How Accurate Is CBCT in Measuring Bone Density? A Comparative CBCT-CT In Vitro Study

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ABSTRACT

Purpose: Recently, cone beam computed tomography (CBCT) has become widely used for oral and maxillofacial imaging. Twenty dry mandibles were CBCT and conventional multislice CT scanned to evaluate if there is a statistically significant difference between the bone density values they produce, defined as gray density values, and to determine any correlation between them.

Materials and Methods: Using software and a radiographic template, the CT and CBCT scan images were overlapped, and two data sets were created, each one giving the respective gray values (voxel value [VV] or Hounsfield unit [HU]) of the same area with the same spatial coordinates. For the statistical analysis, *t*-test, Pearson's correlation, and Pearson's *r* were used.

Results: The differences between the CBCT (VV) and CT (HU) gray density values were statistically significant ($p \leq .05$), whereas the Pearson's correlation coefficients and Pearson's *r*-values demonstrated a statistically significant linear correlation between VV and HU gray density values.

Conclusion: The lower radiation dose and reduced costs of CBCT make this a useful substitute for CT; however, this study has shown that, in order to more accurately define the bone density with CBCT, a conversion ratio needs to be applied to the VV.

KEY WORDS: bone density, computed tomography, cone beam, Hounsfield value

INTRODUCTION

Over the past three decades, osseointegrated dental implant therapy has had successful outcomes, but some clinical reports have indicated a higher success rate when dental implants have been inserted in the mandible rather than in the maxilla.[1,2]

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DOI 10.1111/cid.12027

Clinical studies have also shown that a greater failure rate is associated with poorer volume and/or density of the bone.[3]

The mechanical properties of the bone are an important factor in osseointegration, which determines the primary implant stability.[4]

Several studies have proposed a variety of methods for assessing bone density, but these involve evaluation either at the time of implant site preparation or subsequent to implant placement.[3]

In recent years, the use of a computed tomography (CT) scan has been common for preoperative quantitative and qualitative assessment of implant sites, and the Hounsfield unit (HU) is routinely used to determine the bone density objectively.[3,5,6]

Even more recently, due to the need for less expensive image acquisition protocols or for scanners with lower radiation dose, cone beam CT (CBCT) has been widely employed for oral and maxillofacial imaging,[7] as

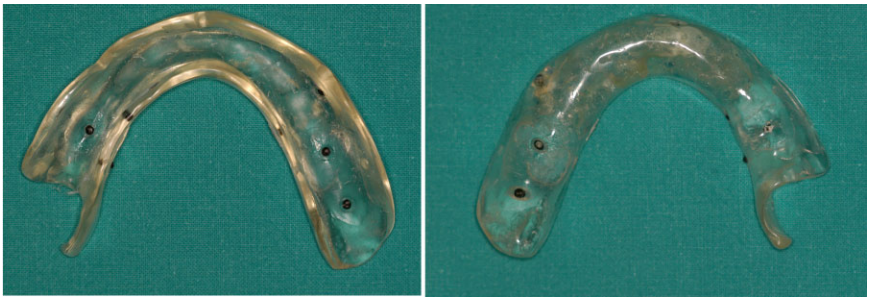

Figure 1 Radio-transparent resin template with nine lead circular radiopaque shots used as landmarks.

it seems to provide good spatial resolution, gray density range, and contrast, as well as a good pixel/noise ratio.[8]

With CBCT, the dimensional accuracy is also comparable with CT, but unlike CT, the gray density values of the CBCT images (voxel value [VV]) are not absolute.[8]

In fact, CT could be calibrated using as a reference the density values of the air (−1,000 HU) and pure water (0 HU); otherwise, CBCT does not consent to be calibrated, and the values, which are based on the difference of gray scale, are already preset by the manufacturer.

The purposes of this study were the following:

1 to evaluate if there is a statistically significant difference between the measurements of bone density values, defined as gray density values, collected when using CBCT (VV) or CT (HU) in implant planning;
2 to determine if there is a correlation between the different gray density values measured through a CBCT (VV) and through a CT (HU).

The hypothesis of this study is that CBCT is a reliable method to evaluate the bone density of the implant sites, but it is necessary to use a conversion ratio to convert the CBCT gray values into CT.

MATERIALS AND METHODS

To evaluate the accuracy of CBCT in determining bone density, the gray density values of specific anatomical specimen areas at the same spatial coordinates were measured using CBCT (VV) and CT (HU).

