# Accuracy of Quantitative Computed Tomography Bone Mineral Density Measurements in Mandibles: A Cadaveric Study

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## ABSTRACT

*Purpose:* The aim was to investigate the accuracy of quantitative computed tomography bone mineral density (BMD) measurements in mandibles, comparing measured BMD with calibrated BMD.

*Materials and Methods:* Seventy mandibles from adult cadavers were used. Twenty tomographic cuts were made in each mandible. In each tomographic cut, a region of interest was located, and the bone density was measured in Hounsfield unit (HU). A polymethyl methacrylate phantom containing four inserts of different predetermined densities (hydroxyapatite 100, 200, 500, and 700 mg/cm$^3$) was used to calculate calibrated bone density. Correlation between measured and calibrated bone densities was calculated.

*Results:* Mean total correlation between measured and calibrated BMD in the 20 sagittal tomography cuts showed almost perfect positive correlation ($r = 0.998$, $p < .001$). However, when average BMD measurements in HU were compared, the measured total BMD (in the 20 sagittal tomography cuts studied) was $54.99 \pm 421.59$, whereas the total calibrated BMD was $49.28 \pm 364.95$, with statistically significant difference ($p = .001$).

*Conclusions:* There are discrepancies between measured and calibrated BMD; in this sense, a calibrated bone phantom with a predetermined mineral density should be used to determine the exact BMD before dental implants surgery.

KEY WORDS: bone mineral density, calibration bone phantom, computed tomography

## INTRODUCTION

In the past three decades, osseointegrated dental implant therapy has produced successful outcomes, but some clinical reports have showed that when failures occur, this is associated with poor volume and/or density bone.[1–3] Although the osseointegration of oral implants depends on many factors, primary stability is the chief determinant and cause of a good outcome. For this reason, primary stability has come to be considered the "key to osseointegration."

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Primary stability is determined by six basic factors: the implant's macro and microgeometry, preparation of the implant bed, the implant insertion technique, rigidity of the structures, and the quantity and quality of the bone, the latter being the most important determinant. The term *bone quality* is a complex factor that covers the biomechanical, structural, and remodelative properties of the bone. Its main measure is bone density, which is considered to be an excellent predictor and the chief conditioner of primary stability, and so osseointegration.[4,5] In this way, achieving primary stability depends on bone density,[6] and in bone that is not very dense, it is often difficult to obtain satisfactory implant anchorage.[7] Therefore, prior to implant placement, an accurate evaluation of bone structure is not only useful but necessary.

Several bone classification systems have already been introduced. Lekholm and Zarb[8] have classified bone density radiographically into four types based on the amount of cortical bone versus trabecular bone.

Misch[9] has related bone density to the clinical hardness of the bone as subjectively perceived during drilling prior to implant placement. Computed tomography (CT) is an established method for acquiring bone images before oral implant surgery.[10] It is also used for objective quantification of trabecular and cancellous bone mineral density (BMD), as well as direct density measurements expressed in Hounsfield units (HU)[11–14] classified as very dense cortical bone (>600 HU), dense cortical–spongy bone (between 400 and 600 HU), and cortical–spongy bone of low density (<200 HU).

Quantitative CT (QCT) provides a site-related measure of BMD (as the amount of bone tissue in a certain volume of bone)[15] and is useful as a noninvasive method for determining a parameter reflecting bone quality prior to implant placement.[11,16] In 2001, Norton & Gamble, using QCT, made a scale of BMD based on HU: bone type 1 (>850 HU), bone types 2 and 3 (500–850 HU), bone type 4 (0–500 HU), and bone type 5 (<0 HU).

Nevertheless, there are numerous variables that can affect the level of accuracy of CT and therefore the precise quantification of BMD. These variables include factors deriving from the operator (cephalic immobilization, creation of the axial parabola, choice of cut thickness, axial reference plane, mA, and exposure time),[17,18] factors deriving from the patient (thickness of cortical bone, superposition of tissues, and dental restoration materials),[19] factors deriving from the hardware,[20] factors deriving from the software,[21] and factors deriving from the transmission of data (image digitalization, compression, and then decompression can affect the QCT of BMD).[22]

In this way, in order to avoid failures in QCT, BMD should be calculated by measuring HU and relating the values obtained to a calibration bone phantom with a predetermined mineral density (MD).[23] Different calibration standards containing $CaCO_3$[24] or calcium hydroxyapatite (HA) in either polyurethane[25,26] or water-equivalent base materials have been used. Use of the actual bone mineral with calcium HA will minimize the dependence of BMD on CT scanning conditions. Therefore, it has become a common consensus to use these standards for QCT of other body regions.

