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# Bone Density Measurement Using Computed Tomography

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## 1. Introduction

Osteoporosis is a major medical, social, and economic problem. Osteoporosis and low bone mass affect an estimated 44 million Americans (National Osteoporosis Foundation, 2008). The lifetime risk of hip, spine, or forearm fractures is estimated to be 40% in white women and 13% in white men above 50 years of age. Considerable attention is therefore focused on assessing bone mass and the ability to identify people at risk of fracture. Determining bone density (BD) helps a doctor determine those at increased risk for osteoporosis-related fracture.

Bone density (or bone mineral density) is a medical term that refers to the amount of matter per square centimeter of bone. Bone density is used in clinical medicine as an indirect indicator of osteoporosis and fracture risk. BD measurements are most commonly made over the lumbar spine and over the upper part of the hip. In recent literature, several approaches have been introduced to measure mandibular and skeletal BD, and then compare these measurements with BD in other parts of the skeleton. The measurement is painless, non-invasive, and involves minimal radiation exposure. In this chapter, bone density using computed the tomography technique will be introduced and discussed.

CT is an imaging technique that shows human anatomy in cross sections and provides a three-dimensional dataset that can be used for image reconstruction and analysis in several planes or three-dimensional settings. CT is used to study bone pathology, from traumatic lesions to bone neoplasm. In addition to morphologic information, CT also provides information about tissue attenuation. Direct Hounsfield unit measurements for BD may be used to examine bone quality. Attenuation values can be extracted from raw CT data and used to reconstruct images. These values can also be used to estimate the density of tissues. CT accurately measures bone density. CT density measurement methods can be used as to separate the trabecular bone from the cortical shell and the posterior elements of vertebrae.

CT density measurements have shown superiority to other modalities Using CT for take density measurements is discussed, including several of its challenges, in the current clinic. The foundations of CT density, classification, and registration are discussed in detail.

## 2. Osteoporosis

### 2.1 What is osteoporosis?

Osteoporosis is a multifactorial pathologic condition that affects the entire skeleton and is characterized by low bone mass in combination with microarchitectural changes, particularly in cancellous and cortical bone. Osteoporosis is the end result of bone loss. Osteoporosis is the most common type of the metabolic disorders of bone. The condition is characterized by reduced bone mass and increased risk of fracture (fragility). Osteoporosis occurs when bones lose minerals, such as calcium, more quickly than the body can replace them, leading to a loss of bone thickness (bone mass or density). As a result, bones become thinner and less dense so that, eventually, even a minor bump or accident can cause serious fractures. These are known as fragility or minimal trauma fractures.

Osteoporosis, which literally means “porous bone,” is a disease that reduces the density and quality of bones. As the bones become more porous and fragile, the risk of fracture is greatly increased. The loss of bone occurs “silently” and progressively. Often, there are no symptoms until the first fracture occurs.

Based on the World Health Organization’s (WHO) definition of osteoporosis, Melton (1995) estimated that 30% of postmenopausal white women in the United States have osteoporosis. Asthmatics, other lung patients, or rheumatoid arthritis patients treated with high-dose corticosteroids lose trabecular bone and experience fractures, as do patients with Cushing's syndrome. Other disorders including renal failure and certain types of cancer cause bone loss, along with chronic use of drugs such as anticonvulsants, anticoagulants, excess alcohol, and too much thyroid medication. Young women who experience amenorrhea due to athletic activity, weight loss, stress, nutritional deficiency, bulimia, anorexia nervosa, or those who have early natural or surgical menopause and do not take estrogen replacement therapy lose bone. Not all of the patients in these groups will develop osteoporosis. However, most of them will lose some bone and thus increase their long-term risk for fractures.

### 2.2 The clinical indication for bone mass measurement

- Estrogen deficient women at clinical risk for osteoporosis
- Individuals planning to dental implant therapy
- Individuals with vertebral abnormalities
- Individuals receiving, or planning to receive, long-term glucocorticoids
- Individuals with primary hyperparathyroidism
- Individuals being monitored to assess the efficacy of an approved osteoporosis drug therapy
- Medicare will only reimburse when BD tests are ordered by the treating health care provider
- Frequency of BD testing is once per two years
- Benefit applies to all Medicare patients including managed care programs
- Non-Medicare payers may have different guidelines (Christopher&Cann, 1989)

### 2.3 Why we measure bone density?

Bone density (or bone mineral density) is a medical term referring to the amount of matter per square centimeter of bone. Bone density is used in clinical medicine as an indirect indicator of osteoporosis and fracture risk.

Simple measurement of bone mineral density using SXA, DXA, QCT, or ultrasound does not predict which patient will develop osteoporosis. However, low bone density, as measured by any of the above techniques, is a strong risk factor for the occurrence of non-traumatic bone fractures that are characteristic of osteoporosis.