This method allowed us to obtain comparable images of the same area under investigation.

The protocol employed in this in vitro study consisted of an integrated sequence that involved the following series of steps:

1 Creation of a radio-transparent resin template with nine lead circular radiopaque shots to be used as landmarks to ensure a perfect overlap (Figure 1).
2 Execution of CBCT and CT scans for all anatomical specimens (20 dry mandibles; Figure 2), employing the same template for both types of scan (Figure 3).

A spiral CT machine (Siemens SOMATOM®, Erlangen, Germany) was used. The CT parameters used were tube voltage of 120 kV, tube current of 72 mAs, high-resolution bone kernel, 0.5-mm nominal slice thickness, 0.5-mm interval, and 0.5-mm pitch. Calibration was performed to ensure that the air was defined as −1,000 HU.

The CBCT used (Soredex SCANORA® 3D, Tuusula, Finland) had an amorphous-silicon, flat-panel image detector and offered a cylindrical volume of reconstruction up to 13 × 14.5 cm with a 14-bit gray density, 0.250-mm pixel size, 90-kV tube voltage, 0.25-mm

Figure 2 One of the dry mandibles used as an anatomical specimen.

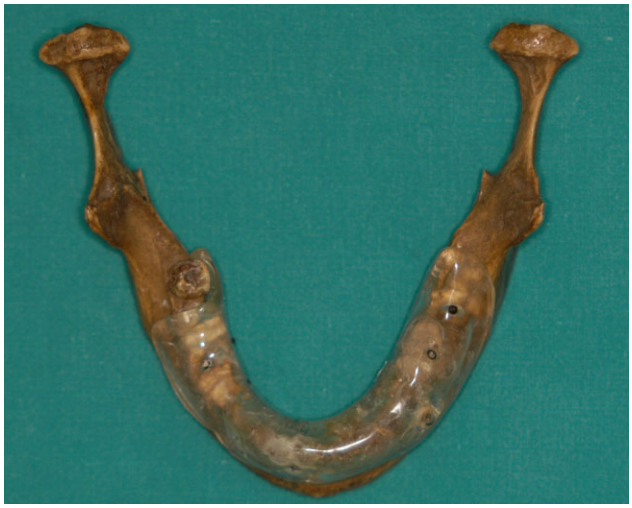

Figure 3 The dry mandible and the resin template used for cone beam computed tomography and computed tomography scans.

nominal slice thickness, 15 mAs, and 40-s exposure time. Unlike CT, the CBCT scanner employed factory-defined gray density attenuation.

All acquired data were saved in Digital Imaging and Communications in Medicine (DICOM) format.

The quantified gray density values of the planned volume were measured and expressed as VV and HU in the CBCT and CT groups, respectively.

3 Overlapping of the DICOM images in order to have the same spatial coordinates for both scans.

The CT DICOM images were imported using software (Mimics®, Materialise, Leuven, Belgium), and the "image registration" tool was used. With the "image registration" tool, it is possible to fuse two data sets by doing a landmark point-based registration (nine lead shots); thus, after importing CBCT DICOM images, a perfect overlap was obtained (Figure 4).

