# Bone Density Assessments of Dental Implant Sites: 1. Quantitative Computed Tomography

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***Purpose:*** *This study was designed to evaluate variations of bone density in designated implant sites using quantitative computed tomography (QCT) and to compare the QCT measurements to subjective evaluation of bone density.* ***Materials and Methods:*** *Sixty-two designated implant sites in jaws of 9 human cadavers were used. Indicator rods, 2 mm in diameter, were placed in all sites. CT images representing 1-mm buccolingual slices immediately mesial and distal to the rods were selected. Bone density (in Hounsfield units) was assessed in a standardized implant area superimposed on the images and was also subjectively evaluated by 2 independent examiners using the Lekholm and Zarb classification.* ***Results:*** *QCT results demonstrated that bone densities may vary markedly when different areas of a designated implant site are compared. The Lekholm and Zarb ratings for the 2 examiners showed coefficients of correlation ranging between 0.5 to 0.7 for the relationships with the QCT values. Within each of the scores used for the subjective classification, however, a wide range of QCT values was observed.* ***Discussion:*** *The results emphasize the importance of the use of radiographic methods prior to implant placement that allow topographically precise assessments of bone density in the region of interest.* ***Conclusion:*** *Access to QCT values should constitute a valuable supplement to subjective bone density evaluations prior to implant placement.* (INT J ORAL MAXILLOFAC IMPLANTS 2003;18:224–231)

**Key words:** *bone density, computed tomography, dental implants*

The overall outcome of dental implant procedures is generally successful (see review by Goodacre and coworkers[1]). However, the success rate is considered to be influenced by both the volume (quantity) and density (quality) of available bone for implant placement. Clinical reports have indicated a higher survival rate for dental implants in the mandible as compared to the maxilla, especially in the anterior region of the mandible, which has been ascribed to better volume and density of the bone. The highest failure rate has been reported for the posterior region of the maxilla, which has been attributed to the fact that this area often lacks sufficient volume and/or density of bone.[2–12]

Accurate analysis of the bone content and architecture would facilitate clinical decision-making regarding patient selection, implant type and surface, and the surgical technique used. Classification systems for its evaluation have been introduced. Lekholm and Zarb[13] classified bone density radiographically into 4 types based on the amount of cortical versus trabecular bone. Type 1 bone is "almost the entire jaw comprising homogenous compact bone," type 2 is "a thick layer of compact bone surrounding a core of dense trabecular bone," type 3 is "a thin layer of cortical bone surrounding a core of dense trabecular bone," and type 4 is "a thin layer of cortical bone surrounding a core of low-density trabecular bone." Misch[14] related bone density to the clinical hardness of the bone as perceived during

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drilling prior to implant placement. D1 (density 1) bone is "oak or maple-like," D2 is "similar to spruce or white pine wood," D3 is "similar to balsa wood," and D4 is "similar to styrofoam."

Truhlar and coworkers[15] modified the classification of Lekholm and Zarb[13] in the assessment of bone density by including the tactile sensation during drilling. They found that bone quality types 1 and 4 occurred less frequently than types 2 and 3. Although variations in density existed for each region under study, type 2 bone predominated in the mandible and type 3 bone was more prevalent in the maxilla. The anterior region of the mandible had the densest bone, followed by the posterior mandible, anterior maxilla, and posterior maxilla.

Trisi and Rao[16] related the Misch[14] classification of tactile sensation during drilling to histomorphometric bone density determinations using human trephine core biopsies. It was found that the D1 and D4 classes had the highest and lowest histomorphometric density, respectively, while D2 and D3 presented similar densities.

A method to obtain objective measurements of the cutting resistance during tapping prior to the placement of implants was developed by Johansson and Strid.[17] This method, when used in jaw autopsy specimens, was observed to correlate closely with microradiographic determinations of the bone density.[18]

Quantitative computed tomography (QCT) is a clinically established and widely applied method in orthopedic medicine for objective bone mineral assessments.[19,20] Norton and Gamble[21] applied QCT to implant sites and compared the QCT bone density values to the Lekholm and Zarb[13] classification system. An overall correlation between the QCT values and the subjective density scores was observed. However, within each of the 4 Lekholm and Zarb classes, they observed a wide range of QCT values.