Slightly more than half of the overall risk for the development of osteoporosis is associated with low bone density, as measured quantitatively. The other factors contributing to fractures are varied, including the internal structure of bone, level of physical activity, neuromuscular coordination, and lifestyle factors that are difficult to quantify. Because of this, bone density is the most useful measurement in estimating an individual patient's relative risk for osteoporosis.

Osteoporosis is a major public health concern, with up to half of all women and even 20% of men having a lifetime risk for osteoporosis-related fracture. Bone mineral density increases until around age 35 and then levels off until menopause. There is an increase in the amount of fat within the trabecular field with age. During the first six to eight years of menopause, there is a sharp decline in bone mineral density. An estimated 1% to 5% of bone density is lost at this time. The higher a woman's overall bone density, the less she will be affected when she loses bone density at menopause. Persons have limited or no estrogen replacement therapies at menopause are the major high-risk group (Reinbold et al., 1988).

Also, one impetus behind this new research is that desire to examine jaw bone quality before osseo-integrated implant treatment has begun. It is hoped, with further research, the success rates of implant therapy will increase (Celenk&Celenk, 2008, 2010)

#### **2.4 How we measure bone density?**

Bone density (BD) is the amount of bone tissue in a certain volume of bone. In recent literature, several approaches have been introduced to measure skeletal BD.

All commercially-available methods for bone density measurement pass a low-intensity beam of x-rays or gamma-rays through a patient, and a radiation detector on the other side measures how much of the beam is absorbed. Part of the beam is absorbed by the bone and part by the surrounding soft tissue, and each technique measures these differently. But, quantitative computed tomography provides a cross-sectional or 3-dimensional image from which the bone is measured directly, independent of the surrounding soft tissue.

### **3. Types of bone mineral density tests**

- Ultrasound
- DEXA (Dual Energy X-ray Absorptiometry)
- SXA (single Energy X-ray Absorptiometry)
- PDXA (Peripheral Dual Energy X-ray Absorptiometry)
- RA (Radiographic Absorptiometry)
- DPA (Dual Photon Absorptiometry)
- SPA (Single Photon Absorptiometry)
- MRI (Magnetic Resonance Imaging)
- QCT (Quantitative Computed Tomography)
- Laboratory tests

#### **3.1 Ultrasound**

Measuring area is the heel. New methods of measuring osteoporosis using ultrasound have also been developed. One such ultrasound system measures BMD at the patient's heel and

takes about a minute. Non absorptiometric methods such as ultrasound of bone do not directly measure bone density, but give alternative information about properties of bone, such as the speed of sound, that are related to bone density and structure. The ultrasound systems for testing osteoporosis are smaller and less expensive than traditional methods. Further, density changes in the heel occur much slower than in the hip or spine. Therefore, ultrasound densitometry should not be used to monitor a patient's response to the therapy (Njeh et al., 1997 & Rang et al., 1998).

Ultrasound densitometry may not be as sensitive as other techniques, such as DEXA or QCT, that measure the spine or hip, since the heel may be normal in bone density even when central sites such as the hip or spine are already significantly abnormal.

However, the new ultrasound densitometry systems will allow many more people access to bone densitometry and potentially diagnose osteoporosis before a traumatic fracture occurs (Njeh et al., 1997 & Rang & Speller., 1998).

### **3.2 DEXA (dual energy X-ray absorptiometry)**

The measuring area is spine, hip, or total body. DEXA (dual energy X-ray absorptiometry) is the most widely available method of bone densitometry, and most insurance plans will cover the cost for the test, given that certain medical indicators are present. Bone mineral density measurement with DEXA is painless and requires no injections, invasive procedures, sedation, special diet, or any other advance preparation. During a DEXA exam, the patient lies fully clothed on a padded table while the system scans one or more areas of bone (usually the lower spine or hip). The entire exam typically takes just a few minutes to complete.

Dual energy x-ray absorptiometry (DXA) measures the bone by computing the difference in absorption of low-energy photons and high energy photons by the mixture of soft tissue and bone in the path of the beam and can generate a 2-dimensional image for localization of the bone.

While DEXA uses x-rays, the radiation dose is less than during a chest x-ray. Each patient's bone density is plotted against the "norm" for a healthy young adult or against age-matched control data. A radiologist or other physician then interprets the data and creates a concise report on the status of the patient's bone density.

DEXA systems have recently received US Food and Drug Administration (FDA) clearance. The accuracy of bone mineral density testing is high, ranging from 85% to 99%. DEXA is the most accurate and widely available BMD test (Mazess et al., 1992).

The interpretation of individual DXA studies is not difficult. However, the responsibility of a physician overseeing a densitometry service lies more in familiarity with the conceptual context as it relates to the role of densitometry in and the management of osteoporosis (Lentle & Prior, 2003).

### **3.3 SXA (single energy X-ray absorptiometry)**

Measuring area is the wrist or heel. This is a method of assessing bone mineral density using a single energy X-ray beam. Single energy x-ray absorptiometry (SXA) computes bone mineral from the increased absorption of the beam as it passes from a constant thickness of soft tissue or water bag into the bone. Localization for SXA is normally done using external landmarks without an image. It is now widely considered inferior to dual-energy X-ray absorptiometry, which uses a second energy beam to correct for absorption of X-ray energy by non-calcium containing tissues (Adams, 1997).

