Quantitative Computed Tomography versus Densitometry in Diagnostic of Osteoporosis

MJ Maciel, JH Correia
Department of Industrial Electronics
Centro Algoritmi, University of Minho
Guimaraes, Portugal
marino.biom@gmail.com (PI), higino.correia@dei.uminho.pt

***Abstract*— Osteoporosis is a bone disease, which leads to an increased risk of fracture and it is in focus worldwide, due to increase of elderly population. There is a continuous correlation between bone mineral density (BMD), osteoporosis and risk of fracture. This study deals with approach the two principal diagnostic techniques of the disease: dual energy x-rays absorptiometry (DXA) and quantitative computed tomography (QCT). These techniques use BMD to access patient's osteoporotic diagnostic. Although DXA is the only technique with a validate criterion defined by World Health Organization (WHO), QCT is the only image technique able to access exclusively to BMD of trabecular bone, firstly affected in case of disease. In comparative analysis between DXA and QCT exams, the main conclusions are the two-dimensional overlapping which negatively affects the DXA results and the incorrect use of the WHO criterion to analyze QCT results.**

***Index Terms*—Osteoporosis; DXA; QCT; T-score; Z-score; WHO criterion.**

I. INTRODUCTION

Osteoporosis is a disease characterized by loss of bone mass and deterioration of bone tissue architecture, which increases the fragility and, consequently, the fracture risk [1,2]. This disease is caused by the disequilibrium between absorption and formation rate in bone renewing cycle, which cause the decrease of the bone structure. The risk of osteoporotic fracture increases progressive and continuously as the BMD decreases [3]. In fact, the main impact of osteoporosis is that leads to occurrence of fractures. Clinical significance of osteoporosis includes vertebral, forearm and hip fractures. However, the fracture risk increases in other body parts, when the bone density is reduced [1,4].

The human skeleton is composed by two types of bone tissue: cortical and trabecular. Cortical bone consists of a compact tissue, which forms the external part of skeleton. On the other hand, trabecular bone, also designed spongy bone, forms the internal part of skeleton. Metabolically trabecular bone is more active than cortical bone because it contains a more number of cells and, consequently, the bone renewing rate is greater [5]. Different clinical observations concluded that the first fractures due osteoporosis occurs on vertebral bodies or distal radius, areas predominantly composed by trabecular bone [4,5].

When BMD decreases, the fracture risk increases. However, it is necessary to distinguish osteoporosis diagnosis and risk of fracture prediction, which implies the distinction between diagnosis and intervention thresholds [1,6]. This will be discussed in the methods of diagnosis. The diagnostic method of osteoporosis should be noninvasive, presents a low-radiation dose and enables post-analysis. Additionally, it should be comfortable for the patient and to be low cost. Technically, the method must have a high level of precision and accuracy in order to discriminate the degree of osteoporosis and fracture risk associated, according to the patient's characteristics (age and sex) [6]. There are two major image modalities used for diagnosis of osteoporosis and prediction of the fracture risk: DXA and QCT.

A. DXA

In the late 80's, as alternative to the dual photon absorptiometry (DPA) method, it emerged the DXA technique, which replaced the radionuclide source by a x-rays source [7]. The DXA's principle is based on the attenuation measure, through the patient's body, of a beam produced by a radiation source with two energies levels (x-rays photons of high and low energy). Since the attenuation coefficient depends of atomic number and photon's energy, the use of two energies allows to calculate the density of two different tissues: bone and soft tissue [7,8].

Currently, DXA is the most utilized method to BMD measurement and osteoporosis diagnosis, due it's economical costs, high precision and low radiation dose applied [5,9]. This technique can be used for BMD measurement at any skeletal site, but it is typically used in central locations, such as lumbar spine (vertebral segments L1-L4) and hip, favored locals for osteoporosis diagnostic due to its elevate percentage of trabecular bone [9].

