

How to determine the bone mineral density of the distal humerus with radiographic tools?

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Abstract

Introduction The aim of this study was to investigate three methods of prediction of the bone quality of the distal humerus: dual-energy X-ray absorptiometry (DEXA), Ct-Scan and plain radiographs.

Materials and methods The bone mineral density (BMD) of 21 cadaveric distal humerus was determined using DEXA at two levels. Then a CT-scan and anteroposterior radiographs were taken. The cancellous density was estimated with the CT-scan. The cortico-medullar index (CMI)

was calculated as cortical thickness divided by total bone thickness on AP views.

Results A significant positive correlation was found between the BMD of the epiphysis and the CMI of $r = 0.61$. The mean BMD of the distal humerus was 0.559 g/cm^2 . Male specimens showed a significantly higher BMD than females. The mean CMI of diaphysis was 1.431 and the mean BMD of the metaphysis region was 0.444 g/cm^2 .

Discussion More than a direct evaluation of the bone density with a CT-scan, the CMI of the distal humerus diaphysis is a predictor of the bone quality of the distal humerus. This should be of great help for the surgeon's decision making in case of fracture of the distal humerus, as open Reduction and Internal Fixation (ORIF) of fractures of the distal humerus can lead to failure due to poor bone quality.

Level of evidence Basic Science Study, Anatomic Cadaver Study.

Keywords Distal humerus · Bone mineral density · Osteoporosis · Dual energy X-ray absorptiometry · Quantitative CT

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Introduction

Osteoporosis is the most common metabolic bone disease in the Western world and is recognized as a major cause of disability and morbidity in older men and women [9]. Reduced bone mass and micro-architectural deterioration of bone contribute to higher risk of fracture of the distal humerus. It is also associated to a higher risk of open reduction and internal fixation (ORIF) failure such as

postoperative implant failure, fracture secondary displacement and non-healing [3, 5–7, 15, 16].

When assessing bone mass, dual-energy X-ray absorptiometry (DEXA) is widely used. Also, peripheral quantitative CT-scan has been shown to be a reliable technique to measure bone mineral density (BMD) of some long bones and spine [12]. In case of fracture DEXA cannot be used because this kind of technology is not available in emergency. Moreover, standard protocol of CT-scan that are available in emergency has no required resolution for determination of the BMD of the humerus. On the other hand, determination of cortical thickness as a predictor of BMD from the femur, metacarpal bone or more recently from the proximal humerus is commonly used [1, 10, 11, 17, 18].

Because there is a high clinical relevance of bone mass and bone quality of the distal humerus in decision process, we have attempted to correlate bone mineral density assessed by DEXA, with peripheral quantitative computed tomography (pQCT) and standard antero-posterior radiographs. The null hypothesis is that with standard imaging studies we can predict patient's BMD.

Methods

Specimen preparation

Twenty-one unpaired fresh-frozen human cadaveric elbows, obtained from donations, were harvested and preserved at $-20\text{ }^{\circ}\text{C}$ to keep intact the structural integrity and biomechanical properties of bone [8]. The dissection was done after an overnight thawing at room temperature. There were three morphologic criteria of exclusion: a pre-existing incision around the elbow, previous distal humeral fracture, and obvious degenerative changes of the distal humerus (confirmed by further plain X-rays and CT-scan). There were 10 males and 11 females and 9 right and 12 left distal humerus. The distal humeri were separated from the ulnae. The entire soft tissues of the elbow were removed to retain the epiphysis and 15 cm of the distal humerus.

Determination of BMD using dual-energy X-ray absorptiometry (DEXA) scan

The BMD of the distal humerus and the metaphysis was measured using DEXA (Hologic Inc, Waltham, Massachusetts). Each distal humerus was fixed horizontally in a custom-made jig containing rice to ensure a reproducible positioning of the specimens, and to simulate soft tissues, without interferences with the measurements [4] (Fig. 1). The same investigator performed all DEXA scans in one session.