### 3.4 PDXA (peripheral dual energy X-ray absorptiometry)

Measuring area is the wrist, heel, or finger. The acronym pDXA (peripheral dual-energy X-ray absorptiometry) is used to describe dedicated devices that are specifically designed to measure the BMD of peripheral skeletal sites using DXA. There is no fundamental difference in technology between peripheral and central DXA. pDXA (Hans et al., 2008),

### 3.5 RA (radiographic absorptiometry)

The measuring area is the hand. RA, or radiographic absorptiometry, uses an X-ray of the hand and a small metal wedge to calculate bone density in the middle phalanges. Radiographic absorptiometry (RA) measures bone density in the fingers relative to an aluminum calibration wedge on the film. RA is one of the most preferred bone mass measurements because it can calculate bone loss quickly and it is a relatively inexpensive option for any medical specialist and medical office (Yang et al., 1994),

### 3.6 DPA (dual photon absorptiometry)

The measuring area is the spine, hip, or total body. Measurement of the BMC of spine and proximal femur (or any part or the entire skeleton) requires measurement of the relative attenuation of two differing photon energies to permit a correction for soft-tissue attenuation. This allows an assay of the calcium content in deeper structures, although the technique only provides an real density of calcium (in grams per square centimeter) not true volumetric density such as may be achieved with quantitative CT (Blake & Fogelman 1997, Genant & Boyd 1977).

### 3.7 SPA (single photon absorptiometry)

The measuring area is the wrist. The method overcame the problems for radiographic photodensitometric techniques, caused by polychromatic X-rays and nonuniformity of film sensitivity and development, by using a single energy g-ray source ( $^{125}\text{I}$ , photon energy 27.3 KeV) and a scintillation detector to measure transmitted photons (Adams 1997). SPA was used to advance bone measurement from the early days of measurement of bone size on radiographs of the hand or crude determinations of optical density from similar images. It is an effective technique for measurements of bone in the distal radius and ulna (Duppe et al., 1997).

### 3.8 MRI (magnetic resonance imaging)

The measuring area is the spine, hip, or total body. MRI might be used effectively, as it is noninvasive and radiation-free, and it is a reliable in vivo method for assessing features of the trabecular bone structure (Wehrli et al. 2000; Majumdar 2002; Strolka et al 2005, Celenk&Celenk 2010). Trabecular bone is highly responsive to metabolic stimuli and has a turnover rate approximately three to 10 times higher than cortical bone, and so it is a prime site for detecting early bone loss and monitoring response to therapeutic intervention.

### 3.9 Laboratory tests

Laboratory tests that measure the amount of collagen in urine samples can indicate bone loss. Lab tests may also be used in conjunction with DEXA or other methods of bone densitometry to diagnose osteoporosis.

## 4. QCT (quantitative computed tomography) and osteoporosis

### 4.1 The foundations of the CT density

Measuring area is the entire body

QCT refers to a class of techniques in which the CT numbers, or x-ray attenuation, of a tissue is properly referenced to a calibration standard and then used to quantify some property of the tissue. Techniques were developed and published from 1978 to 1982 for bone density, lung nodule calcification, liver and brain tumor volumes, body fat measurement, muscle mass, liver iron measurement, kidney stone composition, and tissue blood flow. Of these, bone mineral density, lung nodule calcification, and tissue blood flow have been commercialized.

### 4.2 Why quantitative computed tomography?

CT numbers (i.e., Hounsfield units, HU) are strongly related to biological tissues density (Ciarelli et al., 1991; McBroom et al., 1985). The directly measured Hounsfield number for bone density may be used to examine bone quality. This method is recommended by some authors (Nilsson et al 1988, Shapurian et al 2006, Norton et al 2001). The mean number of HU within each ROI measures and uses the BD as the marker of metabolic alterations within the trabecular field.

QCT was one of the earliest ways of measuring bone density its use has largely been superseded by the use of dual energy x-ray absorptiometry (DXA) (Adams et al. 1997). QCT has several advantages over DXA, providing true volumetric density (so being size independent) separately in trabecular and cortical bone and being free of the inaccuracies caused by spinal DXA by extra-osseous calcification and hyperostosis. Quantitative CT and simple trabecular ROI attenuation approaches bone density measurement simply and accurately. QCT also shows promise as effective tools in measuring BD. However, QCT is not widely available and delivers more radiation to the patient than DEXA.

DEXA T-scores are the standard used by “all the major national and international societies, including the World Health Organization.”

Gugliemi et al (1994) said we believe that considerations should be given to the use of QCT as the gold standard against which other measurements of spinal BD are judged. Development in QCT technology (spiral acquisition) and software has enabled rapid acquisition of 3D volume images and application to other relevant sites. We have therefore reassessed QCT in the assessment of patients with osteoporosis. The analysis showed similar results across the board—with no significant differences for any of the measurements versus DEXA.

