the anterior and posterior femoral flanges were bonded to the bone. Some load could be transferred to the anterior distal femur as compressive strain if there was no bonding of the flanges, which would minimise bone loss. The clinical study by Whiteside and Pafford seemed to support this. In their study, roentgenograms of 110 cases of uncemented total knee arthroplasty were reviewed after 12 to 24 months. The femoral side demonstrated distal bone hypertrophy in 93% suggesting compressive load bearing. None of the femoral components migrated or sank and only a few patients showed bone loss in the distal anterior femur (*28*).

A retrospective review of 185 knees by Cameron *et al* found that almost all cases showed anterior femoral condylar osteoporosis and that femoral component loosening led to regression of the changes suggesting stress shielding (*6*). Similar findings were noted by Mintzer *et al* in a series of 147 patients, where 68% demonstrated that bone loss occurred in the distal anterior femur (*15*). Both of these studies were retrospective radiological reviews.

On the tibial side, Petersen *et al* performed repeated measurements over a period of three years on 25 uncemented TKR's using DPA (dual photon absorptiometry). They noted 22% overall loss of bone mineral in all ROI's of the proximal tibia in the first three years (*16*). Seitz *et al* (*19*) and Regner *et al* (*18*) found similar overall decrease in proximal tibia bone density after two years. In all of the above cases where a change in knee alignment as a result of operation occurred, the tibial condyle that had decreased load postoperatively underwent a rapid significant bone loss whilst a small increase was seen in the condyle where load was increased. Karbowski *et al* published one of the first prospective studies using DEXA for quantative evaluation of the proximal tibia after uncemented TKA. The comparison of BMD values after knee arthroplasty revealed a conspicuous decrease of bone density within 9 months. Bone mineral loss amounted to an average of 9.2% in anteroposterior and 17.8% in lateral DEXA measurements (*12*).

There is a limited number of densitometry studies comparing cemented with uncemented fixation. Seki *et al* (*20*) evaluated bone density and compared amongst four different implant designs. They noted up to 57% decrease in bone density in the distal femora with a cemented femoral component compared with a decrease of up to 28% with a cementless, porous-coated component of the same design.

Abu-Rajab *et al* (*1*) compared periprosthetic bone mineral density between cemented and uncemented LCS total knee replacements in two matched cohorts of 20 patients, two years post operatively. In contrast to Seki *et al*, they reported that the method of fixation did not appear to produce significant differences in the periprosthetic bone mineral density, however, both produced stress shielding around the femoral implants.

Our study showed a decrease in BMD in all ten periprosthetic regions of interest at a median of four years follow-up (range, 2-5 years). This decrease was noted to be greatest in the region posterior to the anterior femoral flange of the prosthesis (LAT-F2) particularly in cemented compared with uncemented prosthesis nearing statistical significance.

Wang *et al* (*27*) studied the effect of alendronate on bone mineral density in the distal part of the femur and proximal part of the tibia after total knee arthroplasty. They noted that oral administration of alendronate for six months postoperatively significantly improved the bone mineral density. While the clinical benefits of alendronate after total knee arthroplasty remain unproven and the duration of follow-up in this study was quite short, the improvement in bone mineral density may have a clinically important effect on prosthetic fixation and the rate of periprosthetic fractures after total knee arthroplasty.

In our study of two groups comparable for comorbidity, osteoporosis score, gender and activity level, the reported bone density under a Rotaglide total knee replacement at a median of four years postoperatively was reduced at several peri-prosthetic sites. However, the method of fixation could not be clearly demonstrated to influence the bone loss differentially. This brings into question the use of the more expensive cementless implants. Reduction in bone density in both the cemented and uncemented group at several peri prosthetic sites remains a concern. Whether or not this can be addressed with medical intervention like post arthroplasty bisphosphonate treatment needs further consideration.

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