The aim of the present ex vivo study was to investigate the accuracy of QCT for BMD measurements in mandibles, comparing measured BMD with calibrated BMD.

## MATERIALS AND METHODS

### Mandibles

A total of 70 normal and dry mandibles from adult cadavers aged 60 to 95 years old (mean age 69) were examined, following state regulations, the study protocol having been approved by the Murcia (Spain) City Hall Health Service.

Thirty of these mandibles conserved teeth, and the other forty were edentulous. In order to homogenize the study, multiple exodontias were performed on the 30 mandibles that conserved teeth.

### Marking the Occlusal Plane

The axial reference plane used in CT was the occlusal plane and was marked on the 30 mandibles that conserved teeth before the exodontias were performed. This was done by marking a line parallel to the teeth from the incisal edge of the central incisor to the vestibular cusps of the second molar. When the occlusal plane had been marked, the teeth were extracted.

For the 40 edentulous mandibles, the occlusal plane was established in the anterior sector by measuring a height of 1 cm (the usual height of the lower incisor crowns) and in the posterior sector by dividing the retromolar trigone in three parts: upper, middle, and lower. Then, a meeting point between the upper third and the middle part was chosen; this point usually measured 1 cm in height.[27]

When the occlusal planes of the mandibles had been established, a Moyco wax piece (Thompson Dental® Manufacturing Company, Montgomeryville, PA, USA) was molded to follow the previously established plane. After placing the wax simulation of the occlusal plane, this was divided in 20 parts using 2-mm lead strips. These strips were placed 5 mm apart so that they corresponded to the 20 tomographic cuts performed on each mandible. Lastly, Fox planes were attached to the wax on each of the 70 mandibles (to be used as a guide for delimiting the occlusal plane radiographically), and each assembly was placed into a polymethyl methacrylate box for radiographic study.

### Dental CT

The CT equipment used was a Multi-CT scan Aquilion 16 TSX-101A/6A (Toshiba® America Medical Systems Inc, Tustin, CA, USA) calibrated each 6 months according Spanish 23 December Royal Decree 1976/1999.

Twenty sagittal tomographic cuts were performed for each mandible, taking the occlusal plane as axial reference plane. The exposure parameters were set at 120 kV, 56 seconds, and 150 mA, and a rectangular collimator was used. Radiographic images were processed using SIMPLANT® software (Materialise Dental®, Madrid, Spain). All CTs were performed by the same experienced technician.

### BMD Measurements

To measure the mandibular BMD in each image, a three-dimensional circular region of interest (ROI) was determined (by the same clinician for all samples), which was between 10 and 20 $mm^2$ in area, in the cancellous bone of the interior mandible. BMD was calculated in HU (Figure 1).

### Bone Density Calibration Phantom

The fox plane attached to the wax on the mandibles was a polymethyl methacrylate phantom containing four inserts of different predetermined density: HA 100, 200, 500, and 700 $mg/cm^3$ (CIRS® Tissue Stimulation & Phantom Technology, Norfolk, VA, USA) (Figure 2).

To calculate the calibrated BMD, the following mathematical formula was used: calibrated BMD = measured BMD × Δ, where Δ was a correction factor obtained from the MD quotient predetermined by the manufacturer of each HA cylinder/MD estimated by CT for each HA cylinder (there were four cylinders in the polymethyl methacrylate phantom; in this sense, the Δ factor was calculated based on 40 samples).