Given the poor agreement between the two methods for the diagnosis of osteoporosis and the much better fracture discrimination with QCT, we believe that consideration should be given to the use of QCT as the “gold standard” against which other measurements of spinal BMD are judged.

Investigators often diagnose osteoporosis by measuring a patient’s bone mineral density (BMD). Bone mineral density measures the amount of calcium in regions of the bones. Bone density is a good measurement for bone quality but it is not sufficient in itself. However, BD might be used to imply bone quality when the density alterations represent changes in trabecular structure (Celenk&Celenk, 2008).

Most methods for measuring BD (also called bone densitometry) are fast, non-invasive, painless, and available on an outpatient basis. Bone densitometry can also be used to

estimate a patient's risk of fracture. These methods compare the numerical density of the bone (calculated from the image), with empirical (historical) databases of bone density to determine whether a patient has osteoporosis, and often, to what degree.

The accuracy of the results remained high whether BD was measured by using QCT or by means of a simple region of interest (ROI) CT density assessment. The "simple ROI" technique can perform without angulations or precise measurements

This information at CT is currently being wasted. ROI measurement of vertebral body trabecular attenuation takes a matter of seconds" and adds value to any routine BD measurement that can be performed with the same CT data. This means that any CT examination that covers any bone alone can effectively rule out osteoporosis and osteopenia without need of a second test.

Reinbold et al. (1986) said that trabecular bone is approximately eight times more metabolically active than cortical bone. Quantitative computed tomography (QCT), which measures trabecular bone density, is therefore highly sensitive to changes in skeletal density.

We can use QCT as the reference standard and any CT examination covers vertebra. The investigators are also looking to detect suspected lumbar compression fractures with QCT, which DEXA can miss this condition.

QCT is the only commercially available 3-dimensional technique, meaning it can be used to measure 100% isolated trabecular bone. All other techniques measure the mixture of trabecular bone and the overlying compact bone. In the spine, trabecular bone is 30-35% of the total, in the distal radius it is 35-50%, and 60-75% in the calcaneus. Trabecular bone is important to measure because it is more metabolically active than compact bone and is the first to change in response to a stimulus such as estrogen deficiency. Trabecular bone in the spine is a more reliable indicator of overall skeletal response than the heavily weight-bearing bone in the calcaneus. However, it is also important to consider that any measurement must be done precisely; otherwise, the measurement will be insensitive.

DEXA can produce false-negative results for osteoporosis in the setting of unsuspected lumbar compression fractures that CT can potentially detect. While DEXA uses x-rays, the radiation dose is less than during a chest x-ray.

Baran et al. (1997) said that the QCT examination, when performed correctly, gives relatively low radiation exposure compared with conventional radiographs or standard CT studies, typically equivalent to a transcontinental airline trip.

Summers et al. (2001) said that "we can record the actual bone mineral density value in grams per cubic centimeter instead of using the T-scores or Z-scores produced by the DEXA phantomless QCT software "because they don't really have a reference standard that's accepted".

Both lumbar QCT and simple ROI measurements are effective at assessing bone mineral density relative to DEXA, which is a reference standard we have to use. We can set a certain level and be at 100% sensitivity for osteoporosis and also exclude osteoporosis in a large fraction of people—over half of people depending on the level—and actually preclude the possible need for DEXA in those cases (Summers et al., 2001).

For the same precision, QCT is 2-3 times more sensitive than DXA and 5 times more than SXA for detecting a change in bone mineral density in early postmenopausal women (Reinbold et al 1988).

### 4.3 How is bone density measured by QCT?

Trabecular bone is approximately eight times more metabolically active than cortical bone (Reinbold 1986). Quantitative computed tomography, which measures trabecular bone, is therefore highly sensitive to changes in skeletal density.

For this purpose we can use both single energy quantitative computed tomography (SEQCT) and dual energy (DEQCT). One disadvantage of single-energy QCT (SEQCT) is that bone mineral measurements are affected by varying quantities of intraosseous fat. It has been calculated. For example, that a 10% increase in intraosseous fat results in underestimation of actual bone mineral content by 7 mg/ml. (Reinbold et al., 1986)

QC T scanning done with dual energy has the advantage of eliminating the effect of marrow fat, resulting in increased accuracy. However, the reproducibility is decreased and there is increased radiation dosage (Genant&Boyd, 1977). The use of dual energy QCT using preprocessing or post processing techniques can reduce this fat induced error in the elderly to 2% to 4%, but it is considered unnecessary for most clinical applications because the inaccuracy is small relative to the normal biological range (Cann&Genant, 1983).

DEQCT correlates well with SEQCT for estimation of bone density and alterations in marrow fat are therefore not a significant problem (Rosenthal et al., 1989).

As a result we are using single energy quantitative computed tomography for measurement bone density.