In recognition of the need for objective determinations of bone densities to guide implant placement, a series of studies has been initiated that will evaluate conventional QCT, 3-dimensional CT, torque resistance during implant placement, and ultimately histologic examination to assess bone density recordings. The aims of this first study are to evaluate the variations of bone density in designated implant sites as measured by QCT and to compare the QCT measurements to subjective bone density evaluation.

## MATERIALS AND METHODS

### Specimens

Human cadavers fixed in formalin, from the Division of Human Anatomy at Loma Linda University, were screened for suitable partially or completely edentulous maxillary and mandibular jaws. An attempt was made to retrieve specimens with potential implant sites representing all regions of the jaws. A total of 36 specimen blocks from 9 skulls, which provided 64 implant sites, were selected and freed of all soft tissues. Each specimen block provided 1 to 4 implant sites, each with a minimum alveolar bone height to accommodate 4.0×10-mm implants.

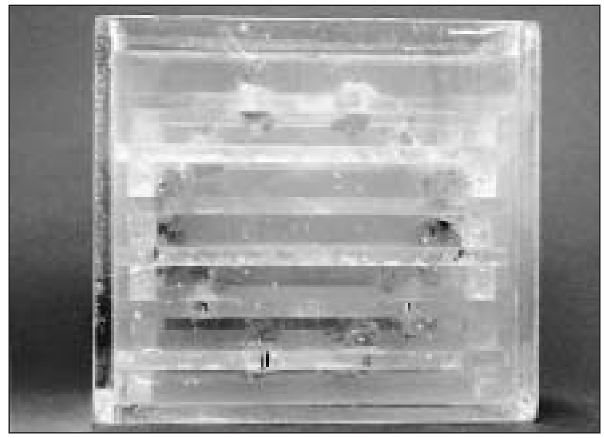


**Fig 1** The Plexiglas box showing 6 shelves with specimens.

### Preparation for CT Scanning

A Plexiglas box with dimensions 22×22×20 cm was assembled and fitted with 6 Plexiglas shelves, each 0.9 cm thick and separated from each other by a distance of 1.6 cm (Acrylite, Cyro Industries, Rockaway, NJ) (Fig 1). Six specimen blocks were placed on each shelf. Each block was positioned in a window (hole) cut in the shelf that was large enough to accommodate the block and secured with orthodontic resin (Bosworth, Skokie, IL). The mesiodistal axis of the alveolar blocks was oriented horizontally, parallel to the shelves and parallel to the lateral walls of the box, and the apicocoronal axis of the blocks was oriented vertically. Maxillary and mandibular blocks were both mounted with the alveolar bone crest facing the top of the Plexiglas box. The orientation of the specimen blocks was governed by the desire to have all 64 indicator rods (see below) and impending implants aligned parallel to each other in both mesiodistal and buccolingual dimensions. The spatial positioning of the specimen blocks on the 6 shelves throughout the box was done in a manner to minimize and equalize attenuation of adjacent bones during radiographic examination, thereby providing the most accurate density readings. For this, the specimen blocks were spread an equal distance from each other and also radially in a circle, concentric to the axis of the scan image.

Aluminum indicator rods, 2 mm in diameter, were then placed in all designated implant sites to a depth of 2 mm and extending 2 to 4 mm coronal to the bony crest. A 2-mm-diameter twist drill guided by a paralleling device was used. Each shelf with its specimen blocks was placed underwater in a vacuum chamber for 4 hours to remove air bubbles, as trapped air would introduce errors into the radiographic examination. All shelves were then transferred underwater into the box.

The box containing specimens was placed on the CT table in a position so that the shelves and the specimen blocks would be parallel to the axis of the table, and therefore the CT slices to be obtained would be perpendicular to this axis and parallel to the indicator rods. A phantom with 2 different sections of hydroxyapatite of known calcium densities for calibration purposes was placed on top of the box (Siemens, Iselin, NJ).

### Acquisition of CT Images

Spiral computed axial tomography using a General Electric high-speed CT/I scanner (Milwaukee, WI) was performed. The machine was set to produce buccolingual cross-sectional images (slices 1 mm thick) through the specimen blocks at 120 kV. A total of 176 QCT slice images were obtained throughout the specimen box. The QCT data were transferred to an Agfa PACS (picture archiving communication system; Impax DS 3000 Version 4.1 SP2; Agfa, Ridgefield Park, NJ) for easy access and analysis. The images were examined sequentially to identify each of the 64 aluminum rod indicators. For each of the sites, an image representing a 1-mm buccolingual slice immediately mesial to the rod and an image representing a 1-mm buccolingual slice immediately distal to the rod were selected for analysis. In this way, each of the designated 4-mm-wide implant sites were evaluated from 2 images, each 1 mm wide and separated by 2 mm (diameter of the aluminum rod). Often, however, depending on the position of the rods within the box in relation to the cross-sectional images obtained throughout the box, the aluminum rods would be seen on 3 sequential slice images. This meant that the adjacent mesial and distal images selected for analysis were often separated by 3 mm.

