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Distal Radius Bone Mineral Density Estimation using the Filling Factor of Trabecular Bone in the X-ray Image

Sooyeul Lee, Ji-Wook Jeong, Jeong Won Lee, Done-Sik Yoo, and Seunghwan Kim
IT-BT Research Group, Electronics and Telecommunications Research Institute (ETRI)
Daejeon, Korea

Abstract— **Osteoporosis is characterized by an abnormal loss of bone mineral content, which leads to a tendency to non-traumatic bone fractures or to structural deformations of bone. Thus, bone density measurement has been considered as a most reliable method to assess bone fracture risk due to osteoporosis. In past decades, x-ray images have been studied in connection with the bone mineral density estimation. However, the estimated bone mineral density from the x-ray image can undergo a relatively large accuracy or precision error. The most relevant origin of the accuracy or precision error may be unstable x-ray image acquisition condition. Thus, we focus our attentions on finding a bone mineral density estimation method that is relatively insensitive to the x-ray image acquisition condition. In this paper, we develop a simple technique for distal radius bone mineral density estimation using the trabecular bone filling factor in the x-ray image and apply the technique to the wrist x-ray images of 20 women. Estimated bone mineral density shows a high linear correlation with a dual-energy x-ray absorptiometry (r=0.87).**

Keywords— **Osteoporosis, Bone Mineral Density, X-ray Image, Distal Radius**

I. Introduction

Osteoporosis is a widespread medical condition affecting middle-aged and older populations [1]. Especially the symptom is more frequent in post-menopausal women. Osteoporosis is characterized by an abnormal loss of bone mineral content, which leads to a tendency toward non-traumatic bone fractures or to structural deformations of bone [2]. Thus, accurate estimation of the bone mineral density (BMD) has been a most important diagnostic indicator for determining the status of osteoporosis and for follow-up study of the patient under the therapy for osteoporosis.

The most important aspect of osteoporosis is fracture in central bones such as femur and spine. Especially, fracture in femur leads to about 20% mortality in case of older osteoporotic populations. BMD is a major indicator of bone strength and, thus, various BMD measuring techniques have been developed so far. The most well known method for estimation of BMD is a dual-energy x-ray absorptiometry (DEXA). The accuracy error of the method in determining BMD of the spine is reported to be below few percent [3]. The reproducibility of the method is also reported to be excellent. Quantitative computed tomography (QCT) is also used for three-dimensional bone density estimation without any superimposition of other tissues [4]. However, these apparatuses need high costs for equipping. In this sense, BMD estimation from conventional x-ray images has been a quite attractive topic because x-ray images have been widely used as a routine screening tool for bone disease inspection. So far, several effective methods to estimate BMD from x-ray images are developed. Generally, BMD estimation from the x-ray image can undergo a relatively large accuracy error or reproducibility error. The most relevant origin of the accuracy or reproducibility error may be unstable x-ray image acquisition condition. Thus, we focus our attentions on finding a BMD estimation method that is relatively insensitive to the x-ray image acquisition condition.

In this paper, we provide a simple method for distal radius BMD estimation using the trabecular bone filling factor in the x-ray image and apply the method to the wrist x-ray images of 20 women.

II. Methodology

A. Materials

In order to estimate accuracy of the method, wrist x-ray images of 20 women are analyzed. Each wrist, together with an 8-step (1.50-12.00mm) aluminum step-wedge, is radiographed using a fine screen-film system under a fixed x-ray exposure condition (51kVp, 5mAs). Each x-ray film has been digitized using a film scanner with a resolution of 200 pixels per inch (PPI) and an 8-bit gray scale. Each person has also undergone BMD measurement on the wrist using a DEXA.

All x-ray images are calibrated using the aluminum step-wedge. Fig. 1 illustrates a calibrated x-ray image. In each calibrated image, rectangular region of interest (ROI) is selected on the distal radius region so that the ROI contains the radius and nearby soft-tissue regions.

B. Methods

Bone is composed of the dense cortical part (cortical bone) and the inner core part (trabecular bone). Generally, bone creation and resorption rates are equal. In osteoporotic person, however, bone resorption rate exceeds bone creation

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Fig. 1: Calibrated x-ray image and a rectangular region of interest

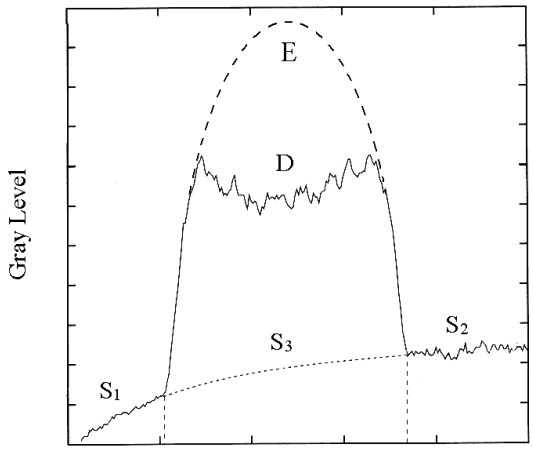

Fig. 2: Gray level profile (solid line) across the radius and interpolated profile (dotted line) in the radius region.