### 4.4 What is Hounsfield unit?

The Hounsfield unit (HU) scale is a linear transformation of the original linear attenuation coefficient measurement in one in which the radio density of distilled water at standard pressure and temperature (STP) is defined as zero, while the radio density of air at STP is defined as -1000 HU. Hounsfield unit are used in medical imaging to describe the amount of x-ray attenuation of each “voxel” in the 3D image. Voxels are normally represented as 12-bit binary numbers and therefore have  $2^{12} = 4096$  possible values. These values are arranged on a scale from -1024 HU to +3071 HU, calibrated so that -1024 HU is the attenuation produced by air and 0 HU is the attenuation produced by water.

For a material X with linear attenuation coefficient  $\mu_x$ , the corresponding HU value is therefore given by

$$HU = \frac{\mu_x - \mu_{water}}{\mu_{water} - \mu_{air}} \times 1000$$

where  $\mu_{water}$  and  $\mu_{air}$  are the linear attenuation coefficients of water and air, respectively. Thus, a change of one Hounsfield unit (HU) represents a change of 0.1% of the attenuation coefficient of water since the attenuation coefficient of air is nearly zero. CT scanners are calibrated with reference to water (Brooks &Chiro 1976). The CT number is directly related to the linear attenuation coefficient for the x-ray and is usually calibrated to 0 for water and to -1000 for air, -120 for fat, +40 for muscle, and +400 or more for bone.

The Hounsfield number of a tissue varies according to the density of the tissue; the higher the number, the denser the tissue. Consequently, the mean Hounsfield number is a ratio in proportion to the atomic weights of the whole particles and particle numbers within the evaluation site. It has been discovered that when there is an increase in the fat amount of ROI volume, there is a corresponding decrease in the amount of minerals and in the Hounsfield number. The reverse has also been observed. The mean Hounsfield number

decreases when the amount of fat increases or the amount of mineral decreases. The Hounsfield number can be used directly to determine bone quality alterations.

CT is another extension of photon absorptiometry, but for a much more general purpose. Rather than a simple measurement of the photon attenuation along a fixed line through an object, as in SPA, a series of measurements are made at any point along that line by (in effect) rotating the source and detector about that point. Thus, a point on the line is “viewed” from up to a thousand different directions. Through the mathematical process known as projection reconstruction, these points along the line are separated from one another, as are points along other lines that make up the two-dimensional axial image plane. This process of reconstructing the CT image produces a map of the x-ray attenuation coefficients in a cross-sectional “slice” of the body, and these coefficients can be used to determine tissue density at any point in the image. The size and number of points along a line in current CT scanners is variable depending on the object being scanned, but ranges from points 0.25 mm up to 1.5 mm in size, and typically 256–512 elements lie along the line. Each “slice” of a patient scanned can also have variable thickness (the portion exposed to the x-ray beam), ranging from 1 mm up to 10 mm thick. Each point, or element, in a given reconstructed image is the same size, but this size can vary from  $0.25 \times 0.25 \times 1$  mm ( $0.0625$  mm<sup>3</sup>) to  $1.5 \times 1.5 \times 10$  mm ( $22.5$  mm<sup>3</sup>). When viewed on a display monitor, these points are called picture elements or “pixels”; when stored in the computer and used for quantitative purposes, they represent volume elements because of the finite slice thickness and are termed “voxels” (Christopher et al 1989,. Cann&Genant 1980).

#### 4.5 Phantom and calibration

Determination of a linear correlation between HU and density is called calibrating the CT dataset and is obtained with a standard protocol-based procedure scanning a calibration phantom with known densities.

Recent commercial modifications of this design, including both liquid and solid bone-equivalent materials, provide slightly different scanning geometries and require scanner-specific cross-calibration to this standard reference using patient data or development of their own normative databases.

Since commercially available CT scanners use kilovoltage x-rays, where the photoelectric effect and coherent scattering play substantial roles, the x-ray attenuation depends not only on the electron density but also on atomic composition of the material. In addition, the CT number also depends on photon energy spectrum, geometrical configuration of the phantom system, detector sensitivity, and, possibly, reconstruction algorithm.

Therefore, the relationship between CT number and effective density for body tissues should be calibrated specifically for each scanning condition of each CT system. However, the involved theoretical calculations may be too complicated to practice without complete understanding of the underlying physics.

All the techniques provide a result for trabecular bone mineral density in terms of mg/cm<sup>3</sup> relative to the K<sub>2</sub>HPO<sub>4</sub> or calcium hydroxyapatite mineral equivalent standard.

The calibration materials are air, water, and ethanol. The polybinary calibration requires only a CT scan of a fat substitute (ethanol) and a bone substitute (40%K<sub>2</sub>HPO<sub>4</sub>) besides water and air. Simplicity and specificity should be mandatory for a standard that has to be routinely practiced by the relevant facilities with the same quality. Furthermore, the simplicity will possibly enable the self-calibration of planning CT images if the patient is scanned with the calibration materials appropriately placed in the scanning field.