### QCT Bone Density Measurements

The selected 128 images mesial and distal to the aluminum rods were analyzed using Impax software (Agfa). This software includes an application to map the bone within a defined area and provides the average bone density within this area in Hounsfield units (HU). A rectangular area, 4.1×10.5 mm, was first mapped onto each image and placed over the image in a position where the impending implant would be placed. The positioning of the rectangle was guided by the direction of the aluminum rod as observed from the adjacent image and also by the desire to have the entire impending implant placed in bone without exposure of the implant threads, as is the case with the clinical management of bone preparation of the alveolar ridge prior to implant placement, where a peaked crest must be leveled to enable complete implant burial. In the present study, on occasion, the 4.1×10.5-mm rectangle had to be shifted apically to define the relevant bone housing for the implant (Fig 2). Bone density readings were then obtained from 3 separate subdivisions of the 4.1×10.5-mm rectangular area: a coronal third, a middle third, and an apical third, each 4.1×3.5 mm (Figs 2 to 5). In addition, a reading of the top 1-mm layer of the coronal third subdivision was taken.

### Subjective Bone Density Evaluation

Prints using 1.5× magnification were obtained for each of the selected images mesial and distal to the aluminum rods used for the QCT measurements (Fig 5). Two independent examiners with extensive clinical dental implant experience rated the bone density of these images for the designated implant sites. On each film, the location and the angulation of the aluminum indicator rod, as observed from the adjacent image, had been indicated by a pencil line.

Each examiner scored the bone density of the implant sites using the classification system of Lekholm and Zarb.[13] Repeat classification of 19 randomly selected images was also performed by the examiners for the purpose of evaluating the intraobserver reproducibility of the ratings.

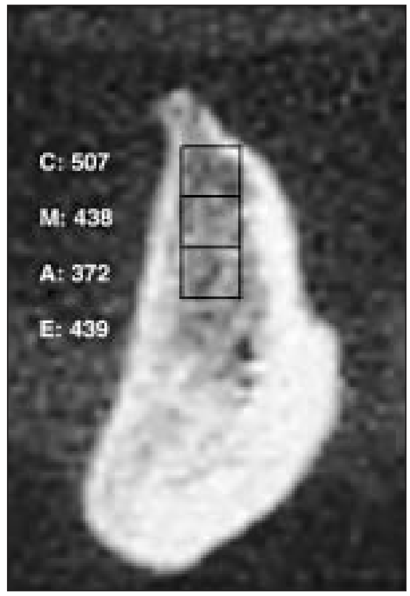
### Data Analysis

Images from 2 designated implant sites could not be analyzed because of technical reasons, leaving a total of 62 sites available for the study.

All of the following analyses used implant site as the computational unit.

*Influence of Subject and Region of the Jaws.* Univariate analyses of variance (ANOVA) were used to evaluate the influence of subject and region of the jaws on the QCT density values for the various subdivisions of the rectangular implant areas.

*Comparisons of QCT Bone Density Between Mesial and Distal Implant Area Images.* Subdivisions of the rectangular implant areas from the mesial images were compared to corresponding subdivisions from the distal images with respect to the bone density values. Frequencies (%) of deviations of different magnitude were calculated.



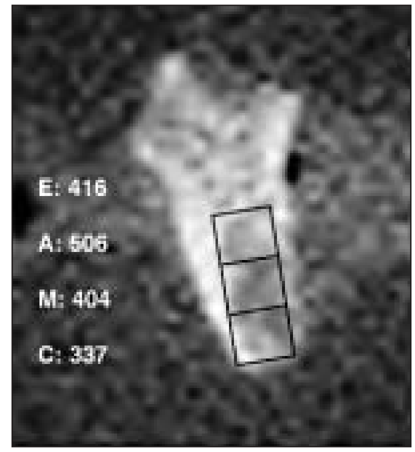




**Fig 2** *(Left)* Image of a designated mandibular implant site (lateral incisor area) displaying the average QCT density values in Hounsfield units for the entire rectangular implant area (E) and the density values for the coronal (C), middle (M), and apical (A) thirds. The rectangular area has been positioned below the superior aspect of the alveolar crest because of the desire to have the entire impending implant placed in bone without exposure of implant threads. This site was classified as Lekholm and Zarb type 2 bone density by both examiners.