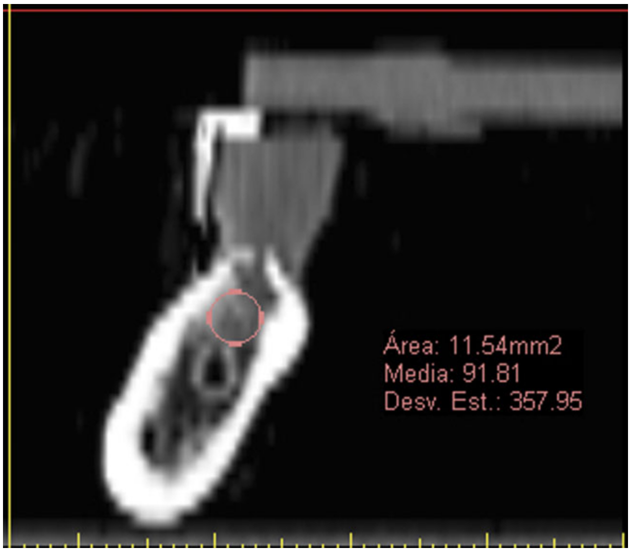


**Figure 1** Marking the region of interest (ROI) in cancellous bone within the mandible body in order to measure the mandibular bone mineral density (BMD) in Hounsfield unit (HU).

**Figure 2** Polymethyl methacrylate phantom positioned on the mandibles.

MD estimated by CT for each HA cylinder in the study was obtained from the mean of 10 density measurements taken along the HA cylinder after 10 different ROI had been established (Figure 3).

### Statistical Analysis

Data were analyzed using *SPSS* version 12.0 statistical software (SPSS® Inc., Chicago, IL, USA). A descriptive study was made of each variable. A *t*-test for two related samples was applied to quantitative variables, in each case determining whether variances were homogeneous. Pearson's correlation coefficient was used to evaluate the correlation among estimated and calibrated BMD. Statistical significance was established as $p \leq .05$.

## RESULTS

When correlation between measured BMD and calibrated BMD was calculated, the Pearson correlation coefficients ranged between 0.996 and 0.999 for the 20

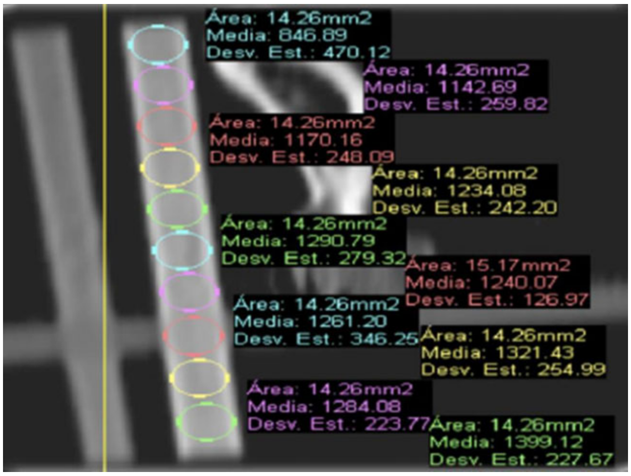


**Figure 3** Bone mineral density (BMD) measurements along the hydroxyapatite (HA) cylinder, having established 10 different regions of interest (ROIs).

sagittal tomography cuts studied, indicating high positive linear correlation between measured BMD and calibrated BMD, with statistically significant differences for each of the 20 tomographic cuts studied ($p < .001$) (Table 1).

In this way, the total mean correlation between measured and calibrated BMD for the 20 sagittal tomography cuts showed a correlation that was close to perfect positive correlation ($r = 0.998$, $p < .001$) (Figure 4).

**TABLE 1 Correlation between Measured BMD and Calibrated BMD**

| Sagittal Tomography Cuts | Correlation between Measured BMD and Calibrated BMD (Pearson's Correlation Coefficient) | *p* Value |
|---|---|---|
| Cut 1 | 0.997 | <.001 |
| Cut 2 | 0.998 | <.001 |
| Cut 3 | 0.998 | <.001 |
| Cut 4 | 0.998 | <.001 |
| Cut 5 | 0.997 | <.001 |
| Cut 6 | 0.996 | <.001 |
| Cut 7 | 0.999 | <.001 |
| Cut 8 | 0.999 | <.001 |
| Cut 9 | 0.999 | <.001 |
| Cut 10 | 0.998 | <.001 |
| Cut 11 | 0.998 | <.001 |
| Cut 12 | 0.998 | <.001 |
| Cut 13 | 0.997 | <.001 |
| Cut 14 | 0.996 | <.001 |
| Cut 15 | 0.999 | <.001 |
| Cut 16 | 0.997 | <.001 |
| Cut 17 | 0.997 | <.001 |
| Cut 18 | 0.997 | <.001 |
| Cut 19 | 0.999 | <.001 |
| Cut 20 | 0.997 | <.001 |

Sample size $n = 70$ mandibles (Pearson's correlation coefficient).
BMD, bone mineral density.