The detector response profile of the CT machines restores the use air or water calibration. The HU curves for the CT scanner are seen to be extremely stable by the use of a phantom in a weekly quality control program.

Also, Reinbold et al. (1988) and Cann&Genant (1980) said that in an effort to improve accuracy and reproducibility, a number of phantoms have been developed to offer reference standards and/or methodologies for QCT studies.

Boden et al. (1989) said that “the early thrust of research in phantom development was directed at correction for CT instability or scan-to- scan variations.” Although early third-generation scanners may have shown considerable scan-to-scan variation, it is no longer the case that functional CT scanners show such variations. Over the last decade, one of the authors, has measured hundreds of CT scanners in the public and private sectors; the variation of intra-scanner CT numbers is within 1 to 2 Hounsfield units (HU) and is systematic and reproducible.

At the same time, Zhao and colleagues (2009) also claim that spine BMD can be automatically calculated without phantom. By accurately segmenting cortical bone and trabecular bone, determining ROI and removing inappropriate data, it is proved that the BMD measurement result by this method is highly consistent with that by with-phantom method.

As a result, BMD calculations with and without phantom are highly correlated.

## **4.6 Examination procedures**

### **4.6.1 Spine**

The following protocols can be used to calculate density in addition to routine CT, specially by taking CT crosssections to evaluate osteoporosis.

The patient place supine on the CT table and a cushion places under the knees to reduce the lumbar lordosis. CT sections are usually taken from lumbar vertebrae. The calibration standard is placed under the lumbar vertebrae. A lateral scanogram (topogram) is made from approximately T12 to S1. This use positions the axial slices through the mid vertebral levels of three to four consecutive lumbar vertebral bodies. Scans are made perpendicular to the axis of the vertebrae. Usually, a low-dose technique is used (120 kVp, 140 mAs) with the table increment and scan thickness, which were both set at 5 mm- 10 mm. Also it can be use a low radiation dose technique (80 kVp, 140 mAs; 140 kVp, 80 mAs) for DEQCT, which results in a skin exposure of 313 mR for each 80- 140 kVp pair (Rosenthal et al., 1989).

We simply lay an ovoid ROI and measure the mean attenuation in Hounsfield units. Reconstructions can perform any thicknesses (at both 1.5-mm and 5-mm) but the 5-mm thicknesses are more compatible with any routine CT study. Regions of interest (ROIs) are manually defined in every axial CT slice. When the ROI is defined, every image may be enlarged to increase accuracy. At the same time, BD values for all patients are determined in the trabecular field of the vertebral corpus by removal of the vertebral cortex (approximately 2-3.5 cm<sup>2</sup>).

### **4.6.2 Mandible**

The mandibular trabecular field (including incisor, molar, and premolar areas) is largely determined by leaving out nontrabecular fields such as teeth, bony cortex, mental symphysis and mandibular canal (approximately 1-1.5cm<sup>2</sup>), and BD measures. In order to

show a more accurate measured density value of the tissue characteristic under study, the measurement sites must be done as large as possible.

#### 4.7 How do we comment QCT results?

QCT, like any bone density measurement, is used to compare a patient with normal control data or an absolute reference value, and to measure the change in bone density with time in a given patient. Researchers have established a “fracture threshold” level for all bone density methods; patients with bone density above this level are rarely seen with osteoporotic fractures, while below it, the prevalence of patients with fractures rises. This level is about 100-110 mg/cm<sup>3</sup> for QCT. As the value decreases below this, the fracture prevalence increases, so below 50 mg/cm<sup>3</sup> most patients already have spinal fractures. At quantitative CT, a BMD threshold of 90 mg/cm<sup>3</sup> yielded 100% sensitivity for osteoporosis or at the L3 level, a trabecular attenuation threshold of 130 HU was 100% sensitive for osteoporosis (Shapurian et al., 2006).

Figures show measurement values on different persons with different Hounsfield Unit to determine bone density (Fig 1-3).