**Fig 3** *(Right)* Image of a designated maxillary implant site (canine area). The apical third (A) of the rectangular implant area shows a higher Hounsfield value than the coronal third (C). This site was classified as Lekholm and Zarb type 3 bone density by both examiners.

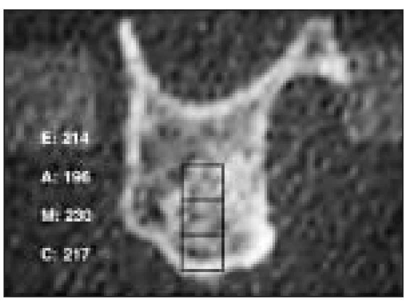



**Fig 4** Image of a designated maxillary implant site (second molar area). Low Hounsfield values are seen for all subdivisions of the rectangular implant area. This site was classified as Lekholm and Zarb type 4 bone density by both examiners.

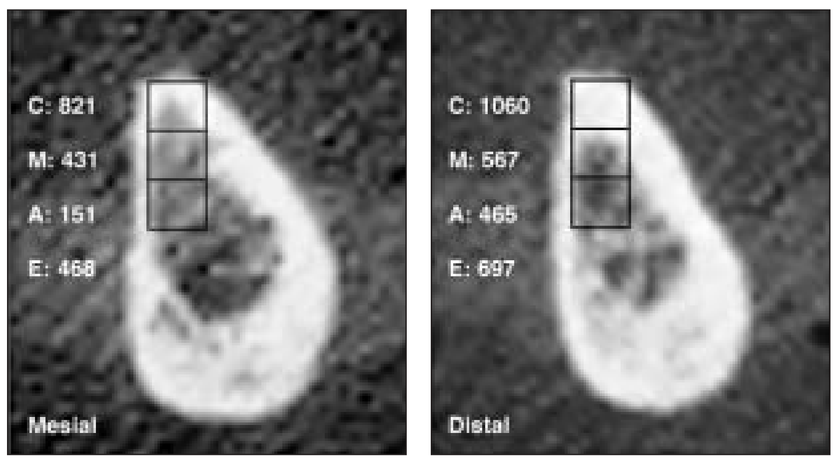



**Fig 5** Mesial and distal images (2 to 3 mm apart) of a designated mandibular implant site (canine area). Notable differences in Hounsfield values are evident when the 2 images are compared. This site was classified as Lekholm and Zarb type 2 bone density by both examiners.

*Comparisons of QCT Bone Density Within Each Implant Area Image.* Within each of the 62 mesial and 62 distal images, the various subdivisions of the rectangular implant areas were compared with respect to the bone density values. Frequency distributions of the differences between the various subdivisions were calculated.

*Reproducibility of Subjective Scoring.* The results of repeat classification using the Lekholm and Zarb system for the selected 19 images for the 2 examiners were evaluated from calculations of intraclass coefficients of correlation.

*Correlations Between QCT Bone Density and Subjective Scoring.* The relationships between the QCT bone density values and the Lekholm and Zarb ratings for each of the 2 examiners and for each of the sets of 62 mesial and 62 distal images were determined from calculations of Spearman's rho. For these correlations, the average QCT value for the entire implant area was used (all 3 subdivisions).

## RESULTS

### QCT Bone Density and Influence of Subject and Region of Jaws

The distribution of designated implant sites available for study among the 9 cadavers and the 4 different regions of the jaws is presented in Table 1.