B. QCT

QCT was introduced in middle 1970 and is commonly used to measure the BMD of trabecular bone in lumbar spine. The first step of a QCT exam is very similar to a conventional computed tomography (CT) exam: it is based on x-rays and it provides a axial image by measurement of the linear absorption coefficients [10]. A CT image acquisition is realized in two main steps: initial acquisition of the date, by measuring of attenuation coefficients (in Hounsfield Units - HU) and the topographic reconstruction, which uses a complex mathematical process to form the image through the acquired data. To convert HU into BMD is necessary the use of

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phantoms, that are included in image acquisition field. These phantoms contain different concentrations of materials with attenuation characteristics similar to bone. With the phantom concentration known and through measurement of the phantom attenuation in CT scan, it is possible to convert cortical and trabecular bone attenuation in BMD [10,11].

II. GOALS

The aims of this work, after known the different diagnostic methods, are to:

Aim 1: explore in detail the evaluation of BMD with the QCT. It is intended to explore the *syngo* software of the CT SOMATOM Esprit and especially the Osteo division, which is used for BMD quantitative study;

Aim 2: make QCT exams to a number of patients with different degrees of osteoporosis. These results will be important to comparative analysis with DXA results;

Aim 3: compare the diagnosis of osteoporosis with QCT and DXA techniques. The primordial aim is to analyze the WHO diagnostic criterion of osteoporosis applied to QCT exams and discuss the parameters provided by two methods.

III. EXPERIMENTAL DETAILS

This section describes the most important fundamentals used to make the osteoporotic analyses, including the WHO criterion which is based on DXA exams. After, the experimental protocol of QCT exams is presented as well as its important considerations. Finally, the clinical tests are presented.

A. The WHO criterion

According to WHO, diagnostic of osteoporosis is done based to DXA results [6,12]. These are expressed in terms of T-score and Z-score. Mathematically, T-score represents the deviation of patient's BMD relatively to the BMD average from healthy control group, of the same gender. Thus, this value shows how much patient's bone density varies or deviates from the mean bone density of a healthy adult population (aged between 20 and 35) [5,12]. On the other hand, Z-score value allows comparing patients' BMD with the BMD average of a reference group of same age and sex. Therefore, if the patient is a 60 years old woman, Z-score compares the resultant BMD with the average of BMD for women with 60 years. Like T-score, Z-score is expressed in standard deviation (SD), a mathematical term which calculates how many the effected test varies from average [12].

BMD, T-score and Z-score are the three parameters provided by DXA and QCT exams and used for osteoporosis diagnosis. However, WHO defined the criterion of osteoporosis taking account the DXA results, particularly the T-score value [5, 6,12]:

- **T-score≥-1.0**: normal BMD, i.e., close to the BMD mean of young population reference.
- **-1.0>T-score≥-2.5**: low BMD, i.e., is between 1 e 2.0 SD below of average density of the healthy control population. This condition is called osteopenia.
- **T-score≤-2.5**: when BMD value is 2.5 or more SD below of healthy population average it is diagnosed osteoporosis.
- T-score≤-2.5 with one or more fractures in clinical history: established osteoporosis.

B. QCT in CT SOMATOM Esprit equipment

In most CT systems is used QCT exam to BMD access of lumbar spine, mostly formed by trabecular bone. In this case it is necessary a phantom which is placed in side of the acquisition field of the CT image, i.e., positioned under the patient, at the column level.

Firstly it is required a topogram for vertebral bodies localization and cutting planes definition (normally vertebrae L1, L2 and L3), assuring the insertion of phantom. Fig. 1 shows a lumbar spine topogram, which is used for vertebral localization.

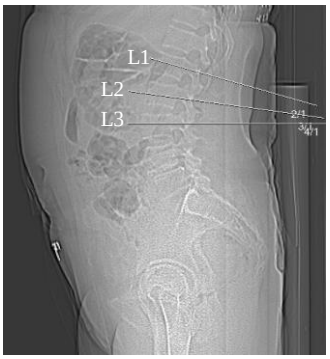

Figure 1 - Lumbar spine topogram, with positioning of L1, L2 and L3 cutting vertebral planes.

