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Bone Mineral Density of the Femur in Autopsy Retrieved Total Knee Arthroplasties

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ABSTRACT

Bone mineral density (BMD), as measured by DEXA, can vary depending on bone rotation and fat content of soft tissues. We performed DEXA measurements, under controlled positioning, on 24 autopsy-retrieved femora from patients who had fully functional and asymptomatic successful TKA to determine periprosthetic BMD changes and compared results to 24 normal cadaveric femora. In TKA specimens, BMD was affected by gender, preoperative diagnosis, and zone under analysis. The lowest mean BMD was in the anterior femoral condylar zone. Males had higher mean BMD at all zones while patients with preoperative diagnosis of osteoarthritis had higher BMD in the posterior condylar zone. The mean BMD in the anterior femoral condylar zone in TKA specimens was significantly lower than in normal specimens without arthroplasties, most likely due to stress shielding.

More than 700,000 total knee arthroplasty (TKA) procedures are performed annually in the United States alone [1]. Every year, the frequency of these procedures continues to rise [2]. Currently, an increasing number of procedures are being performed in younger patients [3,4]; TKA survivorship has been reported to be around 95% at mid-term to long-term follow-up periods according to large US joint registries [5,6]. A growing number of TKA revisions are expected in the future. Implants may fail for different reasons: loosening, infection, instability, arthrofibrosis, extensor mechanism deficiency, component malpositioning, and/or periprosthetic fracture [7–9]. To date, mechanical loosening and infection remain the top concerns of failure. Loosening of both the femoral and tibial components in TKA may result from bone quality changes at the bone–implant interface [10,11]. In hip arthroplasties, low preoperative BMD has been found to be a predictor of delayed osseointegration and component loosening [12,13]. The femoral periprosthetic bone quality around a TKA is directly affected by several factors such as type of degenerative joint disease (DJD) [14–17], quantity and quality of preexistent bone matrix [18–21], and bone remodeling following the procedure [22,23]. Bone remodeling is influenced by the orientation and magnitude of the functional strains at the periprosthetic bone interface. An implant, in direct contact with bone, will shield certain areas from the mechanical forces needed for its normal maintenance and remodeling, causing it to become osteopenic and decreasing its strength [22,24], which may lead to long term implant failure and even complicate revision surgeries due to poor remaining bone mass around the implant [25,26].

Previous authors have reported their findings on the periprosthetic bone density changes around the components of TKA [27–37]. Currently the most precise and accurate method to quantitatively assess BMD has been achieved by dual energy x-ray absorptiometry (DEXA) [38,39]. It has been successfully utilized to measure periprosthetic bone density around femoral components in total knee arthroplasty [33–37]; however, DEXA scanning is not as accurate as previously thought [40]. The measured BMD can vary depending on the rotation of the femora [39,41–44], and the fat content of soft tissues surrounding the bone of in-vivo patients or in-situ cadavers [44,45]. Our main objective was to accurately determine the BMD in the femoral bone of clinically successful autopsy retrieved TKA specimens, and compare the ratios of the measurements to those in similar zones in normal cadaveric specimens. As secondary objectives we describe the differences in BMD related to patient's age at surgery, gender, weight, length of implantation, method of fixation, the preoperative diagnosis that led to DJD, and roentgenographic findings on TKA specimens.

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Materials and Methods

Study Design

Forty-eight knee specimens were studied. Twenty-four were autopsy retrieved distal femurs that had previous TKA procedures performed by the senior authors (DSH, KAK). All the prostheses were primary porous coated anatomic (PCA) from Howmedica (Rutherford, NJ). The mean age at surgery for the TKA specimens was 72.6 ± 2.0 (SE) years (range, 53 to 87), sixteen were from females; nineteen were from patients with osteoarthritis (OA) and five from patients with rheumatoid arthritis (RA). Of the TKA specimens, 19 components were uncemented (12 women) and 5 were cemented (4 women). The average length of implantation was 75.6 ± 8.2 (range, 11 to 135) months. For the normal 24 knees (15 women), the mean age was 77.2 ± 2.9 (range, 41 to 91) years. Specimens were obtained at time of death from patients with fully functional asymptomatic TKA based upon quantitative knee scoring systems and roentgenographic reviews. All specimens were collected by trained personnel, wrapped in saline soaked towels, and immediately frozen at −140 °C. In addition, twenty-four distal femurs with no known history of arthritis were obtained from human cadavers. These specimens were formalin fixed and upon dissection were stored at room temperature in air-tight bags. The rationale that we used in order to compare frozen samples against formalin-fixed knees, was based on the findings by Lochmuller et al, [44] who showed no difference in BMD measurements between non-fixed and formalin-fixed bones using DEXA scanning. Specimens were obtained as part of an IRB approved retrieval program instituted by one of the authors (DSH).