**Table 1 Distribution of Implant Sites by Subject and Region of the Jaw**

| | No. of sites | | | | |
|---|---|---|---|---|---|
| Subject | Maxillary posterior | Maxillary anterior | Mandibular posterior | Mandibular anterior | Total |
| A | 5 | 1 | 6 | 3 | 15 |
| B | 1 | 2 | 3 | | 6 |
| C | 2 | | 6 | 2 | 10 |
| D | | 1 | 3 | 2 | 6 |
| E | | 2 | 2 | 2 | 6 |
| F | | 2 | 1 | 2 | 5 |
| G | | 2 | 3 | | 5 |
| H | | | 1 | 3 | 4 |
| I | | | 5 | | 5 |
| Total | 8 | 10 | 30 | 14 | 62 |

**Table 2 Means and Ranges for QCT Bone Density for the Various Subdivisions of the Rectangular Implant Areas for Mesial and Distal Images**

| | Bone density (HU) | |
|---|---|---|
| Location | Mean | Range |
| Mesial image subdivisions (n = 62) | | |
| Coronal 1 mm | 672 | 189–1265 |
| Coronal third | 573 | 168–1031 |
| Middle third | 424 | 23–803 |
| Apical third | 418 | 64–780 |
| Entire area | 472 | 109–800 |
| Distal image subdivisions (n = 62) | | |
| Coronal 1 mm | 651 | 135–1208 |
| Coronal third | 549 | 99–1060 |
| Middle third | 393 | 18–873 |
| Apical third | 383 | 81–780 |
| Entire area | 442 | 71–801 |

**Table 3 Frequencies (%) of Deviations of Different Magnitudes for QCT Bone Density Comparing Mesial and Distal Images of the Various Subdivisions of the Rectangular Implant Areas (n = 62)**

| Magnitude of deviation (HU) | Coronal third | Middle third | Apical third | Entire area |
|---|---|---|---|---|
| ± 0–99 | 52 | 55 | 55 | 60 |
| ± 100–199 | 35 | 26 | 29 | 32 |
| ± 200–299 | 10 | 8 | 13 | 6 |
| ± 300–399 | 2 | 8 | 2 | 2 |
| ± 400–499 | 2 | 3 | 2 | – |

An uneven distribution of sites were available within subjects and within regions.

Means and ranges for the QCT bone density values are presented in Table 2. Overall, for the available implant sites, the highest readings were found for the coronal 1 mm of the rectangular implant areas, followed by the values for the coronal third. The readings for the middle third and the apical third were both lower and comparable. Large ranges of values were seen for all subdivisions of the rectangular implant areas.

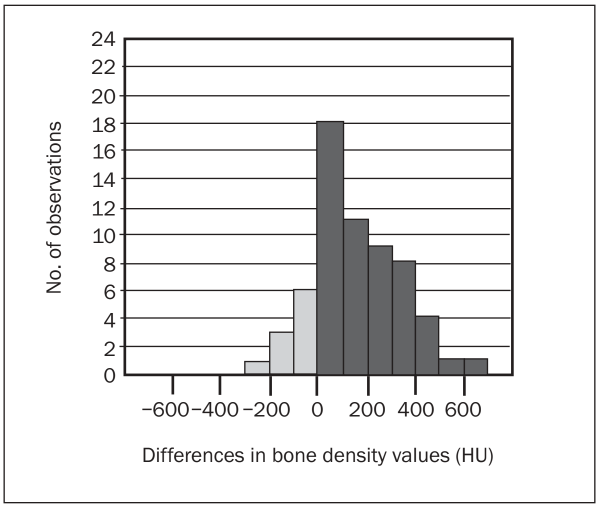
ANOVA demonstrated statistically significant effects of both subject and region of the jaws on the QCT bone density for all subdivisions of the rectangular implant areas, for both mesial and distal images. Together, subject and region of the jaws accounted for 55% to 78% of the variance for these different density values.

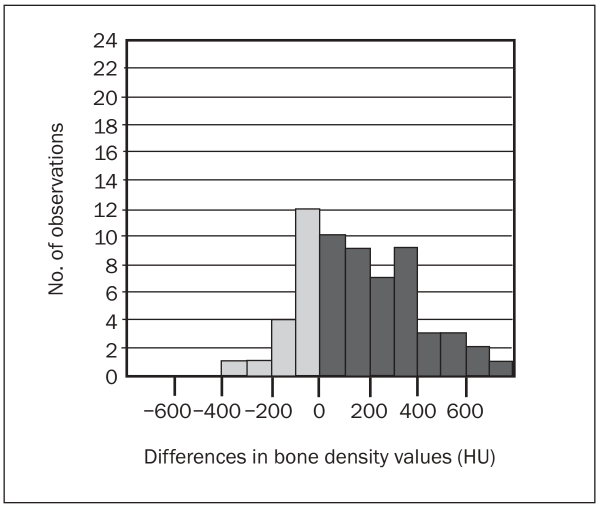
### Comparison of QCT Bone Density Between Mesial and Distal Implant Area Images

Frequencies of deviations of bone density values between mesial and distal images for the various subdivisions of the rectangular implant areas are presented in Table 3. For the coronal third, middle third, and apical third, differences of more than 200 HU were observed for 14% to 19% of the implant sites (Fig 5). Differences of 400 to 499 HU were seen for 2% to 3% of the sites.