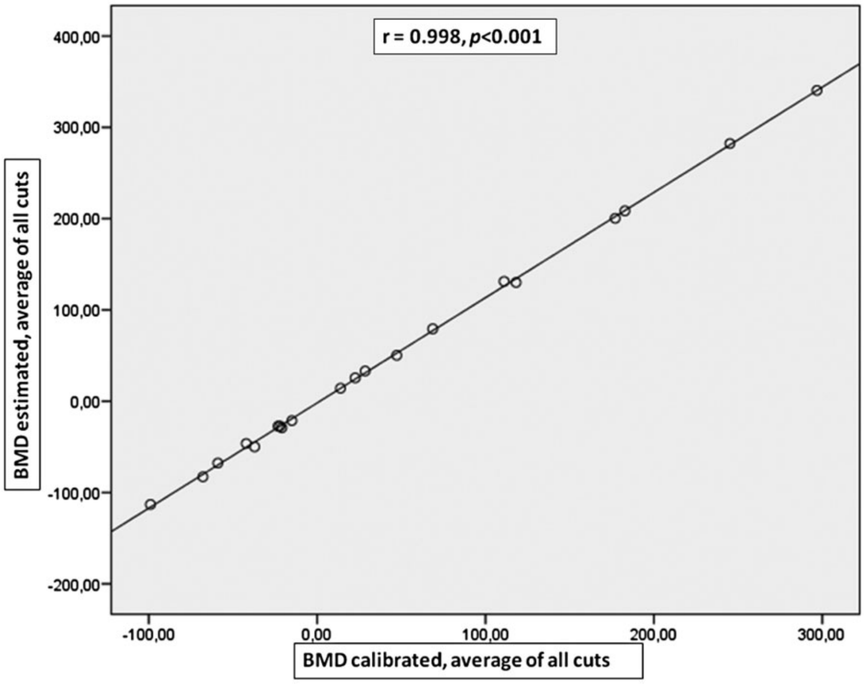


**Figure 4** Total mean correlation between measured and calibrated bone mineral density (BMD) in the 20 sagittal tomography cuts studied.

**TABLE 2 Comparison between Measured BMD and Calibrated BMD (*t*-Test)**

| Sagittal Tomography Cuts | Measured BMD ($n = 70$) Mean ± SD* | Calibrated BMD ($n = 70$) Mean ± SD | *p* Value |
|---|---|---|---|
| Cut 1 | −113.05 ± 347.76 | −98.99 ± 322.77 | .049 |
| Cut 2 | −27.32 ± 355.97 | −23.21 ± 307.53 | .524 |
| Cut 3 | −21.28 ± 361.21 | −15.05 ± 307.48 | .378 |
| Cut 4 | 33.13 ± 371.95 | 28.51 ± 319.81 | .507 |
| Cut 5 | 50.30 ± 394.09 | 47.26 ± 340.58 | .675 |
| Cut 6 | 131.33 ± 413.01 | 111.05 ± 357.33 | .012 |
| Cut 7 | 14.22 ± 422.22 | 13.89 ± 367.91 | .963 |
| Cut 8 | 79.33 ± 390.38 | 68.66 ± 335.18 | .132 |
| Cut 9 | 200.33 ± 459.53 | 177.02 ± 400.02 | .003 |
| Cut 10 | 282.29 ± 527.29 | 245.13 ± 454.15 | <.001 |
| Cut 11 | 340.51 ± 485.38 | 296.81 ± 423.54 | <.001 |
| Cut 12 | 208.48 ± 437.81 | 182.74 ± 380.46 | .001 |
| Cut 13 | 130.13 ± 474.19 | 118.11 ± 417.34 | .127 |
| Cut 14 | 25.59 ± 386.21 | 22.61 ± 334.77 | .684 |
| Cut 15 | −27.17 ± 354.02 | −22.14 ± 303.81 | .434 |
| Cut 16 | −82.78 ± 338.41 | −67.84 ± 292.47 | .021 |
| Cut 17 | −49.84 ± 317.73 | −37.15 ± 325.21 | .055 |
| Cut 18 | −29.11 ± 348.38 | −20.99 ± 299.08 | .238 |
| Cut 19 | −46.29 ± 324.91 | −42.15 ± 281.66 | .493 |
| Cut 20 | −67.69 ± 447.44 | −58.94 ± 382.24 | .392 |
| All cuts | 54.99 ± 421.59 | 49.28 ± 364.95 | .001 |

BMD, bone mineral density.

