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Technical note

A reliable method for measuring proximal tibia and distal femur bone mineral density using dual-energy X-ray absorptiometry

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ABSTRACT

Purpose: To assess the intra- and inter-rater reliability of a standardized protocol for measuring proximal tibia and distal femur bone mineral density (BMD) using dual-energy X-ray absorptiometry (DXA).
Methods: Ten able-bodied individuals (7 males) participated in this study. During one measurement session, the knee of each participant was scanned twice by rater 1 using DXA. Both scans were analyzed twice by rater 1 as well as once by a second rater. Intraclass correlation coefficients (ICCs), standard error of measurements (SEMs) and smallest detectable differences (SDDs) were calculated for the outcome measures proximal tibia and distal femur BMD. A decision study was performed to determine the effect of study protocol adjustments (i.e. increasing the number of scan repetitions, or scan analyses by the same rater) on SEM and SDD values.
Results: High intra- and inter-rater ICCs (0.97–0.98) were found for both proximal tibia and distal femur BMD. Low SEMs (0.017–0.028 g/cm^2) and SDDs (0.047–0.077 g/cm^2) were found, with a slightly better result for proximal tibia BMD. Increasing the number of scan analyses by the same rater did not markedly reduce SEM and SDD values, while increasing the number of scan repetitions did.
Conclusions: Proximal tibia and distal femur BMD can be reliably assessed with this method.

1. Introduction

Osteoporosis of the lower extremities is a severe secondary complication in people with a spinal cord injury (SCI) causing an increased risk of (low-impact) fractures, especially in the proximal tibia and distal femur.[1,2] To manage this so-called immobilization osteoporosis, bone mineral density (BMD) should therefore be measured at these specific sites.[3]

Dual-energy X-ray absorptiometry (DXA) is a commonly used technique to measure BMD, to diagnose and manage osteoporosis, as well as to predict fracture risk.[4] There are standard clinical DXA protocols available to accurately measure whole body and regional (i.e. hip, lumbar spine and forearm) BMD[5]; however, the proximal tibia and distal femur are not standard measurement sites, and can therefore only be measured using a customized protocol.

In the literature, there is not much consistency regarding these customized protocols to measure knee BMD. A large variety was observed in: (1) type of DXA scan algorithm: several studies have used different modified lumbar spine[6,7] or forearm[8] scan protocols, while others have used the small-animal program[9,10]; (2) region of interest (ROI) settings: several studies have used anatomical markers for the ROI setting (e.g. the ROI's height is the same size as the fibular head),[6–8] while others have used the same fixed sizes for all participants (e.g. the proximal 7 cm of the tibia)[10,11]; (3) knee placement: in most studies the knee was scanned frontally with the participants in the supine position,[6,7,9,10] while in one study the participants were placed in the lateral position.[8]

Besides the above-described inconsistency concerning the methods used to measure proximal tibia and distal femur BMD, many studies lack important methodological details (e.g. regarding scan and analysis software used, and ROI settings), making it impossible for other researchers to reproduce these protocols.[9,11–13] Moreover, most methods were not tested on reliability.[7,9,10,12,13]

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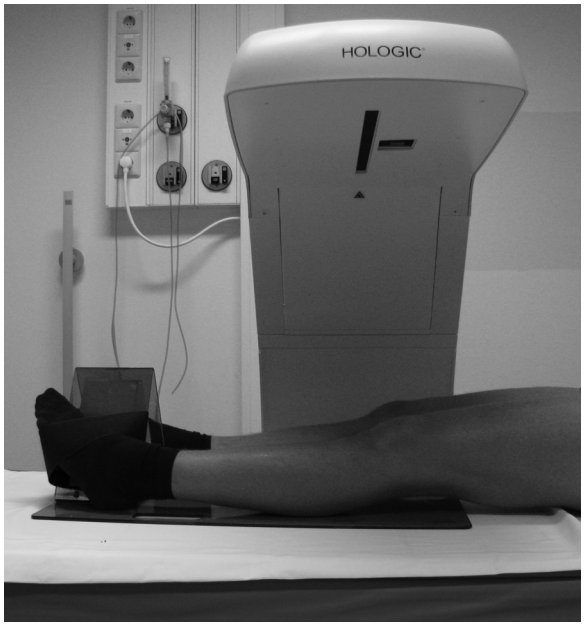

Fig. 1. Scan position for measuring left proximal tibia and distal femur BMD using DXA; the participant was placed in the supine position with the left leg fully extended and the foot endorotated and strapped in a foot positioner.