After vertebrae localization, it proceeds to axial view's acquisition (tomograms). The gantry's inclination adjusts individually for each vertebra according to the cutting plane defined in topogram. For BMD calculation is required a number of steps: firstly is identified the vertebral body in tomogram; it follows the region of interest (ROI) definition, where will be calculated the bone density. *Osteo* software permits the definition of ROIs to trabecular and cortical bone, being the trabecular portion used for osteoporosis diagnostic; finally is necessary the definition and positioning of ROI's phantom, which is used to CT valor calibration. Thus, it is possible to obtain the BMD in the vertebral region defined.

The QCT results include T-score, Z-score and BMD expresses in milligrams of calcium hydroxyapatite per millimetre (mg Ca-HA/ml). Like DXA, QCT expresses individually the results for each vertebral body and the global result, used for osteoporosis diagnostic, is the combination of the 3 vertebral bodies (average). However, while DXA provides a 2D bone density, QCT provides a 3D density, closest to reality. The QCT results are express graphically in a comparative curve of the same gender.

C. *Patients*

In this study it was examined six patients with different degrees of osteoporosis. It was used the DXA exams provided by patients and the QCT exams were realized in Siemens CT SOMATOM Esprit equipment, with a slice thickness of 1.5 mm. Patients with DXA exams, the analysis focuses on comparison of parameters obtained by two techniques and approach of the criterion diagnostic. In patients who don't present DXA exams, an evolution analysis is made and the potentialities of QCT exams are discussed. Finally, patients are grouped into age ranges for a join analyses based on osteoporosis typology common in each age group and sex. Table I shows the patients' characteristics considered under this project.

TABLE I. CLINICAL RECORDS OF PATIENTS

Nº	**Patients' characteristics**			
	Age	***Sex***	***DXA exams***	***QCT exams***
1	57	female	4 exams: 2005-2010	2012
2	54	female	2006, 2010	2012
3	83	female	2011	2012
4	55	male	without exams	2008, 2012
5	57	female	without exams	2012
6	79	female	without exams	2012

IV. RESULTS AND DICUSSION

In this section is presented the main results and their discussion. These are divided in different sub-sections according to the specific analysis.

A. *Diagnostic criterion*

Fig. 2 shows the variation of DXA results for patient 1, who realized four exams. DXA results are based on average of the three vertebrae used for osteoporosis diagnostic (L2, L3 and L4). These exams concluded a T-score value between -1.0 and -2.5 SD, i.e., an osteopenia state for patient 1 according to WHO criterion. However, this variation shows an osteoporotic state improvement with tendency for stabilizing in the late years, result of treatment and medication.

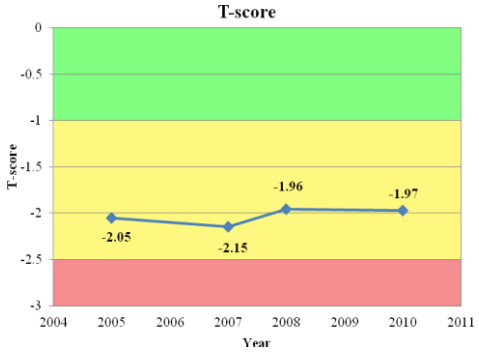

Figure 2 - Patient 1: variation profile of total T-score.

The QCT exam results are presented in Table II, which are compared with the latter DXA exam. The BMD results of two techniques differ in the units and the QCT result is uniquely referent to trabecular bone. *Osteo QCT* software compares the patient's BMD with BMD expected for a patient of the same age and sex. For patient 1 the trabecular BMD expected is 101.3 mg Ca-HA/ml.

TABLE II. PARAMETERS CALCULATED IN BOTH DIAGNOSTIC MODALITIES

Parameter	**DXA 2010**	**QCT 2012**
BMD	0.8452 g/cm^2	82.0 mg Ca-HA/ml
T-score (SD)	-1.97	-2.80
Z-score (SD)	-1.03	-0.70

