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Research article

Model for improved correlation of BMD values between abdominal routine Dual energy CT data and DXA scans

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ABSTRACT

Background: Osteoporosis is a common but underdiagnosed and undertreated disease causing severe morbidity and economic burden. The gold standard for detection of osteoporosis is DXA (dual energy x-ray absorptiometry), which is a dedicated examination for osteoporosis. Dual energy CT (DECT) examinations are increasingly used in daily routine for a wide variety of diagnoses. In the present study, we wanted to examine whether vBMD (volume bone mass density) could be evaluated as a side product in non-contrast as well as contrast phases as well as to evaluate a correction model taking known shortcomings for DXA into account.

Methods: A total of 20 patients, i.e. 79 vertebrae (one excluded due to vertebral fracture), mean age 71 years (range 43–85) with a mean BMI (body mass index) of 26 (range 17–33) were examined with both abdominal/pelvic DECT as well as DXA. Furthermore, aortic calcium was measured as well as the presence of osteoarthritis of the spine (OAS) and osteoarthritis in facet joints (OAF) with a 5-grade scaling system.

Results: A significant correlation was found between DXA BMD and vBMD from DECT with no contrast (WNC) ($r = 0.424$, $p = 0.001$), and with venous contrast (WVC) ($r = 0.402$, $p < 0.001$), but no significant correlation was found with arterial contrast (WAC). Using multivariate linear regression with DXA BMD as dependent, two models were created combining DECT WNC, aortic calciumscore (ACS), OAS and BMI yielding an $R^2 = 0.616$ (model 1) and replacement of WNC to WVC a $R^2 = 0.612$ (model 2). The Pearson correlation between DXA and predictive DXA BMD value of model 1 was $r = 0.785$ ($p < 0.001$) and model 2 $r = 0.782$ ($p < 0.001$).

Conclusion: There is a correlation between DXA BMD and DECT in non-contrast and venous contrast scans but not in arterial scans. The correlation is further improved by quantifying the degree of different confounding factors (osteoarthritis of the spine, body mass index and aortic calcium score) and taking these into account in an explanatory model. Future software solutions with DECT data as input data might be able to automatically measure the BMD in the trabecular bone as well as measuring the confounding factors automatically in order to obtain spinal DXA comparable BMD values.

1. Background/Introduction

Osteoporosis is common in the Scandinavian countries where the lifetime osteoporotic fracture risk of women over 50 years of age is approximately 50% and for men 20% [1]. Similar high incidences are found in other western world countries [2,3]. The gender difference could be dependent on factors such as a lower peak-bone mass, a more rapid bone loss and smaller bone size in women [4]. Osteoporosis fractures cause significant morbidity and are associated with high costs for society estimated to about 1.25 billion Euro in Sweden per year [5]. Despite the fact that effective and cheap treatment options are available, only 12 percent of patients with osteoporosis-related fractures were treated with bone-specific drugs 6–12 months after fracture in Sweden [6]. Efforts like fracture liaison service (FLS) are made to improve this gap of an underdiagnosed and undertreated but common condition [3,6].

Efficient systems for detecting high risk individuals for osteoporotic fractures and initiating treatment interventions early would mean savings on individual suffering but also healthcare costs by preventing new osteoporosis fractures (hip, vertebra, humerus, radius fractures).

In the current study, we use a new software package to detect high-risk patients at an earlier stage by using dual energy CT examinations (DECT) of the abdomen (which also include the pelvis) and generate a volume bone mass density (vBMD) measurement which is correlated to today's golden standard i.e. dual energy x-ray absorptiometry (DXA). As DXA has several known shortcomings [7,8] e.g. overestimating bone

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density in individuals with degenerative and morphological vertebral changes as well as aortic calcifications, we intended to make a correction model that takes these changes into account.

Previous studies have shown that there is a poor correlation between the BMD derived from DECT scans and BMD derived from DXA scans [9]. In an in vitro study, Kuijk et al. [10] showed that a 3 material decomposition of trabecular bone examined with dual energy is a feasible way of computing a valid BMD. As the mindset increases of using clinical radiological examinations done for specific clinical questions for screening purposes for other common diseases as well, the interest in detecting osteoporosis on different kind of CT datasets has been investigated [2,11,12,13,14,15]. Nevertheless, DXA is still seen as the golden standard despite its shortcomings, why a way of being able to correlate results from CT measurements with BMD and T-score measurements from DXA scans is desirable. Thus, we investigated if it is possible to construct a model considering several confounding factors influencing and explaining the differences between BMD measurements from DECT and DXA.

Furthermore, the study aimed to investigate the usability of abdominal/pelvic DECT data, performed without a phantom for diagnosing low BMD, and furthermore to study whether images from contrast scans are possible to use.

2. Methods

Men and women over 35 years of age undergoing a clinical abdominal study with DECT at Linköping University Hospital were invited to participate. Patients unable to give informed consent were excluded from the study as were patients with severe obesity (BMI > 33) or patients with known bone metabolic diseases other than osteoporosis.

