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Bone Assessment after Total Knee Arthroplasty by Dual-Energy X-ray Absorptiometry: Analysis Protocol and Reproducibility

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Abstract. Bone quality is important for the success of joint prostheses implantation, and the assessment of bone density after total knee arthroplasty by means of dual-energy X-ray absorptiometry may be useful for monitoring implant stability. The aim of this study is to suggest a validated analysis protocol for the assessment of bone status after total knee arthroplasty. A dedicated densitometric analysis protocol of five regions of interest was designed, and 10 subjects who had received an uncemented knee prosthesis (8 females and 2 males, aged 55–74 years) underwent three consecutive scans in posteroanterior and lateral projections, with repositioning after each scan to test the suitability and reproducibility of the protocol. The reproducibility of the measurement of bone mineral content and density in the femoral and tibial regions ranged, respectively, from 2.1% to 4.1%, from 0.9% to 2.6% for the posteroanterior scans, and from 2.7% to 5.6% and from 2.3% to 4.7% for the lateral scans, depending on the considered region. Our results confirm that the suggested protocol allows precise assessment of bone mineral content and density, and that dual-energy X-ray absorptiometry is reliable for the evaluation of bone mass around prosthetic implants.

As has been shown recently, dual-energy X-ray absorptiometry (DEXA) is an accurate and precise tool for assessing bone mineral density in the proximity of the femoral component of total hip arthroplasty [1–3]. During the last 3 years, DEXA has provided information concerning the distribution of periprosthetic bone density [4, 5] and data on bone loss around implants [4–6].

The assessment of bone status after total knee prosthesis (TKA) is equally interesting. The role of bone strength of the proximal tibia in component stability is under investigation [7–9], and it has also been found that significant discrepancies in bone distribution between the medial and lateral compartments (and a consequent further threat to stability) can be expected in the presence of valgus or varus knee deformities [9, 10]. Stress-shielding phenomena with evidence of marked osteopenia in the anterior aspect of the distal femur are another concern in total knee arthroplasty [11, 12]. Finally, the assessment of bone density may be useful in making the choice between a cemented or a cementless implant [13].

The aim of this study was to suggest a validated analysis protocol for the assessment of bone mineral status after TKA.

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Material and Methods

In all, 10 (8 females and 2 males, aged 55–74 years) were enrolled in this study, all of whom had primary osteoarthritis of the knee and underwent uncemented TKA without patella replacement (8 Miller Galante II, Zimmer and 2 TCKS, 3M). None of the subjects had experienced any intraoperative or postoperative complications, and neither their discharge from hospital nor their return to full weight bearing activity had been delayed. At the time of enrollment (2–26 months after surgery), none of them had suffered any symptoms or signs of infection or loosening. Periprosthetic bone mineral content (BMC, grams) and bone mineral density (BMD, g/cm^2) were assessed by means of DEXA (QDR 2000, Hologic Inc., Waltham, MA), using the ''prosthetic hip'' scanning software version 6.0, which allows the metal parts included in the scan window to be automatically removed from the calculation. In some cases, the titanium screws of the Miller Galante II tibial component were not recognized as metal by the software because of their small diameter and titanium composition; when necessary, they were manually excluded by the operator.

The densitometric analysis protocol requires a scan in posteroanterior projection (PA), with the knee in full extension and 15° of internal rotation, and a scan in lateral projection (LL) with the knee in 20° of flexion and neutral rotation. The device for positioning the lower limb for hip scans was used to control rotation for the PA scans, and rubber supports of different heights were used for the LL scans. Two rice bags were also used as a soft tissue substitute. For the LL scans, the degree of knee flexion was checked by means of a goniometer.

For the analysis, five regions of interest (ROIs) were defined in both projections: two for the femoral side and three for the tibial side (where BMD was independently measured). For the PA scan of the proximal femur, one medial and one lateral ROI were identified in the metaphyseal region, using the edge of the prosthetic femoral shield as a landmark. For the LL scan, one anterior and one posterior ROI were identified, using the long axis of the femoral diaphysis as a boundary. For the tibia, three ROIs were iden-

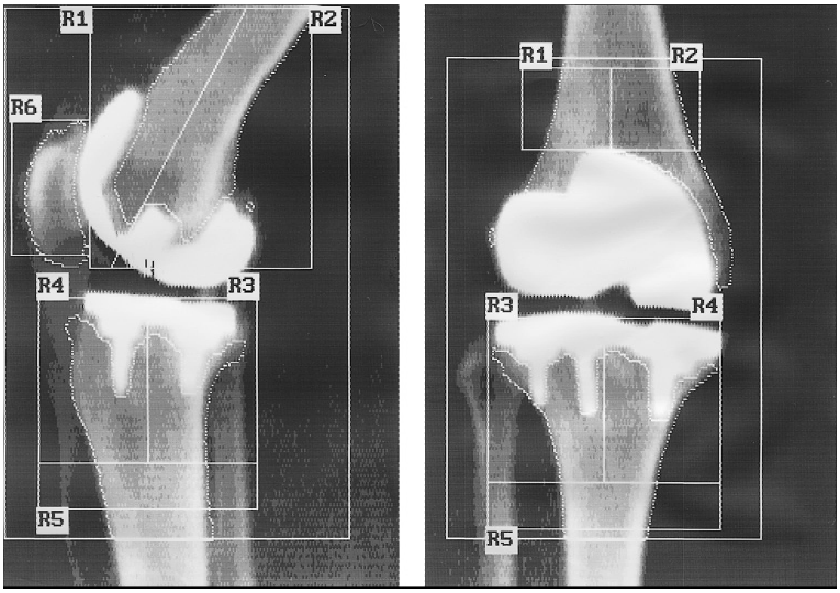

Fig. 1. Analysis protocol for the evaluation of the bone status around total knee arthroplasty. (a) Five regions of interest (ROIs) are identified in the posteroanterior projection: one medial and one lateral ROI proximal to the femoral shell, and one medial, one lateral, and one distal ROI under the tibial component. (b) In the laterolateral projection, five ROIs are also identified: one anterior and one posterior ROI proximal to the femoral shell, and one anterior, one posterior, and one distal ROI under the tibial component. A sixth ROI for the evaluation of the patella may be added.