The BMD value in QCT exam is lower than BMD expected for a female patient with 57 years old. In comparative analysis of the two diagnostic methods it is verified a significant worsening of T-score value (decrease in T-score value of -1.97 to -2.80 SD) and an improvement of Z-score value (increase of -1.03 to -0.70 SD). This comparison reveals a discrepancy, which means that shouldn't be used different diagnostic techniques alternately. In addition, the QCT diagnostic criterion should be different. Firstly by discrepancy verified in T-score and Z-score values. Patient 1 would present osteoporosis an advanced state if was followed the same diagnostic criterion, i.e., the WHO criterion. The permanency and stability in osteopenia state revealed by DXA examinations are now questioned. Secondly, QCT technique only uses trabecular bone density to the diagnosis, which is 3D. As such, it can't be compared to 2D density provided by DXA technique, which results of overlapping between cortical and trabecular tissue. As such, the WHO criterion shouldn't be applied to QCT exams. In accordance to J.E. Adams [10], QCT criterion should resort directly to density value obtained for trabecular bone, primarily affected in case of osteoporosis. Thus, a density range from 80 to 120 mg hydroxyapatite/cm^3 diagnoses osteopenia. If density is less than 80 mg/cm^3 is diagnosed osteoporosis. In this way, patient 1 continues in the thresholds of osteopenia, maintaining the tendency of DXA exams.

B. *DXA Overlapping*

This analysis is carried out by patients 2 and 3. Patient 2 presents osteopenia in two DXA exams. In the latter DXA exam, patient 2 presents an osteoporotic state near of normality (T-score of -1.08 SD). QCT exam reveals also an osteopenia state, result of 95.3 mg Ca-HA/ml density. Fig. 3 shows the QCT exam realized by patient 2, with topogram, vertebral tomograms and final analysis. On the other hand, patient 3, which is an 83 years old female, presents osteoporosis in DXA and QCT exams. Nevertheless, QCT reveals a worse state than DXA. In fact, a BMD of 20.5 mg Ca-HA/ml diagnoses osteoporosis with a high fracture risk.

Tables III and IV summarize the BMD of vertebrae L2 and L3, both used in two diagnostic modalities, for patient 2 and 3, respectively.

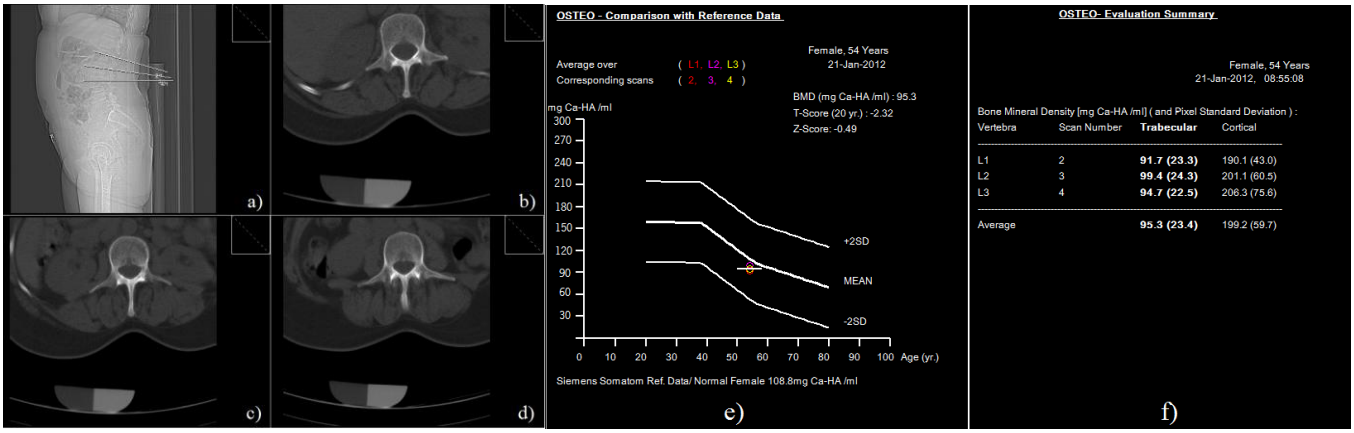

Figure 3 - QCT exam of patient 2: a) topogram; b) L1 tomogram; c) L2 topogram; d) L3 tomogram; e) statistical results and graphical representation; f) trabecular and cortical BMD values for the three vertebrae.