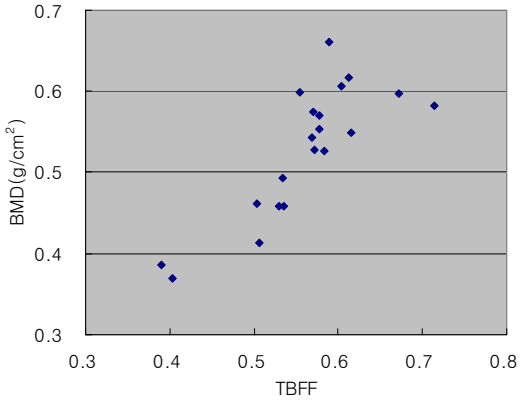

Fig. 3: TBFF vs. DEXA BMD

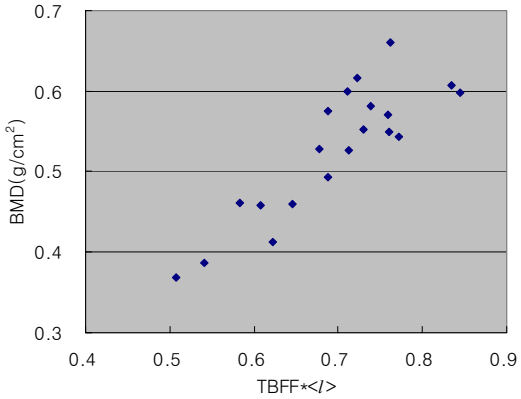

Fig. 4: TBFF*<*l*> vs. DEXA BMD

rate, leading to a loss of bone mineral content. Trabecular bone is resorbed more rapidly than the cortical bone in osteoporosis. This implies that the trabecular bone is more reflective of the state of osteoporosis and that early stage intervention in osteoporosis can be possible through the screening of the trabecular bone. Thus, we develop a simple BMD measurement method based on the filling factor of trabecular bone.

In order to estimate the trabecular bone filling factor (TBFF), we analyze gray level features of the distal radius in the x-ray image as follows. First, bone region is segmented from soft-tissue regions. In the wrist x-ray image, bone region is easily segmented from nearby soft-tissue regions using the gradient method. Then soft-tissue effects, contained in gray levels in the radius region, are eliminated. Sotf-tissue effects are eliminated straightforwardly. In Fig. 2, profile S_1-D-S_2 shows an original gray level profile along a transverse line *l* in Fig. 1. A soft-tissue effect (S3) is obtained by interpolating profiles S_1 and S_2 into the radius region using a 4th order polynomial. Finally, envelop profile E, which is obtained if it is assumed that the trabecular bone is completely filled, should be estimated. The simple method to obtain the profile E is to fit two steepest edge profiles to an ellipse with linearly modulated amplitude.

Now TBFF can be obtained by averaging the area ratio between D-S_3 and E-S_3 for all transverse line *l*.

III. Results

In order to inspect TBFF as a measure for distal radius BMD, we have measured distal radius BMD using a DEXA in the same ROI in Fig. 1. Fig. 3 shows the result. The linear correlation coefficient between the TBFF and the DEXA BMD is 0.82. This is a high correlation, so that TBFF can be used as a direct measure of the distal radius BMD.

TBFF itself is devised by considering only the filling fraction of trabecular bone. Thus, the TBFF does not measure the size effect of the radius. For the same TBFF, as the radius size becomes larger, BMD should also become larger. Considering this fact, we have devised a modified measure as TBFF*<*l*>, where <*l*> is the average transverse

bone size along *l* in the ROI. The result is shown in Fig. 4. The linear correlation coefficient between the TBFF*<*l*> and the DEXA BMD is 0.87. This is a significant improvement and leads to an accuracy about 92%.

IV. Conclusions and Future Study

In this study, we have provided a simple distal radius bone mineral density measurement method using the trabecular bone filling factor. The trabecular bone filling factor itself and its radius-size-modified value show good linear correlations with the DEXA BMD.

For the clinical use of these results, TBFF and its modification should provide good reproducibility. Especially, reproducibility is very important for follow-up study of the patient under the therapy for osteoporosis. As a preliminary study, we have investigated several patients under different x-ray imaging conditions. Tentative reproducibility error is about 3%. For the precise measurements of the accuracy and reproducibility of the methods, we will study more massive patients group in the future.

In osteoporosis study, fracture risk prediction is very important. Thus, the TBFF and its modifications can be applied to find promising measures to better distinguish between normal group and high fracture risk group. We leave this for future studies.

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