A horizontal line at the level of the dense line surrounding the olecranon fossa separated the two regions of



Fig. 1 Specimen positioning using rice bags to simulate soft tissues and get a reproducible position through the experimental protocol

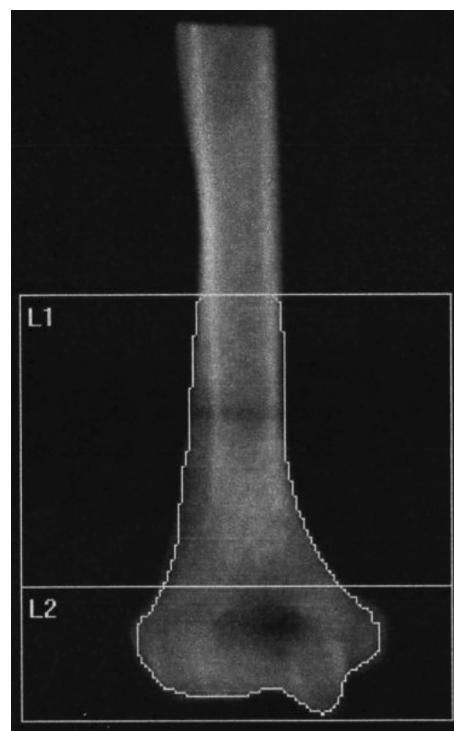


Fig. 2 DEXA evaluation of the two regions of interest of the distal humerus: epiphysis and metaphysis

interest (ROI) of the distal humerus epiphysis from that of the diaphysis. Both ROI heights were equal (Fig. 2). The BMD (g/cm^2) of each ROI was calculated using the software of Hologic.

Determination of the cortical thickness of the distal diaphysis and the cortico-medullar index (CMI) from radiographs

Each distal humerus was fixed horizontally in the same custom-made jig used for the DEXA measurements. A

radiopaque ruler was positioned next to the first AP view to make sure that the magnification factor was 1:1.

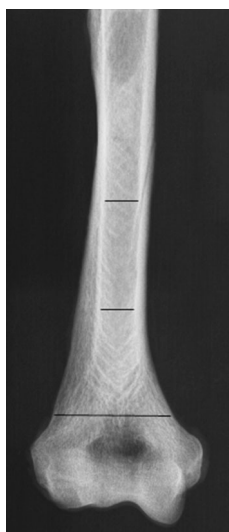
The lateral and medial thickness of the distal humeral diaphysis was measured at two different levels: the first one 3 cm above the superior dense line of the olecranon fossa of the distal humerus and the second one 7 cm above the same line (Fig. 3). The cortical thickness was measured using OsiriX (v 4.1.2, 32-bit) with a precision of 0.01 mm. The width of the medulla was also measured at those two levels. The cortico-medullar index (CMI) was calculated as cortical thickness divided by total bone thickness on AP views, as defined by Virtama and Telkkae [19]. All measurements were performed twice, on two different days by the same investigator and in case of difference between those two values, a third measurement has been performed during a third session.

Peripheral quantitative computed tomography (pQCT) scanning

We used a 64-row multi-detector CT scanner, LightSpeed VCT (GE Healthcare, Milwaukee, WI) to investigate the 3-D architecture of the distal humerus. For measurements, each humerus was fixed horizontally in the same custom-made jig with the bi-condylar plane parallel to the Ct table plane. First, a coronal scout scan was performed to specify the scan length. Then axial images were computed at a standard protocol: 512×512 pixels, jointed slice, slice thickness 1 mm, pixel size 0.22 mm, field of view 10.5 cm.