However, when the mean BMD measurements in HU were compared, statistically significant differences were found for cut 1 ($p = .049$), cut 6 ($p = .012$), cut 9 ($p = .003$), cut 10 ($p < .001$), cut 11 ($p < .001$), cut 12 ($p = .001$), and cut 16 ($p = .021$). Total measured BMD (for the 20 sagittal cuts studied) was 54.99 ± 421.59, whereas total calibrated BMD was 49.28 ± 364.95, with statistically significant difference ($p = .001$) (Table 2).

## DISCUSSION

Sufficient quantity and quality of bone is required for the successful installation of a dental implants and its long-term prognosis. When severe resorption of the alveolar ridge in vertical and/or horizontal dimensions and loss of bone quality occur following tooth loss, this will jeopardize the success of dental implants.[28] In this way, an accurate evaluation of bone structure prior to implant placement can be considered a necessity. Several bone classification systems have already been introduced. In 1985, Lekholm and Zarb[8] suggested a bone classification system based on macrostructure, whereby the morphology and distribution of cortical and trabecular bone are the determinants of bone quality. In 1993, Misch[9] advocated a density-related macrostructure bone classification, whereby bone quality is assessed subjectively through tactile sense when the bone is drilled. In 1995, Friberg and colleagues[29] proposed an objective cutting resistance procedure that would provide a composite value of mechanical characteristics predicting bone quality for initial stability. Nevertheless, all these indices are practitioner dependent and so lack objectivity. HU scores that can be measured from CT images have been proven to be an objective and reliable method to assess bone density preoperatively as they have been found to strongly correlate with bone histomorphometry[23] and BMD values.[19]

Nevertheless, there are multiple variables that can affect the accuracy of CT and therefore the precise quantification of BMD. In order to avoid failures in QCT, BMD should be calculated by measuring HU and relating the values obtained to a calibration bone phantom with predetermined MD. In 2008, Verdonck and colleagues[30] concluded that calculating absolute BMD values based on CT scans using the Simplant software was not possible unless calibration bone phantoms with predetermined BMD values are coscanned. The materials for calibration bone phantoms are composed of usually CaCO3 and calcium HA, in polyurethane or water bases, the latter being the most commonly used.[31] Other materials such as $K_2HP0_4$ have also been used for fabricating radiological phantoms for calculating calibrated BMD.[32,33]

The postmortem specimens used in the study provided a good representation of actual clinical situations in which the degree of variance in bone quality would have a significant biochemical impact on treatment planning and prognosis; this ex vivo model has been used in other research.[14,34]

The results obtained in the present study (with a phantom containing four HA inserts of different predetermined density) indicated an overvaluation of bone quality for measured BMD compared with calibrated BMD. The lack of precision between measured BMD and calibrated BMD turns more evident in clinical in vivo densitometries.[35] However, these discrepancies are smaller in mandibles from cadavers. Therefore, a further in vivo study should be performed to evaluate the precision of the proposed method.

These discrepancies between measured and calibrated BMD could lead to poor surgical planning, incorrect preparation of the surgical bed, the wrong choice of implant design, and reduced primary stability, which in turn could lead to implant failure.[36,37] The importance of establishing accurate BMD has been stressed by numerous authors who have considered BMD to be one of the main factors that have a decisive influence on the primary stability of dental implants, and so the predictability of implant treatments.[38] In this way, authors such as Martinez and colleagues[6] in full awareness of the importance of BMD for implant dentistry have proposed clinical protocols designed to respond to the existing BMD aimed at improving primary stability.

The present study found that there are discrepancies between measured BMD and calibrated BMD. For this reason, a calibrated bone phantom with a predetermined MD should be used to determine the exact BMD prior to dental implant surgery. Clinically, the phantom could be stabilized with a disposable bite fork, and mineral rods inserted in the device remains extraorally providing the occlusal plane to the radiologist.

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