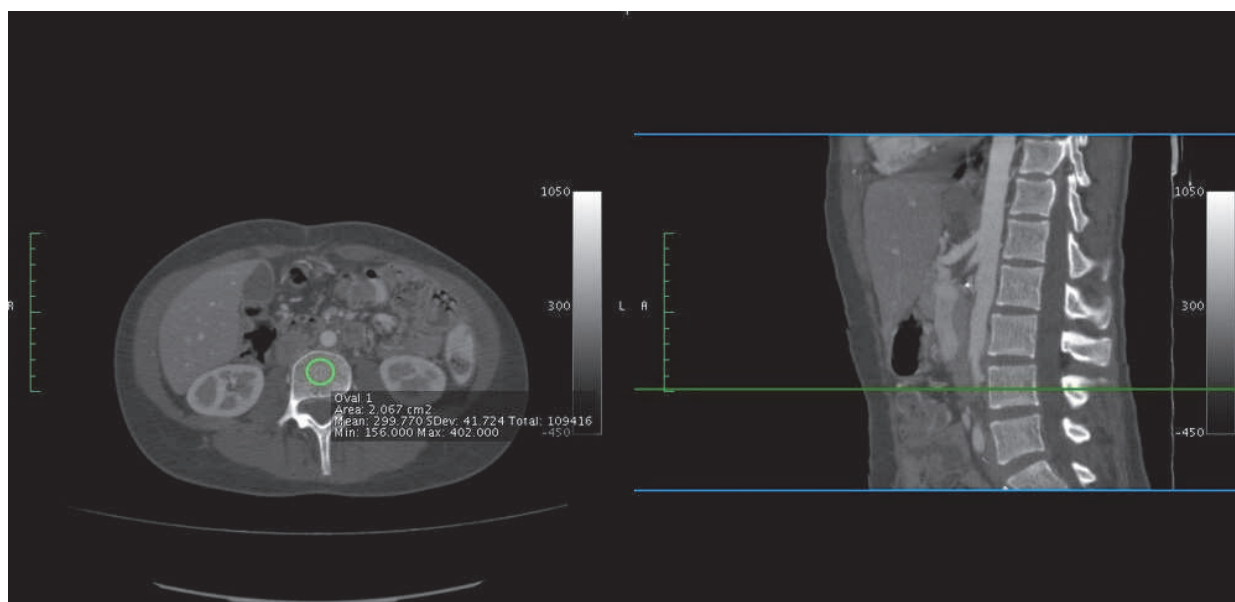


Fig. 1. Axial L3 vertebral CT slice of 20-year old woman shows nonosteoporotic L3 vertebral bone density measurement in Hounsfield Unit (mean: 299 HU).

The QCT value for a patient, when added to other diagnostic information, can be helpful in deciding an approach to treatment. Serial QCT measurements can establish the rate of change of bone mineral density in both treated and untreated patients, but the sensitivity of the method depends on how well the technique is done at a given hospital. In most cases, a change of 8-10 mg/cm<sup>3</sup> can be significant or at least indicate a trend, and several serial measurements all changing the same way improve confidence in the result. Women who are 1-3 years post menopause average 7 mg/cm<sup>3</sup>/yr loss, so yearly measurements can be helpful. Bone loss may be slower in older individuals. The frequency for each patient will depend on other diagnostic and treatment factors, and it is important to interpret the bone density results within the context of each individual's clinical status.

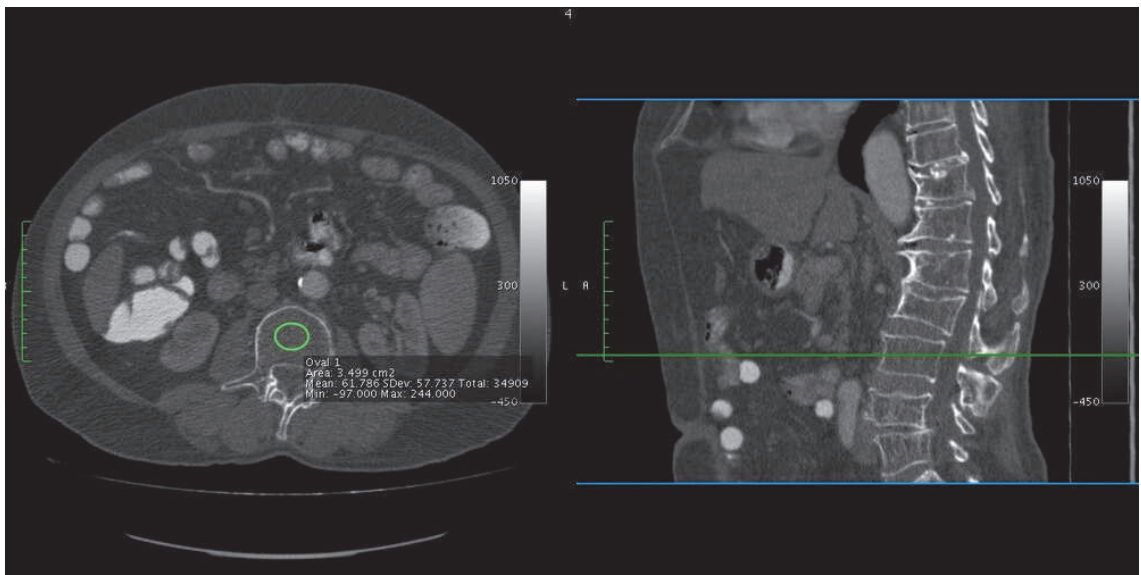


Fig. 2. Axial L3 vertebral CT slice of 61-year old man shows osteoporotic L3 vertebral bone density measurement in Hounsfield Unit (mean: 63 HU).

