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Changes in Bone Density in Metal-Backed and All-Polyethylene Medial Unicompartmental Knee Arthroplasty

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ABSTRACT

Background: Proximal tibial strain in medial unicompartmental knee arthroplasty (UKA) may alter bone mineral density and cause pain. The aims of this retrospective cohort study were to quantify and compare changes in proximal tibial bone mineral density in metal-backed and all-polyethylene medial UKAs, correlating these with outcome, particularly ongoing pain.
Methods: Radiographs of 173 metal-backed and 82 all-polyethylene UKAs were analyzed using digital radiograph densitometry at 0, 1, 2, and 5 years. The mean grayscale of 4 proximal tibial regions was measured and converted to a ratio: the GSRb (grayscale ratio b), where GSRb > 1 represents relative medial sclerosis.
Results: In both implants, GSRb reduced significantly to 1 year and stabilized with no differences between implants. Subgroup analysis showed less improvement in Oxford Knee Score in patients whose GSRb increased by more than 10% at 1 year (40/255) compared with patients whose GSRb reduced by more than 10% at both 1 years (8.2 vs 15.8, $P = .002$) and 5 years (9.6 vs 15.8, $P = .022$). Patients with persistently painful UKAs (17/255) showed no reduction in GSRb at 1 year compared with a 20% reduction in those without pain ($P = .05$).
Conclusions: Bone mineral density changes under medial UKAs are independent of metal backing. Medial sclerosis appears to be associated with ongoing pain.

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Joint registries show higher revision rates for unicompartmental knee arthroplasties (UKAs) compared with total knee arthroplasties (TKAs) [1–3]. Unexplained pain is the second most common reason for UKA revision after aseptic loosening [4,5], and undoubtedly contributes to the poorer survival of UKA compared with TKA. Elevated proximal tibial strain with repetitive microfracture and remodeling may contribute to this pain [6]. Tibial bone models of UKAs have shown greater microdamage under all-polyethylene (AP) tibial components compared with metal-backed (MB) components [7]. In TKA, tibial component metal backing distributes stresses more evenly than in AP implants, but causes stress shielding along undersurface projections [8]. The clinical significance of this is unclear with equivalent long-term outcomes in both types of TKAs [9]. Both overloading and shielding of bone can alter bone mineral density (BMD).

Bone mineral density is routinely measured using dual x-ray absorptiometry (DEXA), but can be measured using digital radiologic densitometry. This technique derives changes in BMD from calibrated anteroposterior (AP) radiographs of the knee and has been validated against DEXA [10]. It has been used to assess changes in tibial BMD in TKA [11] and to investigate the role of altered BMD in TKA failure [12]. Stress shielding and low BMD may cause reduced cancellous support to implants resulting in subsidence. Alternatively, proximal tibial microdamage and adaptive remodeling from overload may cause pain and a relative increase in BMD under the implant.

The primary aim of this study was to examine changes in tibial BMD in medial UKAs of 2 designs: a mobile-bearing MB implant and a fixed-bearing AP implan\t. We hypothesized that medial BMD would increase under the less stiff AP tibial components due to repetitive microfracture and remodeling. Secondary aims included investigating the effect of patient demographics on BMD and the effect of BMD changes on clinical outcome, with particular reference to unexplained pain.

Abbreviations: BMD, bone mineral density; GSRa, grayscale ratio a (digital radiodensitometry ratio of medial to lateral proximal tibial condyles); GSRb, Grayscale ratio b (digital radiodensitometry ratio of medial fourth to lateral three fourths proximal tibial condyle).

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Materials and Methods

Ethical approval was obtained for this study. Patients who had undergone UKA from 1999 to 2007 at our institution were identified using our prospectively collected arthroplasty database. All patients who had undergone a cemented Oxford mobile-bearing MB UKA (Biomet, Swindon, United Kingdom) or a cemented Preservation fixed-bearing AP tibia UKA (DePuy, Johnson & Johnson Professional Inc, Raynham, Massachusetts) were included in the study. The second of bilateral UKAs were excluded, as were patients who had died.

Medical and operation notes were reviewed for all patients. Data recorded included age, sex, weight, and body mass index (BMI).

To assess BMD, AP weight-bearing knee radiographs were examined at 5 time points for each patient: preoperative, immediate postoperative, and at 1, 2, and 5 years postoperatively. All radiographs on radiographic film were digitized using a UMAX Power Look 2100XL flatbed scanner (RSA Biomedical, Naperville, Illinois) at 256 (8-bit) grayscale and 300-dpi resolution and were saved as TIFF files for analysis. Digital radiographs from the PACS system (Kodak Carestream, Rochester, New York) were exported for analysis as TIFF files. Image analysis was performed using ImageJ 1.45 m, a public-domain Java-based scientific image processing and analysis package [13]. Implant alignment [14] and pixel value statistics were measured after calibration, producing a range of grayscale values from 0 to 255 for each pixel. Each image was calibrated such that air (black pixels) had a value of 0 and the femoral component (white pixels) a value of 255 [11]. The mean grayscale value of pixels within user-defined regions of interest (ROIs) were calculated. Regions of interest were defined using the tibial anatomical axis and standardized measurements (Table 1) to create 4 ROIs: 2 medial (A1 and A2) and 2 lateral (A3 and A4; Fig. 1). Regional boundaries were selected to maximize trabecular bone content and exclude artifact from fibular head, cement, and peripheral cortical bone [11] (Fig. 1D).