Femoral rotation can affect the BMD measured with DEXA [39,41–44]. Therbo et al [43] demonstrated these variations when the knee was rotated while measuring distal femoral TKA periprosthetic BMD in a lateral view, using a DEXA machine similar to ours (Norland XR-26 mark II, Norland Corporation, WI). Furthermore, fat contained within soft tissues of in-vivo or cadaveric in-situ bones can influence the BMD obtained with DEXA scan [40,44,45]. To reduce the variability of the BMD measurements within our study, an aparatus was developed in order to accommodate the knees and obtain a true lateral view. Additionally, the femora were stripped from their soft tissues. Thus, while performing the DEXA scanning, we guaranteed neither rotation nor superimposition of the femoral component nor influence of soft tissues, obtaining a more accurate BMD measurement.

Roentgenographic Analysis

The TKA specimens were thawed using a bath of warm normal saline and unwrapped for roentgenographic analysis and DEXA scanning, as previous studies have shown that frozen samples yield a higher BMD when using DEXA scanning [46]. The normal specimens were removed from their sealed bags, analyzed and resealed for storage. In order to avoid the inherent error of soft tissues and fat composition that is introduced during scanning [40,44,45], soft tissue was removed from each knee to expose the femoral shaft and the femoral component of the prosthesis. Antero-posterior (AP) and lateral roentgenographs of all the specimens were obtained. A foam positioner was utilized to align the specimens in a true AP position. The specimens were then rotated and tilted until a true lateral roentgenograph view was also obtained. For the TKA specimens the presence of loose beads of the component in the femur was recorded from previous roentgenographs available.

DEXA Scanning

DEXA scanning evaluated the BMD of all the 48 specimens. The specimens were placed using the same pre-designed foam positioner in order to obtain a true lateral image. This device ensured precise positioning of successive specimens, and thus reduced the influence of the rotation of the anisotropic bone on the measured BMD [39,41–44]. DEXA measurements were obtained using a Norland XR-26 densitometer (Norland Corporation, WI) and analyzed using Norland software version 2.2.2. Bone mineral density was measured in g/cm^2. To ensure accuracy of the DEXA scanner, daily calibrations were performed employing a dual material standard, as recommended by the manufacturer. One investigator completed all BMD measurements for the TKA and normal knee specimens.

Scan acquisition was started approximately 40 mm above the proximal end of the retrieved femoral component and continued until approximately 30 mm below the distal end of the femoral component. The scans were obtained using a pixel size of 1.5 mm × 1.5 mm and a scan speed of 60 mm/s. Average scan time duration was 4.5 min. The Norland software provided a subroutine to measure the density close to the bone–implant interface. Five zones on the lateral view were selected for bone density measurements in both sets of specimens (Fig. 1). Zones 1 and 2 referred to the anterior proximal and distal parts of the femoral condylar area, respectively (Fig. 1). Zone 3 and 4 referred to the distal and proximal mid part of the femoral condylar area, respectively (Fig. 1). Zone 5 referred to the posterior part of the femoral condylar area (Fig. 1). Each zone was referenced from specific locations on the implant or anatomical landmarks, thus allowing for the duplication of their relative size and location among all specimens. Using tools available in the Norland software package, the operator defined each zone manually on all the specimens. A mean BMD value was also calculated for the five zones in each of the specimens.

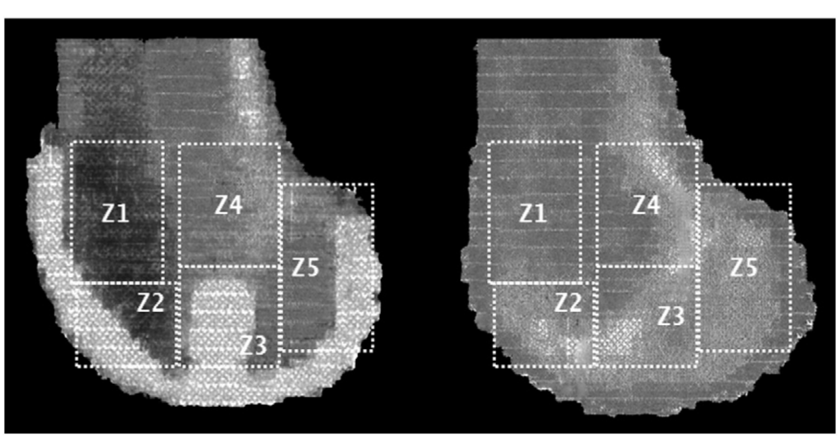

Fig. 1. Representation of the five zones used for BMD measurements in the knee specimens.