TABLE III. PATIENT 2: DXA AND QCT COMPARATIVE PARAMETERS

Vertebra	DXA 2006 (g/cm^2)	DXA 2010 (g/cm^2)	QCT 2012 (mg Ca-HA/ ml)	
			Trabecular	*Cortical*
L2	0.853	0.924	99.4	201.1
L3	0.906	0.955	94.7	206.3

TABLE IV. PATIENT 3: DXA AND QCT COMPARATIVE PARAMETERS

Vertebra	DXA 2011 (g/cm^2)	QCT 2012 (mg Ca-HA/ ml)	
		Trabecular	*Cortical*
L2	0.673	19.1	243.1
L3	0.730	13.8	301.6

Both patients present in DXA exams a superior BMD for vertebra L3. However, analyzing QCT exams, vertebra L3 only presents a superior cortical bone density. In terms of trabecular density, which is firstly affected in case of osteoporosis, it is vertebra L2 that presents a superior density. Furthermore, cortical density is much higher than trabecular density. Thus, this contradiction allows concluding that cortical density affects negatively DXA measurements, due to overlapping. QCT exam is more precise than DXA exam once it accesses exclusively to trabecular density.

C. *QCT evolutionary analysis*

For QCT evolutionary analysis is used the patient 4, who performed two QCT exams. This analysis is focused in cortical and trabecular density changes. Fig. 4 shows the trabecular BMD behavior of vertebra L2. The same analysis can be conducted for cortical BMD and for the other vertebrae. Patient 4 is an osteoporotic patient with a total trabecular BMD (average of all vertebrae) of 73.9 mg Ca-HA/ml at 2008 and 73 mg Ca-HA/ml at 2012, i.e., there weren't major changes in patient's state. The same behavior is verified individually in vertebra L2 (Fig. 4), either to the left side either to the right anatomical site.

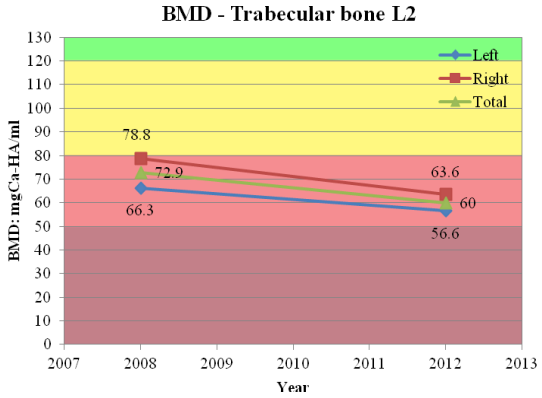

Figure 4 - Patient 4: evolution of trabecular BMD for vertebra L2.

So, QCT exams allow to realize a more complete analysis than DXA exams, which only separate the BMD (overlapping between cortical and trabecular bone) for each vertebral body. Fig. 5 resumes the possibilities of QCT analysis.

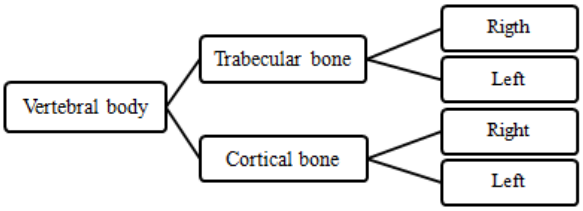

Figure 5 - QCT analysis provide vertebral body separation; cortical/trabecular bone separation and right/left analysis.

D. *Primary and secundary osteoporosis*

The patients considered in this project are now grouped in two groups for a joint analysis: age group of 50 to 60 years and the patients with more than 70 years. Tables V and VI present the two age group and the QCT results.

TABLE V. PATIENTS WITH 50 TO 60 YEARS OLD

Patient Data			QCT 2012			
Patient	***Age***	***Sex***	***BMD*** [a]	***T-score***	***Z-score***	***Diagnostic***
1	57	female	82	-2.8	-0.7	Osteopenia
2	54	female	95.3	-2.32	-0.49	Osteopenia
4	55	male	73	-3.84	-1.57	Osteoporosis
5	57	female	126.5	-1.19	0.91	Normal

[a] mg Ca-HA/ml

TABLE VI. PATIENTS WITH MORE THAN 70 YEARS OLD

Patient Data			QCT 2012			
Patient	***Age***	***Sex***	***BMD*** [b]	***T-score***	***Z-score***	***Diagnostic***
3	83	female	20.5	-5.03	---	Osteoporosis
6	79	female	79.9	-2.88	0.32	Osteoporosis

