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Is central skeleton bone quality a predictor of the severity of proximal humeral fractures?☆

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ABSTRACT

Introduction: The objectives of this study were to evaluate the correlation between bone attenuation around the shoulder joint assessed on conventional computed tomography (CT) and bone mineral density (BMD) based on dual-energy X-ray absorptiometry (DEXA) of the central skeleton and the correlation between the bone quality around the shoulder joint and the severity of the fracture pattern of the proximal humerus.

Materials and methods: A total of 200 patients with proximal humeral fracture who underwent preoperative 3-dimensional shoulder CT as well as DEXA within 3 months of the CT examination were included. Fracture types were divided into simple and comminuted fracture based on the Neer classification. After reliability testing, bone attenuation of the glenoid, three portions of the humeral head, and metaphysis was measured by placing a circular region of interest on the center of each bony region on CT images. Partial correlation analysis was used to assess the correlation between the bone quality around the shoulder joint on CT and the BMD on the central skeleton after adjusting for age and body mass index. Partial correlations between fracture classification and CT/DEXA results were also evaluated.

Results: Bone attenuation measurements of the glenoid and humeral head showed good to excellent reliability (intraclass correlation coefficient, 0.623–0.998). Bone attenuation of the central portion of the humeral head on CT showed a significant correlation with the BMD of L1, L4, the femoral neck, and femoral trochanter (correlation coefficient, 0.269–0.431). Bone attenuation of other areas showed a lower correlation with BMD by DEXA. As the level of the Neer classification increased from a 2 to 4-part fracture, bone attenuation of the central humeral head decreased significantly ($r = -0.150$, $p = 0.034$). However, the BMD on DEXA was not a predictive factor for comminuted fracture of the proximal humerus.

Conclusions: DEXA examination of the central skeleton may not reflect the bone quality of the proximal humerus and severity of proximal humeral fracture. Direct assessment of the bone quality of the proximal humerus is recommended to determine the osteoporotic nature of the fracture.

Introduction

Osteoporosis is a systemic skeletal disorder characterized by the microarchitectural deterioration of bone tissue. With the rapid progression of an aging society, the prevalence of osteoporosis has been gradually increasing [1]. Low bone mineral density (BMD) has long been recognized as a major risk factor for fracture in the elderly population [2]. Osteoporotic bone tissue may lead to high morbidity and mortality caused by fragility fractures [3,4]. The cost of treatment for osteoporotic fractures is also a heavy burden on patients' families, society, and the country [5]. Therefore, the prevention and prediction of osteoporotic fractures have become a major issue in health and medical fields.

Dual-energy X-ray absorptiometry (DEXA) of the central skeleton has been used as the gold standard for the estimation of BMD. The World Health Organization international reference standard for diagnosing osteoporosis is the evaluation of relative bone quality at the femoral neck, and the lumbar spine can also be

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assessed in postmenopausal women and men older than 50 years [6]. However, the peripheral bone quality cannot be screened using the current BMD evaluation system because the measurement area in DEXA is limited to the central skeleton. Recently, the assessment of peripheral BMD has attracted attention because peripheral bone fractures have features of osteoporotic fractures [4]. Several alternative screening tools have been introduced to assess peripheral BMD, such as radiographic absorptiometry, quantitative ultrasound, and conventional and quantitative computed tomography (CT) [7]. Among them, conventional CT is widely performed to identify unrecognized disease and is easy to use [8]. As there is a correlation between the BMD measured by conventional CT in the lower extremity and that measured by DEXA [9], and peripheral bone attenuation on the lower extremity CT adequately reflects central BMD on DEXA [8], lower extremity CT is a useful screening tool for osteoporosis.

However, the correlation between the BMD measured by conventional CT in the upper extremity and that measured by DEXA has not been defined. Although proximal humeral fracture has been accepted as a typical osteoporosis-associated fracture [10], DEXA of the central skeleton has traditionally been used for the diagnosis of osteoporosis, and it is not clear whether the BMD of the central skeleton adequately reflects the bone quality of the proximal humerus.

The objectives of this study were to evaluate the correlation between bone attenuation around the shoulder joint assessed on conventional CT and BMD based on DEXA of the central skeleton and the correlation between the bone quality around the shoulder joint and the severity of the fracture pattern of the proximal humerus.

Materials and methods

This retrospective study was approved by the Institutional Review Board of our hospital. Informed consent was waived because of the retrospective nature of this study.