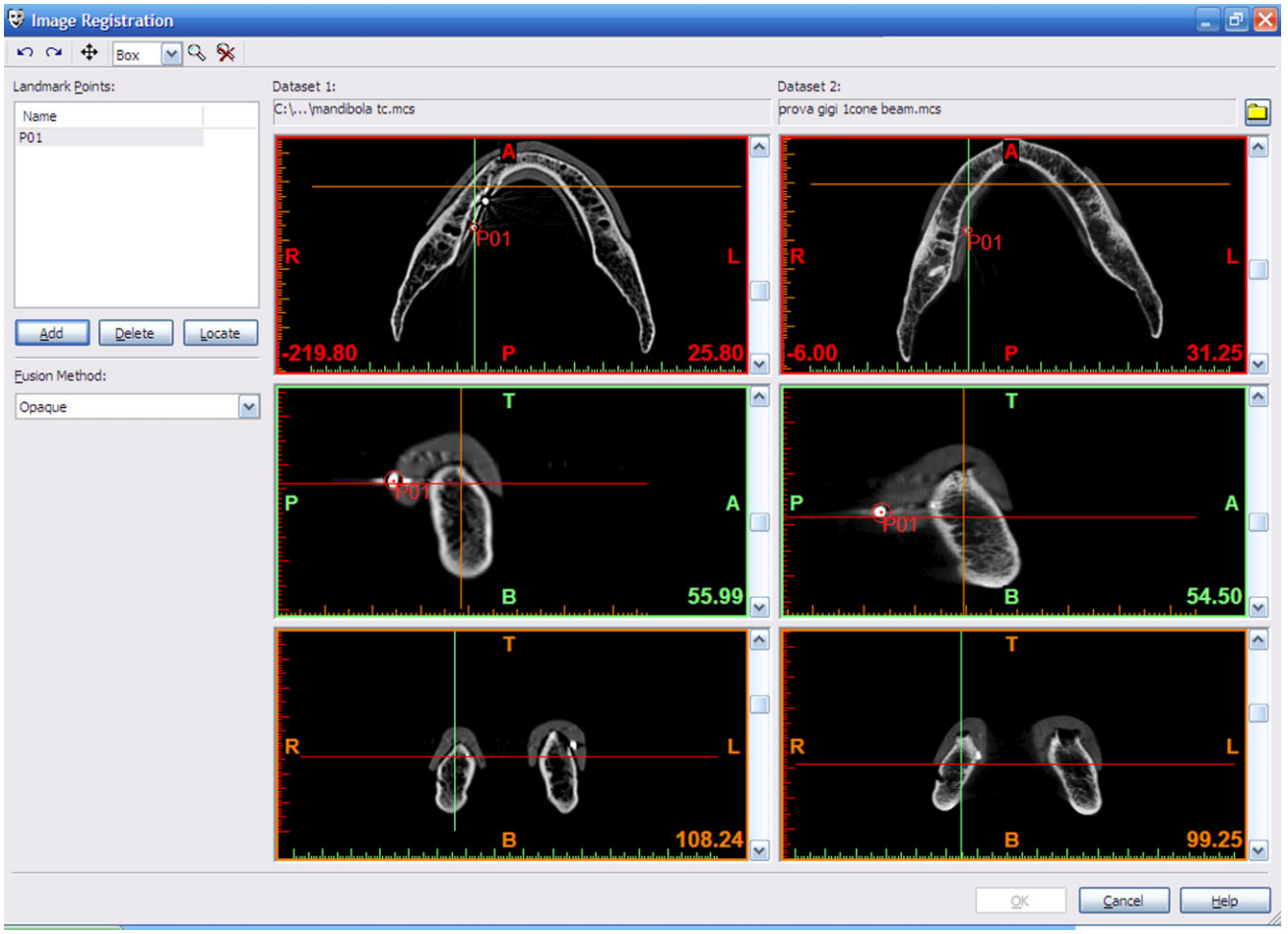

Figure 4 Overlapping of two data sets (cone beam computed tomography and computed tomography) of Digital Imaging and Communications in Medicine images, using the Mimics® software "image registration" tool.

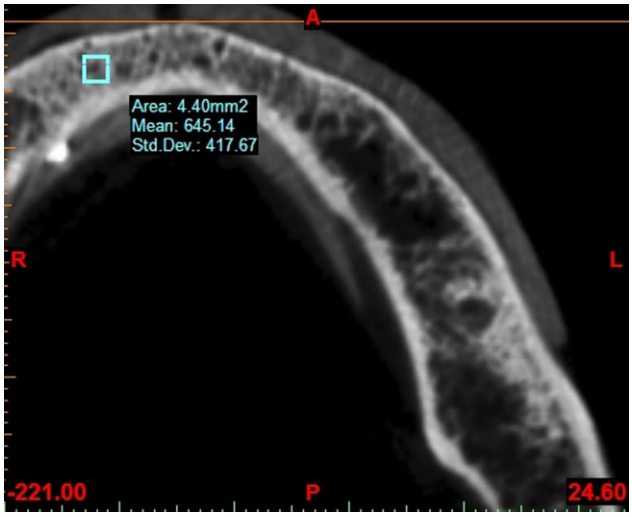

Figure 5 Determination of cancellous bone cone beam computed tomography gray density values (voxel value [VV]). The drawn square shows a mean value of 645.14 VV. The coordinates of the square are indicated below the figure in red.