### Comparison of QCT Bone Density Within Each Implant Area Image

Frequency distributions of the differences of the bone density values between the various subdivisions of the rectangular implant areas for the distal images are presented in Fig 6. The values were often higher in the coronal third than in the middle



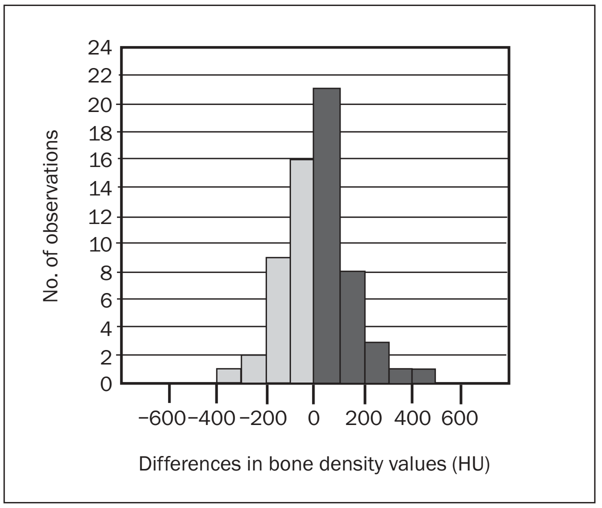




**Figs 6a to 6c** Frequency distributions of the differences of the bone density values in Hounsfield units between the various subdivisions of the rectangular implant areas for the distal images. Dark gray bars indicate positive differences; light gray bars indicate negative differences.

**Fig 6a** *(Above left)* Coronal third versus middle third.

**Fig 6b** *(Above right)* Coronal third versus apical third.

**Fig 6c** *(Right)* Middle third versus apical third.




and apical thirds, with deviations in HU sometimes amounting to several hundred units. In some instances, however, the values were notably lower in the coronal third than in the middle and apical thirds (Fig 3). Although the variations in values were smaller when comparing the middle and apical thirds, differences of several hundred HU were also observed between these subdivisions. The results for the mesial images (not shown) corresponded to those for the distal images.

### Reproducibility of Subjective Scoring

The repeat ratings by the examiners using the Lekholm and Zarb classification indicated excellent reproducibility, as demonstrated by intraclass coefficients of correlation of 0.96 and 0.93 for examiners 1 and 2, respectively.

### Correlation Between QCT Bone Density and Subjective Scoring

Statistically significant coefficients of correlation amounting to 0.7 and 0.7 (examiner 1) and 0.5 and 0.6 (examiner 2) were observed for the relationships between the QCT bone density values and the Lekholm and Zarb classification for mesial and distal images, respectively. Although overall relationships were observed, wide ranges of Hounsfield units were present within each of the 4 Lekholm and Zarb classes, particularly for the ratings used most frequently (ie, bone densities types 2 and 3). A scatter plot to illustrate this is presented in Fig 7.

Examples of individual images together with the recorded Hounsfield units and Lekholm and Zarb classifications are provided in Figs 2 to 5.

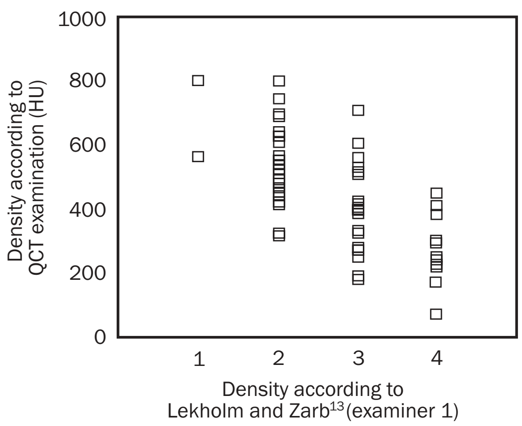



**Fig 7** Scatter plot illustrating the relationship between the QCT bone density values in Hounsfield units and the Lekholm and Zarb ratings by examiner 1 for distal images (Spearman's rho = 0.7, n = 62).