tified for both the PA and the LL scans: for the PA scan, one medial, one lateral, and one distal region; for the LL scan, one anterior, one posterior, and one distal region. A diaphyseal midpoint was used to divide the medial and lateral or anterior and posterior regions, calculated in the proximal limit of the ROIs for the femoral segment and in the distal limit for the tibial segment. In addition, for the LL scans, another ROI was planned to measure the patella (Fig. 1). For both the PA and the LL scans, the operator manually excluded the fibula from the analysis.

The reproducibility of the BMC and BMD measurements was calculated in each subject by making three consecutive scans in the PA and LL projections on the same day, with the subject being repositioned after each scan. The reproducibility of paired measurements was determined as described elsewhere [14].

Results

The average BMD values found in the distal femur and proximal tibia around the metal implants range from 0.722 to 1.192 g/cm^2. The measured bone densities are mainly related to the amount of cortical bone, with higher values being found in the regions with a higher cortical content (posterior femur, anterior, and distal tibia). The variability in BMD of the different ROIs in this sample ranged from 12% to 28% for the PA projections, and from 14% to 34% for the LL projections. The correlation coefficients between the BMD of the PA and LL scans of each segment ranged from 0.66 to 0.96 for the femur and from 0.57 to 0.98 for the tibia.

The short term *in vivo* reproducibility of BMC and BMD in the femoral and tibial ROIs ranged, respectively, from 2.1% to 4.1% and from 0.9% to 2.6% for the PA scan, from 2.7% to 5.6% and from 2.3% to 4.7% for the LL scan (Table 1).

Discussion

Bone mineral assessment around knee arthroplasty is presently at its very beginning. The effect of bone status on the stability of the tibial component and the roentgenographic occurrence of significant osteopenia in the anterior part of the proximal femur after TKA are the main incentive for the potential use of DEXA.

The accuracy and precision of DEXA for the evaluation of bone density in the proximity of metal implants has been thoroughly assessed in several studies of patients undergoing total hip arthroplasty [1–4, 15]. Further evidence of the feasibility of DEXA in this field comes from the studies of Robertson [16], who showed that DEXA was better than the other considered methods at assessing bone mineral changes in the proximity of the TKA, and Banks [17], who tested the application of the orthopedic software for the hip in patients with TKA.

In a more recent densitometry study, Levitz et al. [18] demonstrated an average bone loss of more than 5% per year below the tibial component in seven patients followed for 8 years after surgery: They concluded that a similar bone loss may be responsible for the sharp step-off seen in the survival curves of TKA 10–12 years after surgery.

Unfortunately, these researchers measured only the proximal tibia and did not provide a precise protocol for the analysis. Given the problem associated with repositioning and limb rotation, and bearing in mind that the scarcity of soft tissue around the joint can affect measurement reproducibility, we think that a dedicated and validated analysis protocol is advisable.

The regions of interest chosen in the present protocol followed both methodological and clinical guidelines: Delineated ROIs must be reliably relocated on subsequent scans, large enough to contain an adequate number of pixels to ensure precise repositioning, and must include regions that are relatively uniform from the mechanical and physiological points of view. The identification of medial and lateral regions in the PA projection, and anterior and posterior regions in the LL projection is simple but consistent with the evaluation of the mechanical load rearrangements that take place after TKA.

The reproducibility of our results confirms the consistency of our choices, which allows a precise and noninvasive assessment of BMD redistribution. Given the experience of Levitz [18], who found the average annual rate of bone loss after TKA to be greater than the expected varia-

Table 1. Reproducibility values for the measurement of bone mineral content (BMC, grams) and density (BMD, g/cm^2) in the proximity of a total knee prosthesis using the dual-energy X-ray absorptiometry and the suggested analysis protocol

Region of interest PA projection	Precision error % BMC	Precision error % BMD	Region of interest LL projection	Precision error % BMC	Precision error % BMD
Lateral femur	3.0	2.6	Anterior femur	4.5	2.3
Medial femur	4.1	1.4	Posterior femur	5.6	2.3
Lateral tibia	3.0	2.2	Posterior tibia	4.8	2.7
Medial tibia	2.1	2.2	Anterior tibia	3.7	4.7
Distal tibia	2.8	0.9	Distal tibia	2.7	2.3
Global PA	2.2	1.4	Global LL	2.5	2.5

tions with normal aging, the reproducibility values found in our study are definitely adequate for the long-term monitoring of implants. The rotational problems associated with the lateral scans did not prevent reliable data from being obtained which, in some cases, may add valuable information (as is suggested by the correlation coefficients between the PA and LL projections).

Finally, the positioning and the time necessary for the scans were well tolerated by the patient, even in the case of an early postoperative examination.

Although this methodological approach for following up the implantation of a knee prosthesis is promising, further long-term studies are required to assess its clinical impact. However, the use of validated protocols is crucial for the acquisition of solid experience.

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