Analysis of the image was performed using OsiriX (v 4.1.2, 32-bit). Each distal humerus was examined at two different areas: (1) medial: in the central part of the tro-

Fig. 3 Plain X-ray showing the zones of measurements of the lateral and medial thickness of the distal humeral diaphysis: 3 and 7 cm above the superior dense line of the olecranon fossa



chlea humeri; (2) lateral: in the central part of the condyle humeri. To standardize the measurements, a 5-mm circular region of interest (ROI) was placed in the center of each zone of analysis. Based on previous studies, CT values of pixels were recorded in Hounsfield units (HU) [14]. Each measurement was repeated on three different slices separated by three slices, and the average value was chosen for analysis.

Statistical analysis

All statistical analyses were performed using xlstat 2007 (Addinsoft, Paris, France). The Kolmogorov–Smirnov goodness-of-fit test was used to check the assumption of normality for the continuous variables. Since normality was confirmed, repeated-measures analysis of variance (ANOVA) was used to compare ROIs. The Pearson product–moment correlation coefficient (r) was calculated to evaluate the linear association between DEXA, CMI and pQCT density measurements. Linear regression analysis based on least squares was used to derive equations for predicting the BMD from cortical thickness.

A cut-off P value of 0.05 was adopted for all statistical significance.

Results

Main measurement results are summarized in Table 1.

BMD of the distal humerus

The mean BMD of the metaphysis region was 0.91 g/cm^2 ($SD = 0.224$), and the mean BMD of the epiphysis was 0.559 g/cm^2 ($SD = 0.139$). Male specimens showed a significantly higher BMD in the metaphysis region and the epiphysis ROI than females.

Cortico-medullar index (CMI)

The mean CMI of the superior region at 7 cm was 1.431 ($SD = 0.711$), and the mean CMI of the inferior region at 3 cm was 2.116 ($SD = 0.519$).

pQCT

The mean BMD of the metaphysis region was 0.444 g/cm^2 ($SD = 0.124$) for the condyle humeri and 0.397 g/cm^2 ($SD = 0.134$) for the trochlea humeri cancellous bone. No statistical difference has been found between medial and lateral RIO ($p = 0.097$).

Table 1 Details of the measurements done for each specimen

No.	Gender	DEXA		X-rays		CT-scan	
		BMD metaphysis (g/cm ²)	BMD epiphysis (g/cm ²)	CMI sup	CMI inf	BMD lateral	BMD medial
1	M	0.829	0.538	1.33	2.25	0.498	0.453
2	M	0.608	0.291	2.52	2.52	0.205	0.217
3	M	0.429	0.296	3.22	3.16	0.428	0.402
4	F	0.879	0.529	1.42	2.06	0.444	0.494
5	M	0.585	0.85	1.66	3.04	0.212	0.194
6	M	0.75	0.399	2.14	2.55	0.339	0.409
7	F	1.132	0.606	1.15	2.04	0.457	0.117
8	F	1.06	0.673	1.08	1.94	0.435	0.327
9	F	1.062	0.6	1.05	1.91	0.494	0.532
10	F	1.078	0.688	0.75	1.62	0.619	0.558
11	F	0.492	0.294	2.86	3.19	0.153	0.168
12	M	0.899	0.556	1.33	2.08	0.601	0.459
13	F	1.094	0.606	1.04	1.91	0.499	0.551
14	F	1.15	0.604	0.54	1.45	0.447	0.237
15	M	0.899	0.553	1.47	2.40	0.468	0.393
16	M	0.938	0.556	1.52	1.96	0.473	0.476
17	F	1.197	0.603	0.61	1.54	0.489	0.447
18	M	0.841	0.556	1.29	1.69	0.473	0.467
19	F	1.065	0.695	1.10	1.69	0.470	0.552
20	M	1.04	0.595	1.26	1.80	0.521	0.434
21	F	1.076	0.644	0.72	1.64	0.608	0.459

Correlation between BMD and CMI/pQCT

A significant positive correlation was found between the BMD of the epiphysis and the CMI at 7 cm of $r = 0.61$ ($p = 0.018$, 95 % CI). Regarding the pQCT, a correlation was found but not as strong as with the CMI, $r = 0.352$ ($p = 0.047$, 95 % CI) (Fig. 4).