## DISCUSSION

Preoperative evaluation of bone density is essential to assist the clinician with the treatment planning of implant therapy. Accurate information on bone density will help the surgeon identify suitable implant sites, thereby improving the success rate of the procedures. To obtain this preoperative knowledge, adequate radiographic examination is required. This study was designed to assess bone density from CT images.

Postmortem material (cadaver), kept in 4% formalin, was used. Cadavers were chosen because this is part of a continuing investigation using the same specimens that will evaluate various methods to assess bone density, which finally will include histologic examination. It is understood that the findings from such a series of studies in cadavers may not correspond to those observed in living jawbone. However, studies measuring the resistance to reverse torque forces on implants placed in cadaver versus fresh bone have reported comparable results.[22,23]

The availability of cadavers was limited, especially since edentulous sites with sufficient bone volume were sought. This resulted in an uneven distribution of designated implant sites in this material. Therefore, bone density data obtained from various regions of the jaws may not be fully representative. Nevertheless, comparisons of bone density determinations within the available material should be meaningful.

QCT is an established method for measurement of bone mineral density and provides quantitative data of trabecular and cortical bone.[19,20] It allows precise 3-dimensional anatomic localizations and furnishes direct density measurements, expressed in Hounsfield units. The units are based on a linear scale defined only by 2 points: the attenuation of dry air, set at –1,000 HU, and the attenuation of pure water at 25ºC, set at 0 HU. Cortical bone may show HU values in the range +1,000 to +1,600. Trabecular bone shows lower HU values. Negative readings might indicate that the trabecular bone has been mostly replaced by fat. Few studies have reported on the use of QCT relating to oral implants.[21,24]

As this research plan includes placement of 4.0×10.0-mm implants in designated sites, a rectangular area of 4.1×10.5 mm was chosen as the region of interest (the closest fit to the size of the implants, including immediate adjacent areas, that could be mapped out with the available software). As mentioned, the positioning of the rectangle was guided by the direction of the aluminum rod as observed from the adjacent images, and by the desire to have the entire impending implant placed in bone without exposure of implant threads. This meant that in many sites, because of the anatomy of the ridge, the superior aspect of a dense crest was not included in the areas to be measured. This is a reflection of what may happen in a clinical setting, as in many instances the superior part of a peaked bone crest may be removed during osteotomy to avoid having exposed implant threads.

As expected, the highest mean value for bone density was found for the coronal 1 mm of the rectangular implant areas, followed by the value for the coronal third. Still, the values obtained for these subdivisions were generally lower than 1,000 HU, indicating that dense cortical bone was seldom encountered. This could be explained by the fact that available cadavers may represent elderly people with osteoporotic changes and a high proportion of fat marrow.

Comparisons of bone density values between mesial and distal images (2 to 3 mm apart) also revealed frequent deviations amounting to several hundred HU. Bone density values from the coronal, middle, and apical thirds of the rectangular implant area revealed that differences of values amounting to several hundred HU often occurred between these subdivisions. Sometimes these differences occurred in an unexpected direction; for example, the values were lower for the coronal third than for the middle and apical thirds. These variations, observed within designated implant sites, emphasize the importance of use of radiographic methods prior to implant placement, which allow topographically precise assessments of bone density in the region of interest. In addition, it would seem prudent to explore as much of the recipient site as possible to allow selection of the most promising bone density.

The objective QCT bone density readings were compared to the subjective scoring system proposed by Lekholm and Zarb,[13] as was accomplished by Norton and Gamble.[21] Originally, this classification, using 4 degrees of bone density, was based on radiographic evaluation. Over the years, it appears that the classification has been modified to also include the tactile sensation as perceived during drilling. The original radiographic classification was used and applied to the designated implant sites. Although overall relationships were observed, wide ranges of Hounsfield values were present within each of the 4 Lekholm and Zarb classes, particularly for the ratings used most frequently, bone densities types 2 and 3. These same findings were made by Norton and Gamble.[21] This may be a reflection of the limitations of a subjective system for bone density assessment. It would seem that access to objective, radiographic bone density values should constitute a valuable supplement to subjective assessments prior to implant placement. This was pointed out by Norton and Gamble,[21] who appropriately added that CT is hampered by the high doses of radiation needed.

In the next proposed study of this series, using these same specimens, the authors will investigate whether QCT using a newly developed scanner that requires considerably less radiation can be used to provide comparable objective bone density values.

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