Regions were transposed to all radiographs of a given patient to ensure that the same areas were measured. Mean density measurements were recorded for each ROI in each patient at each follow-up. To facilitate quantitative comparison of radiographs taken at different times, the mean grayscale was represented as a ratio, the grayscale ratio (GSR). This compared the density of medial to lateral ROIs (GSRa, Eq. (1)) and the most medial ROI to the remainder of the proximal tibia (GSRb, Eq. (2)) corrected for area. All measurements were taken by a single observer (C.E.H.S.). A GSR > 1 reflected a relative medial sclerosis.

$$\mathrm{GSRa} = \frac{\left(\overline{A1}(A1pix) + \overline{A2}(A2pix)\right)}{(A1pix + A2pix)} \Big/ \frac{\left(\overline{A3}(A3pix) + \overline{A4}(A4pix)\right)}{(A3pix + A4pix)} \qquad 1$$

$$\mathrm{GSRb} = \overline{A1} \Big/ \frac{\overline{A2}(A2pix) + \left(\overline{A3}(A3pix) + \overline{A4}(A4pix)\right)}{(A2pix + A3pix + A4pix)} \qquad 2$$

where $\overline{A} =$ mean grayscale of ROI pix $=$ area in pixels of ROI

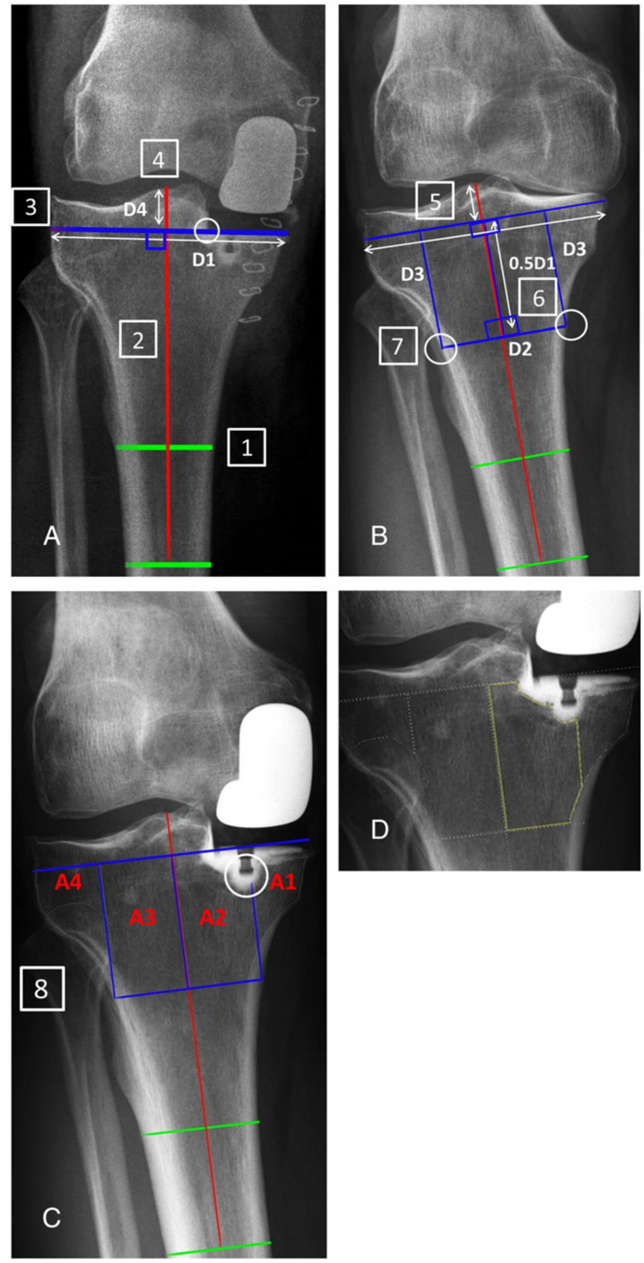

Fig. 1. A-C, Delineating the ROIs. D, ROIs for analysis with exclusion of fibular head, cortical condensation, and cement (magnified).

Table 1
Standardization of the ROIs.

Step	Figure	Description
1	1a	Tibial diaphysis measured at 2 points (green lines)
2	1a	Tibial anatomical axis (AA, red line) drawn by bisecting green lines
3	1a	Line D1 drawn through lateral corner of implant perpendicular to AA
4	1a	Vertical distance from lateral tibial spine to D1 measured as D4. This is a proxy measure of tibial resection depth and is represented as a % of D1.
5	1b	D4 used to transpose D1 on to a preoperative radiograph
6	1b	Line D2 drawn parallel to D1 at a distance 0.5 D1 to mark distal boundary
7	1b	2 vertical lines (D3s) drawn where D2 intersects the cortices
8	1c	4 ROIs thus created: A1, A2, A3, A4
9	1d	ImageJ polygon tool used to select each region for analysis, excluding the fibular head, cortical condensations, and cement

Prior to surgery, all patients completed a Short-Form (SF-12) health questionnaire [15] (physical and mental components) and Oxford Knee Score (OKS) [16]. Postoperative questionnaires (SF-12 and OKS) were sent at 12 months. In April 2013, a similar questionnaire was sent to patients with the addition of patient satisfaction measurements [17] and knee specific pain questions. Patients were asked to indicate the pain level from their knee with a visual analog pain scale (VAS) from no pain (0) to the worst pain imaginable (100). If pain was present, patients were asked to indicate its location by ticking as many boxes as applied from “at the front of the knee,” “at the back of the knee,” “on the inside edge of the knee,” “on the outside edge of the knee,” “at the top of the shinbone,” “all over the knee,” and “other.” Patients were asked if they had undergone revision or reoperation of their UKA for any reason with tick-box options. These data were correlated with the notes.