To define equation to determine the BMD of the epiphysis from CMI, we found: epiphysis BMD (g/cm²) = $0.78 - 0.15 \times \text{CMI}$ at 7 cm. With the Ct-scan that equation was: BMD (g/cm²) = $0.39 + 3.95E - 04 \times \text{BMD measured}$.

Discussion

Osteoporotic bone changes in the elderly showed a higher risk of fractures, especially of the vertebral bodies, distal radius, proximal femur and also proximal and distal humerus. It is known that osteopenic changes are correlated with aging [20], and we demonstrated in this study that this phenomenon is homogenous in the distal humerus cancellous bone (no difference comparing the density of the trochlea and the condyle). The importance of bone quality has also been emphasized for successful outcome of elbow

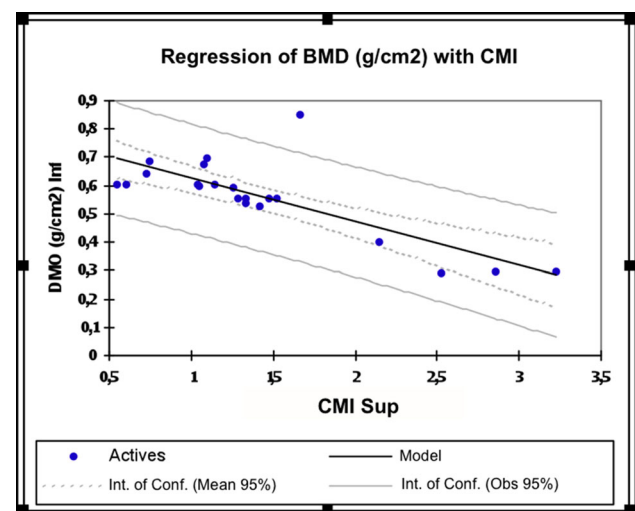


Fig. 4 Correlation between the CMI at 7 cm and the BMD

reconstruction surgeries. To our knowledge few studies have investigated the bone density of the distal humerus [10, 11, 13]. There is no simple method that allows reliable quantitative assessment of bone quality of the distal humerus.

Unlike DEXA, a major advantage of QCT over other techniques is its ability to isolate and measure trabecular

bone separately from cortical bone. High-resolution multislice CT is an useful tool for the assessment of bone micro-architecture [2]. The CT value is correlated with BMD [14, 20]. But those two techniques are not widely used in emergency or in a fractured bone, because of the rare access to these technologies. This is not the case for standard radiographies. We found a significant positive correlation between the CMI measured on plain X-ray and the BMD. These findings may help the clinician to estimate bone quality and patient's BMD through a simple equation. The use of the cortical thickness as a marker of osteoporosis has already been proven in previous studies [17, 18]. Meema and Meema showed about 1200 patients that medial plus lateral thickness of the distal humerus below 6 mm indicates that the patient has bone osteoporosis [10]. Those results were also assessed by Bloom and Laws in 1970 [1]. Both studies emphasize that the cortical thickness decreases after 50 years of age.

The limitation of this study is the small number of specimens and no comparative biomechanical analysis of the distal humerus cancellous bone.

Conclusion

Distal humerus fractures represent a frequent cause of old patient admission in trauma unit. We think that distal humerus fractures in the elderly will be better managed by inferring the real quality of cortical and cancellous bone quality. This means that if we have to treat a distal humerus fracture in elderly patients, we need to determine bone quality for each case to know if an osteosynthesis is feasible or if total elbow prosthesis is the best option. This study evaluated the correlations between DEXA measurements, CMI and QCT of distal humerus. It has highlighted that with a simple AP view of the distal humerus, an appropriate evaluation of the degree of osteoporosis can be investigated, and by this way may help the surgeon to choose more appropriate methods to treat fractures of the distal humerus in older patients, mainly between ORIF and total elbow prosthesis.

Compliance with ethical standards

Conflict of interest The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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