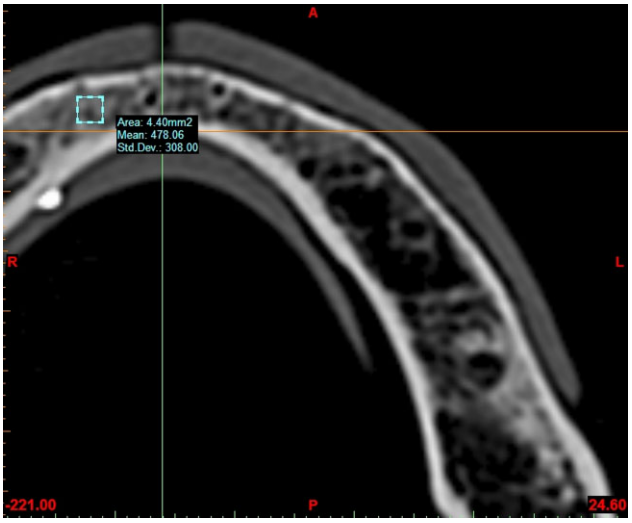

Figure 6 Determination of cancellous bone computed tomography gray density values (Hounsfield unit [HU]). It should be noted that the area and the coordinates of the drawn square are the same as in Figure 5 (–221.00, 24.60). The mean gray density value recorded was 478.06 HU.

This software runs until it finds the exact overlap between the images of CT and CBCT scans and does not require any intervention by the examiner, thus excluding any possible human measurement error.

The final result was the creation of two sets of data relating to the same areas (spatial coordinates): one set gave gray values in terms of HU, while the other set gave values in terms of VV.

4 Calculation of the gray density values for CBCT (VV) and CT (HU) images.

A square with the same spatial coordinates was drawn for both data sets, and the gray density value within the square was determined. For each anatomical specimen, 30 measurements were made (10 in the cancellous-cortical bone, 10 in the cancellous bone, and 10 in the cortical bone), and the gray density values were determined in the following six groups, which were paired according to the area under investigation:

Group A1: cancellous-cortical bone CBCT gray density values (VV);
Group A2: cancellous-cortical bone CT gray density values (HU);
Group B1: cancellous bone CBCT gray density values (VV) (Figure 5);
Group B2: cancellous bone CT gray density values (HU) (Figure 6);
Group C1: cortical bone CBCT gray density values (VV) (Figure 7);
Group C2: cortical bone CT gray density values (HU) (Figure 8).

Statistical Analysis

The volume gray density values of the groups were analyzed using the *SPSS*® for Windows software (Statistical Package for Social Science, IBM Corporation, Armonk, NY, USA).

Descriptive statistics of gray density values (HU and VV) consisting of the mean, standard deviation, and minimum–maximum were calculated for each study group.

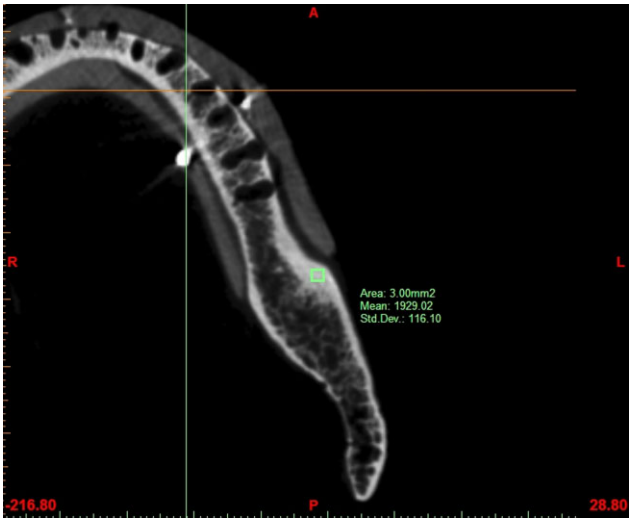

Figure 7 Determination of cortical bone cone beam computed tomography gray density values (voxel value [VV]). The drawn square shows a mean value of 1,929.02 VV. The coordinates of the square are indicated below the figure in red.