All medical records of consecutive patients over the age of 20 with proximal humeral fracture between January 2004 and February 2015 were reviewed. Patients who underwent 3-dimensional (3D) shoulder CT at our institution were included in this study. The exclusion criteria were as follows: (1) high-energy trauma; (2) CT performed at other institutions; and (3) inadequate CT scan available for review, including previous surgery or other conditions that affected the measurement site. Motor vehicle accidents and falls from a height greater than 2 m were defined as high-energy trauma, whereas falls from a standing height were defined as low-energy trauma [4]. Among the patients included in this study, patients who also underwent DEXA within a 3-month interval of their CT examination were evaluated to access the correlation between the bone quality around the shoulder joint on CT and the BMD of the central skeleton. Demographic data, including age at injury, sex, and Neer classification of the proximal humeral fracture were collected by medical records and CT image review. The humeral fractures were divided into two subgroups based on the Neer classification as follows: simple fracture (2-part fracture) and comminuted fracture (3- and 4-part fracture). CT studies were performed using Somatom sensation-64 (SIEMENS, Erlangen, Germany) with 120 kVp and 3.0-mm slice thickness for the shoulder. CT was performed with patients in the supine position. BMD studies were performed using Lunar Prodigy Advance (GE Healthcare, Milwaukee, WI, USA) with a standard protocol. All CT images were digitally acquired using a picture achieving and communication system (PACS; Infinitt, Seoul, Korea), and measurements were subsequently carried out using PACS software.

Measurement of parameters and reliability test

Five orthopedic surgeons with 21, 10, 8, 7, and 3 years of orthopedic experience, respectively, held a consensus building session before measuring bone attenuation on CT images. Because there was a lack of studies on the evaluation of bone attenuation around the shoulder joint, the panel decided that bone attenuation on the glenoid, humeral head, and humeral metaphysis would be measured on CT images by placing a circular region of interest (ROI) on the central part of each bony region. A circular ROI with an area ranging from 80 to 100 mm^2 was placed manually on the cancellous bone area, avoiding subchondral sclerotic bone and fracture lines [8]. The mean bone attenuation of each region was measured using Hounsfield units (HU).

Measurement methods for each specific region from CT images were as follows: For bone attenuation of the glenoid, the sagittal image in which the measured anteroposterior length of the glenoid was largest was selected. This could be confirmed using the dynamic navigation tool of the PACS software. The axial line passing through the center of the glenoid of the scapula was identified using dynamic navigation for the selected sagittal image. A circular ROI was placed on the center of the glenoid on the selected axial image, avoiding the cortex. For bone attenuation of the humeral head and metaphysis, the sagittal image in which each measured bony region was largest was selected. Using dynamic navigation for the selected sagittal image, the coronal line passing through the highest point of the humeral head was selected. The articular side of the humeral head was divided into three areas: proximal, central, and distal. A circular ROI was placed on the center of each region on the selected coronal image of the humeral head. For measurement of the ROI on the humeral metaphysis, a circular ROI was placed on the center of the metaphysis, as close as possible to the fracture line on the selected sagittal image (Fig. 1).

Following consensus building, reliability testing was conducted before recording the main measurements. Interobserver reliability was determined using intraclass correlation coefficients (ICCs) for three surgeons with 8, 7, and 3 years of orthopedic experience, respectively. These three surgeons performed the measurements on the CT images independently without knowledge of the other surgeons' measurements. Four weeks after all three surgeons

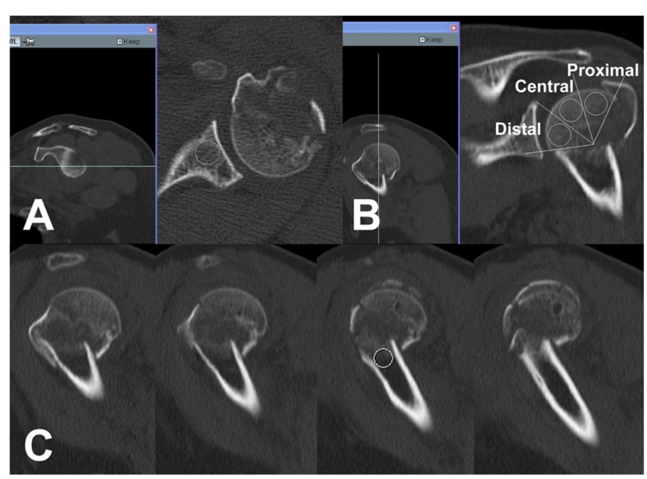

Fig. 1. Image selection on the sagittal or coronal plane of a shoulder computed tomography scan. The image used for measurement of the region of interest measurement took place on the axial (A, glenoid) or coronal (B, humeral head) plane was selected by using dynamic scout navigation to choose the central portion of each bony region in the sagittal plane. A circular region of interest was placed on the center of the metaphysis on coronal plane to assess bone attenuation of humeral metaphysis (C).