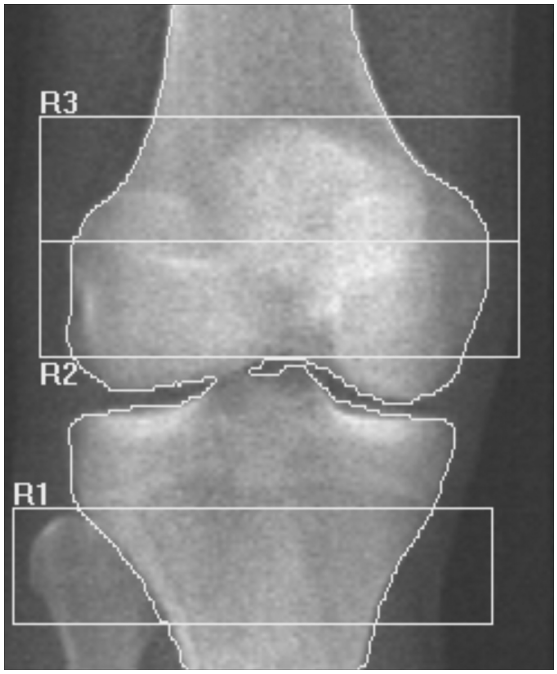

Fig. 2. A frontally scanned knee where both the patella and fibular head are completely visible in the scan. R1 is the ROI of the proximal tibia; R2 and R3 are the ROIs of the distal femur, with the height of R2 matching the height of R1 and R3 including R2 and the entire patella.

Therefore, the purpose of this study was to assess the intra- and inter-rater reliability of a standardized method for measuring proximal tibia and distal femur BMD using DXA. Moreover, it was investigated whether this protocol could be optimized. Results of this study might lead to better osteoporosis diagnosis and management in people with disabilities and diseases where the knee is affected (e.g. SCI, cerebral palsy, Duchenne muscular dystrophy and knee osteoarthritis).

2. Methods

2.1. Participants

Ten able-bodied persons (7 males; mean age 35 (25–58) years; mean body mass 75.3 (56.4 – 91.2) kg; mean height 183.9 (167.0 – 193.7) cm; no history of knee fractures) provided written informed consent and participated in this study which was approved by the Medical Ethics Committee of the VU University Medical Center Amsterdam.

2.2. Scan procedure

Proximal tibia and distal femur BMD were measured using DXA (Hologic Discovery, Hologic Inc., Waltham, MA, USA). After thorough discussions with radiologists and Hologic, we hypothesized that an adapted forearm scan protocol is most suitable for knee measurements, since the knee anatomically has more similarities with the forearm than with the lumbar spine or a small animal. Furthermore, since for many people with SCI it is inconvenient to maintain a lateral position, scans were performed with the participants in supine position.

A radiologic technologist (rater 1) positioned the participant's non-dominant leg into the correct alignment and rotation: the leg was placed in full extension, and the foot was endorotated (to reduce overprojection of the tibia and fibula as much as possible) and strapped in a foot positioner (Fig. 1). The knee was scanned frontally using the forearm scan protocol, such that both the patella and fibular head were completely visible in the scan, and that the joint space of the knee was horizontal (Fig. 2); participants were repositioned and scans were repeated by rater 1 until these criteria were met. In case of movement artifacts, the scan was also performed again.

During one measurement session, for each participant the above-described scan procedure was performed twice by rater 1 to obtain a total of two proper knee scans per person. Between repeated scans, the participants stepped down from the DXA table and were then completely repositioned by rater 1. Scan time was approximately 30 s, and exposure to radiation was less than 0.2 μSv per scan.[14]

2.3. Analysis

Following the advice of Hologic, the proximal tibia and distal femur were analyzed using the forearm subregion analysis protocol. The automatic bone detection function was used to shade all bone pixels in the scan and the image was corrected manually for erroneously included or excluded bone pixels; fibula bone pixels were excluded. To take anthropometrical differences among people into account, the ROIs were set to anatomical markers. The distal horizontal edge of the ROI of the proximal tibia (R1) was placed at the most distal point of contact between the fibular head and the tibia, and the proximal horizontal edge was placed at the upper edge of the fibular head (Fig. 2). For the distal femur, two ROIs (R2 and R3) were set to also examine the effect of the patella on the reliability of the measurement, with R2 including only a part of the patella and R3 including R2 and the entire patella. The bottom horizontal edge of both R2 and R3 was positioned at the top of the space between the femoral condyles, with the height of R2 matching the height of R1, and the proximal horizontal edge of R3 placed at the upper edge of the patella (Fig. 2). The width of R1–R3 was set outside the bone area but inside the soft tissue area (no air was included). After setting R1–R3, the analytic software accompanying the system (Apex 13.3.3) automatically performed the BMD calculations.