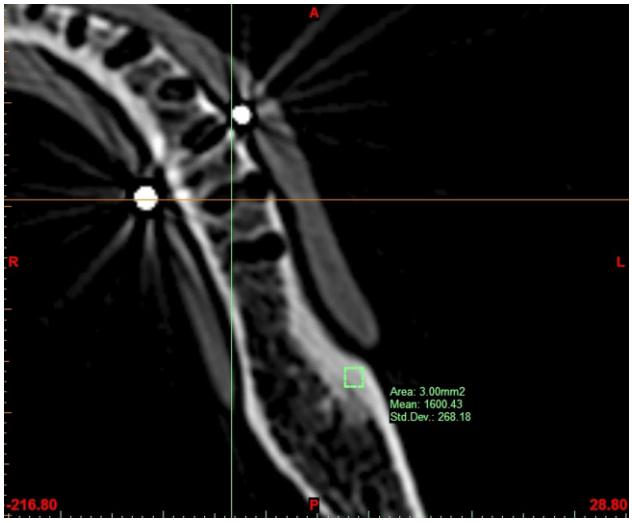

Figure 8 Determination of cortical bone computed tomography gray density values (Hounsfield unit [HU]). It should be noted that the coordinates of the drawn square are the same as in Figure 7 (–216.80, 28.80). The mean gray density value recorded was 1,600.43 HU.

The *t*-test was used to determine if there was a statistically significant difference between the two paired groups (group A1 vs A2, group B1 vs B2, and group C1 vs C2). Significance was set at $p \leq .5$.

Correlation between gray density values (HU and VV) of different groups was tested using the Pearson's correlation coefficient.

The Pearson's *r*-values were used to assess the magnitude of the covariance, regardless of the gray values of the CBCT and CT measurement sites. All measurement sites were used as the computational unit.

Again, a *p* level below .05 was accepted as statistically significant.

RESULTS

Quantitative data of each paired group were described with mean values, minimum–maximum values, and standard deviation (Table 1).

When using the *t*-test, the differences in the gray density values between the CBCT and CT groups were statistically significant for all paired groups (Table 2).

The Pearson's correlation coefficients demonstrated a statistically significant correlation between the compared groups (Table 3).

The Pearson's *r*-values showed a linear correlation between the gray density values of the CBCT and CT.

In scatter plots, the clusters shaped by the CBCT and CT gray values indicate the presence of a linear association between them (Figure 9, A–C).

The presence of a close linear correlation consented to determine the conversion ratio to transform the gray density values of CBCT (VV) to that of CT (HU).

In particular, in the present study, the conversion ratio was approximately 0.7 (0.7 × values of CBCT = values of CT).

DISCUSSION

The relationship between CBCT- and CT-based gray density values (VV and HU) was analyzed in this study.

Evaluation of the bone density prior to the insertion of implant may be of critical importance, especially when multiple implants are planned. In some cases, in fact, as a result of the disuse atrophy, the mineral content of the alveolus in totally and partially edentulous jaws may have decreased dramatically, resulting in an increased risk of implant placement into the compromised areas.

In a recent review aimed to survey the definition of bone tissue characteristics and methods of assessing them in studies of dental implant planning and placement, Ribeiro-Rotta and colleagues[9] concluded that there is a diversity of classifications of bone tissue characteristics and of methods used to examine and assess jawbone tissue.

TABLE 1 Descriptive Statistics: Mean, Minimum–Maximum Values, and Standard Deviation

	Mean	Maximum	Minimum	SD
Group A1 (VV)	1,053.31	2,700.77	88.37	490.15
Group A2 (HU)	744.35	1,890.54	61.86	366.70
Group B1 (VV)	816.62	1,110.00	645.00	84.29
Group B2 (HU)	572.45	777.00	436.00	58.42
Group C1 (VV)	1,505.26	2,006.00	1,019.00	151.02
Group C2 (HU)	1,354.00	1,896.00	840.00	143.19

HU = Hounsfield unit; VV = voxel value.

TABLE 2 *t*-Test Regarding the Differences between the CBCT and CT Gray Density Values

	Sig.	Difference between Means	Standard Error
Group A1 vs group A1	.000*	308.96	61.21
Group B1 vs group B2	.000*	244.17	10.25
Group C1 vs group C2	.000*	151.26	20.81

*Statistically significant ($p \leq .05$).
CBCT = cone beam computed tomography; CT = computed tomography.

The authors[9] suggested a strong need for future uniformity in the design of implant studies. Similar assessment methods, classification system, and measurement units are essential prerequisites for comparing the results of different studies and for improving the understanding of treatment outcomes in relation to different bone characteristics.