The DXA scan was done within 1 month after the DECT.

2.1. Protocols

DECT scans were made on a second generation 128-section dual-source CT scanner (Somatom Definition Flash; Siemens Healthcare, Erlangen, 2014) and a 128-section dual-source CT scanner (Somatom Force, Siemens Healthcare, Erlangen, 2016). Regarding the Somatom Definition Flash the two x-ray tubes were operated at 100 and 140 kVp with tin filter and a quality reference mAs of 230 at 100 kVp and of 178 mAs for 140 kVp. The two x-ray tubes on the Somatom Force were operated at 80 and 150 kVp with tin filter and a quality reference mAs of 246 at 80 kVp and 123 mAs at 150Sn kVp. During the project we changed the CT machine from a Somatom Definition Flash to a Somatom FORCE. The parameters on the FORCE were changed regarding to our clinical protocol which we use in clinical practice for abdominal dual energy scans. The software used in this project takes these changes into account and delivers vBMD values independent of the kV settings. A summary of the parameters is shown in Table 1.

All scans were performed in the craniocaudal direction in supine position and extended from right above diaphragm to just below the symphysis.

In eight patients, a custom-made bone density calibration phantom was included in the scans. The phantom (QRM-BDC/6) was made by QRM GMBH Möhrendorf, Germany and included 6 rods of different hydroxyapatite equivalents with HU of 0, 100, 200, 400, 600 and 800. The phantom has a length of 400 mm with a concave shape and was placed under the patients in supine position. The appropriate position covering L1-L4 was checked on the topogram images prior to the scan. The phantom was used for internal quality control.

Table 1
Summary of the parameters used for the dual energy CT scans with different scanners.

Parameter	Somatom Definition Flash	Somatom Force
Rotation Time (s)	0.5	0.5
Pitch	0.6	0.6
Collimation (mm)	32 × 0.6	128 × 0.6
Kernel	D30f/3	Br36d/3
Slice thickness/Increment (mm)	1/0.6	1/0.5

2.2. Bone density measurement in dual energy CT

The software used to analyze the amount vBMD in the trabecular part of the vertebrae was provided by Siemens as a part of this research project. The software uses a 3-material decomposition algorithm developed by Krauss et al. for virtual non-enhanced imaging to isolate bone attenuation where calcium was substituted instead of iodine to isolate the bone fraction from other tissues in every voxel.

With this software, embedded in Siemens research platform (eXamine), 10 consecutive measurements per vertebra (region of interest, ROI)) were performed in the axial images. The ROI size was defined by the maximum circle/oval that could be placed safely in the axial plane of a vertebra, without contamination of the cortical bone. 10 consecutive ROIs where placed in each vertebra with as even coverage of the vertebra in the z plane as possible (Supplement Fig. 1). The mean value of these 10 measurements was used for further analysis. Separate measurements were made in non-contrast, arterial- and venous contrast series. The placement of the ROIs was performed by one radiologist with 10 years of experience.

2.3. DXA protocol

The DXA scan was performed in accordance to clinical routine examinations. All scans were performed on a Discovery DXA system (Hologic, Bedford, Massachusetts). Images of the lumbar spine (L1–L4) were obtained in an AP direction where the manufacturer's software automatically calculates a BMD value in g/cm^2 for each. Vertebrae were excluded if fractured.

2.4. Calcium measurement in aorta

The amount of aortal calciumhydroxyappatite (CaHA) (Vol/mm^3) in front of each vertebra was calculated by the CaScoring module in the software package "syngo.Via" VB10 B (Siemens Healthcare, Erlangen). The axial scan of the original data set was separated by defining the image number range for each separate vertebra. These subsets of data were imported separately into the CaScoring analysis module and calcifications in the part of the aorta ventrally of the vertebrae were defined with a threshold of 80 mg/cm^3 = 249 HU. The result is shown as vol/mm^3 per vertebra.

2.5. Osteoarthritis scoring of the intervertebral space and facet joints

The osteoarthritis scoring was performed with a 5-grade scaling system in accordance to the Kellgren Lawrence grading system [16]. The 5-point scoring was performed by one radiologist with 10 years of clinical experience. In brief, grade 0 represented no radiographic features of osteoarthritis present, grade 1: doubtful joint space narrowing (JSN) and possible osteophytic lipping, grade 2: definite osteophytes and possible JSN, grade 3: multiple osteophytes, definite JSN, sclerosis, possible bony deformity and grade 4: large osteophytes, marked JSN, severe sclerosis and definite bony deformity.

Both the grade of osteoarthritis of the spine (OAS) and osteoarthritis in the facet joints (OAF) was analyzed.

2.6. Statistical analysis

For the statistical analysis the software package from SPSS (IBM SPSS Statistics version 23.0, Chicago, USA) was used.

Pearson correlation and linear regression models were used to