[b] mg Ca-HA/ml

In patients with 50 to 60 years old, it is possible to observe that the two female patients have osteopenia, associated with menopause. On the other hand, only the male patient has osteoporosis, in this case associated with his lifestyle. Patient 5 reveals an osteoporotic regular state. Thus, female patients have a high predisposition to develop primary osteoporosis, in this particular case postmenopausal. In turn, the male patient is associated to secondary osteoporosis. This observation is in agreement with literature, which reveals great association of primary osteoporosis to female sex and secondary osteoporosis to male sex.

For T-score parameter it is verified that patient 4 presents a BMD far from average density expected for the healthy control group (patients with 20 years old), i.e., presents the lowest T-score (-3.84 SD). This patient presents also the lowest Z-score value (-1.57 SD), which means there is a large deviation from the average density for male patients with 55 years old.

Although patient 1 and 2 have osteopenia, which corresponds a trabecular BMD between 80 and 120 mg Ca-HA/ml, they have a density that doesn't deviate too from the average density of reference group with same age and sex (Z-score value is greater than -1.0 SD). However the patient 1 has an osteoporotic state more serious than patient 2, having all evaluative parameters lower. From all patients, only the patient 5 presents a normal osteoporotic state, with a BMD superior than 120 mg Ca-HA/ml. This value provides the best Z-score value, i.e. patient 5 presents a density higher than density expected for the reference group formed by females with 57 years (positive Z-score).

The female patients, who are used in analysis of patients with more than 70 years, have osteoporosis associated with natural aging. It is once more primary osteoporosis, maintaining the association trend of primary osteoporosis with female patients. With these two patients it may be noted two extreme cases. On the one hand, the patient 3 has an osteoporotic state too severe. A BMD smaller than 50 mg Ca-HA/ml diagnoses osteoporosis with a high risk of fracture. On the other hand, patient 6 presents osteoporosis but in an initial state, i.e. has a density near of values range which diagnose osteopenia (80-120 mg Ca-HA/ml). Additionally patient 6 has a positive Z-score, i.e. has a trabecular density higher than density expected to 79 years old females (71.1 mg Ca-HA/ml, as can be seen in Fig. 6).

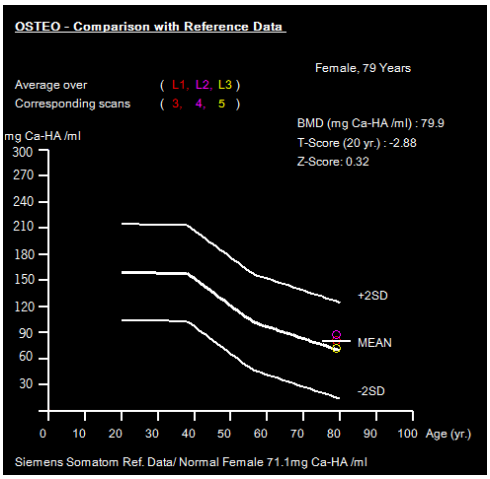

Figure 6 - QCT analysis from patient 6 with trabecular BMD of reference group.

V. CONCLUSIONS

DXA technique has some advantages like low-cost and low-radiation dose. Furthermore it has a diagnostic criterion defined by WHO. However DXA provides a 2D BMD, result of trabecular and cortical overlapping. Unlike, QCT provides a 3D BMD, separately for trabecular and cortical bone. Nevertheless, QCT presents a higher cost and a radiation dose superior than DXA. QCT is lacking a WHO diagnostic criterion.

In this study was possible to conclude that DXA and QCT diagnosis criterions are different, i.e. the WHO criterion isn't applicable to QCT exams. The DXA overlapping affects negatively the results. Thus, the QCT is more precise than DXA and allows a diagnosis in a more preliminary state. Also QCT's evolutionary analysis is more detailed. Finally, the diagnosis and monitoring of osteoporosis shouldn't be done using different techniques or by alternately accessing different anatomical sites.

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