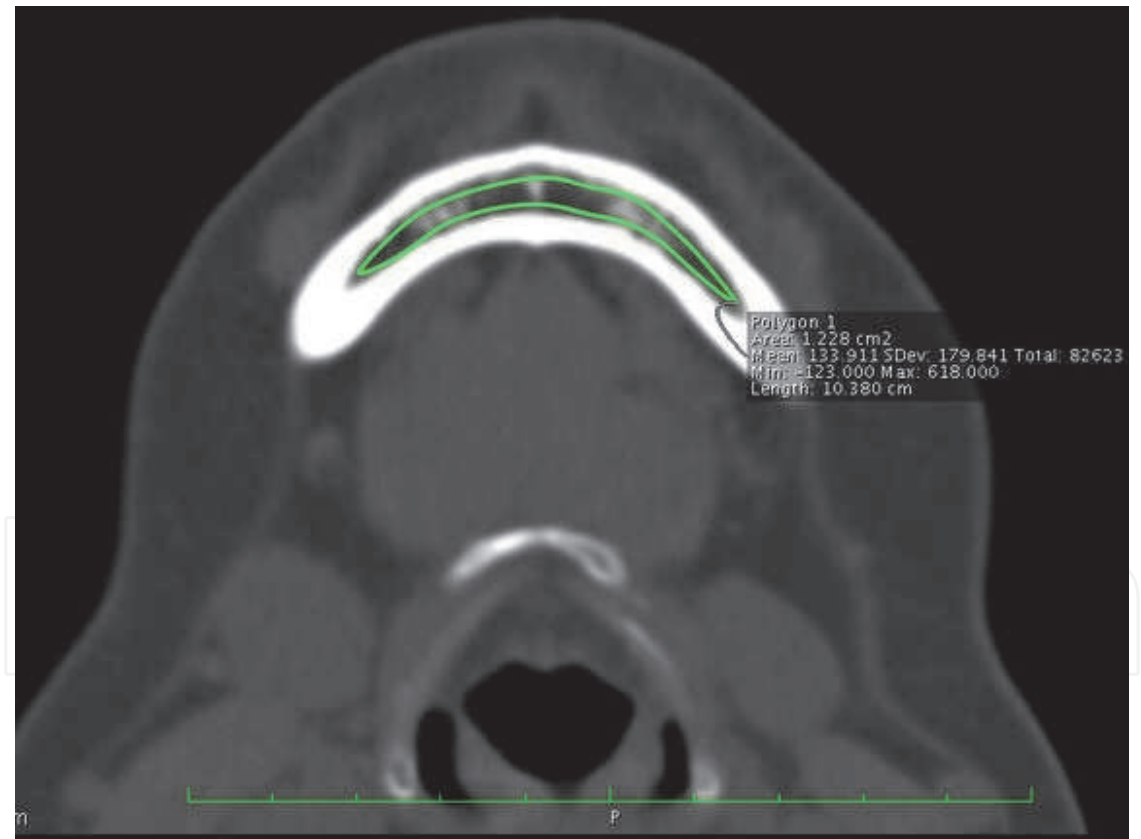


Fig. 3. Axial mandible CT slice of 36-year old woman shows nonosteoporotic mandible bone density measurement in Hounsfield Unit (mean: 133 HU).

4.8 Conclusion

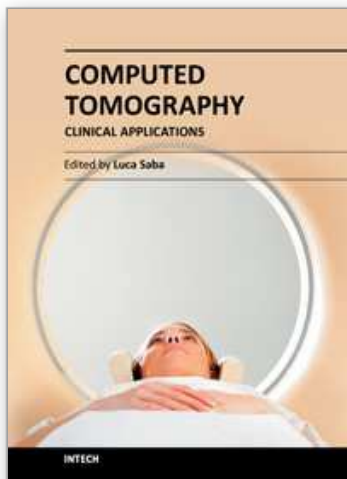
- 1. The density of trabecular areas where QCT and bones metabolic changes are highest can be calculated in addition to their cortexes, specially, at vertebra.

2. There is no need to use phantom if routine calibrations are made during measurements on the latest generation devices.
3. We can obtain accurate and precise osteoporosis results with QCT bone density measurement as a HU.

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## Computed Tomography - Clinical Applications

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Computed Tomography (CT), and in particular multi-detector-row computed tomography (MDCT), is a powerful non-invasive imaging tool with a number of advantages over the others non-invasive imaging techniques. CT has evolved into an indispensable imaging method in clinical routine. It was the first method to non-invasively acquire images of the inside of the human body that were not biased by superimposition of distinct anatomical structures. The first generation of CT scanners developed in the 1970s and numerous innovations have improved the utility and application field of the CT, such as the introduction of helical systems that allowed the development of the "volumetric CT" concept. In this book we want to explore the applications of CT from medical imaging to other fields like physics, archeology and computer aided diagnosis. Recently interesting technical, anthropomorphic, forensic and archeological as well as paleontological applications of computed tomography have been developed. These applications further strengthen the method as a generic diagnostic tool for non-destructive material testing and three-dimensional visualization beyond its medical use.

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