CT has been widely used to evaluate the dimension and density of the bone as it provides quantitative and qualitative data of the medullary and cortical bone.[3,5,6,10–13]

With CT, bone density measurements are given in HU based on density values for air (−1,000 HU) and pure water (0 HU). The cortical bone ranges from +1,000 to +1,600 HU values.[11]

Due to its relatively low cost and reduced radiation dose, CBCT has become more widely used for oral and maxillofacial imaging, providing good spatial resolution, gray density range, and contrast, as well as a good pixel/noise ratio.[7]

In CBCT, the dimensional accuracy is also comparable with CT, but in contrast to CT, the gray density values of the images (VV) are not absolute.[8]

Arisan and colleagues,[8] in a recent study aimed at determining the relationship between CT- and CBCT-based gray density values, revealed gray density values ranging from 167 to 989 HU and from 229 to 1,042 VV.

In the present study, the gray density values measured in the CBCT groups were higher than those measured in the CT groups, results that were similarly reported in another study.[14]

The reason for this phenomenon was attributed to various technical factors such as x-ray beam hardening, scattered radiation, and "projection data discontinuity-related effect," all of which resulted in a decrease in the dynamic contrast of the CBCT scanners compared with multislice CT.[8]

According to Arisan and colleagues,[8] the effect of beam hardening is more pronounced when the radiopacity increases, which can explain the significant

TABLE 3 Pearson's Correlation between CBCT and CT Groups

		Group A1	Group A2	Group B1	Group B2	Group C1	Group C2
Group A1	Pearson's correlation		0.977*				
	Sig.		.000				
	n		100				
Group A2	Pearson's correlation	0.977*					
	Sig.	.000					
	n	100					
Group B1	Pearson's correlation				0.931*		
	Sig.				.000		
	n				100		
Group B2	Pearson's correlation			0.931*			
	Sig.			.000			
	n			100			
Group C1	Pearson's correlation						0.978*
	Sig.						.000
	n						100
Group C2	Pearson's correlation					0.978*	
	Sig.					.000	
	n					100	

*Statistically significant ($p \leq .05$).
CBCT = cone beam computed tomography; CT = computed tomography.

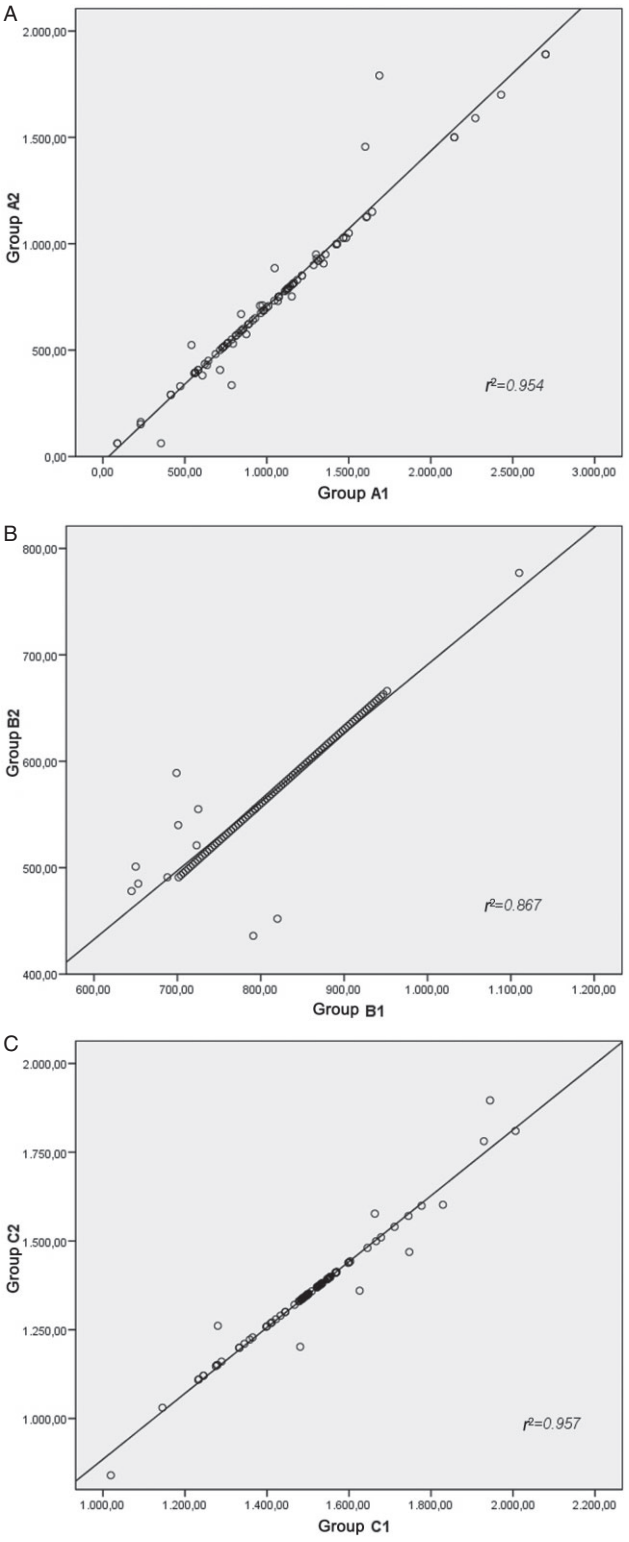

Figure 9 *A–C*, Scatter plots visually identify the relationship between the cone beam computed tomography and computed tomography gray values in the study groups. In each study group, the points follow a linear pattern that indicates a high linear correlation. The high values of r^2 indicate that the points are close to the straight line. The linear relationship is strong if the points are close to the straight line.

differences between the HU and VV in the cortical bone compared with the more similar results found in the trabecular, low-density maxillary bone.

In contrast to Arisan and colleagues,[8] the results of the present study did not show smaller differences between measurements taken in areas of the bone marrow compared with those in areas of the cortical bone.

In a recent investigation conducted by Naitoh and colleagues, the relationship between VVs obtained from CBCT and bone mineral densities (BMDs) obtained from multislice CT was evaluated in the mandible.[14]

A high-level correlation between VVs of CBCT and BMDs of multislice CT was observed ($r = 0.965$).

Also, the same authors[14] transformed the BMDs of CBCT from the VVs in one hundred twenty-eight implant sites using a regression line, and then the absolute difference between the values and BMDs of multislice CT was calculated. The difference was from 1 to 182 mg/cm^3 HA, with a mean of 46 mg/cm^3 HA (SD 36).

This high correlation between VV of CBCT and BMDs of multislice CT was close to that reported in a previous study conducted by Aranyarachkul and colleagues.[15]

These authors,[15] comparing HU density recordings made using the conventional quantitative CT (QCT) method with HU density recordings made with the quantitative CBCT (QCBCT), observed that QCBCT bone density values were generally higher than the corresponding QCT recordings. The relationships between the QCT and QCBCT values were close, as demonstrated by the Pearson's correlation coefficients, which ranged from 0.92 to 0.98.

Unlike the protocols used in the cited research,[14,15] where a single arbitrarily chosen cross-sectional image of the designated implant area was referred for the quantification of the gray density values, the methodology of the present study is rather sophisticated using dedicated software that allows the exact overlap between the images of CT and CBCT scans and does not require any intervention by the examiner, thus excluding any possible human measurement error.

The present study also demonstrates the possibility of correlating the gray density values recorded by CT and CBCT; in fact, a correlation between VV of CB CT and HU values of multislice CT was observed.

More specifically, in this study, the conversion ratio between the two gray values was determined and defined

equal to 0.7; thus, to convert the CBCT gray values into CT, it is necessary to multiply CBCT values by 0.7.

This conversion ratio, moreover, is approximate and may vary based on the CBCT used; a conversion ratio between CT and CBCT gray density values has never been proposed before, and comparable data are not present in the literature.

Whether the CT or the CBCT values are closer to the corresponding histological bone densities remains to be learned, and this topic will be addressed, relating both CT and CBCT gray values to histological measurements of bone density.

CONCLUSION

This study demonstrated that the utilization of a CBCT to evaluate the bone density of implant sites can be useful due to its lower radiation dose and lower costs; however, the surgeon needs to be aware that VVs are not absolute values. Nevertheless, there is a linear correlation between the gray density values of CBCT and CT, which allows the surgeon to convert CBCT gray density values (VV) into absolute values (once the correct conversion rate has been established) and, in so doing, ensure a more successful result.

ACKNOWLEDGMENT

The authors thank Dr. Rossella Cappabianca, sociologist, specialized in methodology of social research, for the statistical analysis.

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