Assessment of Human Alveolar Bone Density by Using Volumetric CT Machine

Prasit Aranyarachkul

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Assessment of Human Alveolar Bone Density
by Using Volumetric CT Machine

by

Prasit Aranyarachkul

A Thesis submitted in partial satisfaction
of the requirements for the degree of
Master of Science in Periodontics

December 2002
Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

Max Crigger, Professor of Periodontics

Joseph Caruso, Associate Professor of Orthodontics

Eloy Schultz, Professor of Radiology
ACKNOWLEDGEMENTS

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ABSTRACT OF THE THESIS

Assessment of Human Alveolar Bone Density by Using Volumetric CT Machine

by

Prasit Aranyarachkul

Master of Science, Graduate Program in Periodontics
Loma Linda University, December 2002
Dr. Max Crigger, Chairperson

This study evaluated bone density in designated implants sites using cone-beam computed tomography (CBCT) and compared the measurements to those of quantitative computed tomography (QCT) and subjective bone density evaluation. Sixty-two designated implant sites in 9 human cadavers jaws were used. Indicator rods, 2 mm in diameter, were placed in all sites. CT images representing 1 mm bucco-lingual slices immediately mesial and distal to the rods were selected for density evaluations. Bone density in Hounsfield units (HU) was assessed in a standardized implant area superimposed on the images, and also subjectively evaluated by 2 independent examiners using the Lekholm & Zarb (1985) classification. Density measurements in HU in most of the areas, except for mesial middle third, of CBCT were comparable to those of QCT with Intraclass Correlation Coefficient values more than 0.8. When CBCT measurements were related statistically to CBCT subjective reading, there was a moderate association interpreted by Spearmans rho value 0.5. However, there was a low agreement of intra-machine and inter-machine subjective readings with Kappa statistics value 0.32 and 0.36, respectively. Reproducibility of subjective scoring by Lekholm and Zarb Classification of images from CBCT is not statistically different (P > 0.05) from that of images from QCT.
This cone-beam CT machine could be considered as a new modality of diagnostic tool in dental treatment, especially when bone density values are important.
INTRODUCTION

The long-term clinical success of dental implants is reportedly influenced by both the quantity and quality of available bone.\textsuperscript{1-5} Bone structure quality varies from site to site, and from patient to patient. Accurate pre-operative evaluation of bone quality is essential to assist the clinician with the treatment planning stages of implant therapy. Clinical reports have indicated a higher survival rate of dental implants in the lower jaw, which have been ascribed to better bone quality and quantity existing in the anterior mandible.\textsuperscript{4-12}

Evaluation of bone density is essential to assist the clinician prior to implant placement. Classification systems for osseous evaluation have been introduced. Lekholm and Zarb\textsuperscript{13} classified bone density radiographically into 4 types based on the amount of cortical vs trabecular bone demonstrated. Type 1 bone is “almost comprised of 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\textsuperscript{14} related bone density to the clinical hardness of the bone as perceived during drilling prior to implant insertion. He expressed the hardness in terms of different materials. 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\textsuperscript{15} in a similar model relying on the tactile sensation during drilling found that bone quality types 1 and 4 occurred less frequently than types 2 and 3. Although variation 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\textsuperscript{16} related the Misch\textsuperscript{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 overlapping densities.

QCT is an established method for measurement of bone mineral density and provides quantitative data of trabecular and cortical bone.\textsuperscript{17,18} It allows precise 3-dimensional anatomic localizations and furnishes direct density measurements, expressed in Hounsfield units (HU). The units are based on a linear scale defined only by two points; the attenuation of dry air set at -1,000 HU, and the attenuation of pure water at 25° C set at 0 HU. Cortical bone may show HU values in the range (+) 1,000-1,600. Trabecular bone shows lower HU values. Negative readings might indicate that the trabecular bone is mostly replaced by fat. Few studies have reported on the use of QCT relating to oral implants.\textsuperscript{19,20}

Computed tomography is routinely employed in the diagnosis and treatment planning of dental and maxillo-facial structures, with particular reference to dental implant surgery.\textsuperscript{21-25} Special application software allows attainment by reformating two-dimensional images perpendicular to the dental arch and panoramic views of the dental arch as well as three-dimensional views. However, the cost and complexity of these machines, along with the relatively higher dose absorbed by the patient, limit the use of
this modality. In addition, the amount of radiation delivered to the patient for each QCT scan is 3 mGy\(^1\), an amount that precludes the practice of repeated surveys.

A new type of computed tomography machine devoted to the imaging of dental and maxillo-facial structures has been introduced. The new machine uses a cone-shaped X-ray beam centered on an X-ray area detector (cone-beam technique or CBCT)\(^{26-28}\). With this machine, the volume data can be acquired in a single rotation of the beam and sensor. The technique seems to be very promising due to inherent quickness in volumetric acquisition and to high efficiency in X-ray use. The amount of radiation absorbed by the patient for each CBCT scan is 0.62 mGy.\(^2\) The machine is less expensive and has a higher resolution in an axial plane than a conventional CT system. Potential disadvantages are; however, the scattered radiation\(^2\) and the limited dynamic range of the X-ray area detectors, based on the presently employed image intensifier tube and TV chain. This specific problem is not unique to the CBCT method as image intensifiers have also low diameters as regards CT applications; thus, “truncated-view” artifacts also occur\(^3\).

The aim of the study was to assess bone quality of human cadaver specimens using standard computerized (QCT) and cone-beam computed tomography (CBCT). Replicate measurements of the same bone tissues allowed mathematical and clinically relevant comparisons. Moreover, the aim was to determine if the cone-beam computed tomography can discriminate density variations to apply clinically. For this, the results with the NewTom will be compared with the results of the same specimens obtained by the well established, strictly linear density based principle of conventional computed tomography.
MATERIALS AND METHODS

Specimens

Specimens used were suitable partially or completely edentulous maxillary and mandibular human cadavers jaws, fixed in formalin, from the Division of Human Anatomy at Loma Linda University. An attempt was made to retrieve specimens with potential implant sites representing all regions of the jaws. A total of 64 implant sites distributed among 36 specimen blocks from 9 skulls 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 3.75 x 10 mm fixtures.

Preparation for CT scanning

A cubic, plexiglass box with dimensions 22 x 22 x 20 cm was assembled and fitted with 6 plexiglass shelves, 0.9 cm thick and separated from one another by a distance of 1.6 cm (Acrylite, Cyro Industries, Rockaway, NJ, USA). Six specimen blocks were placed on each shelf. Each block was positioned in a window (hole) cut out in the shelf, large enough to accommodate the block, and secured with orthodontic resin (Bosworth Co, Stokie, IL, USA). The mesio-distal axis of the alveolar blocks was oriented horizontally, parallel to the shelves, and also parallel to the lateral walls of the box, and the apico-coronal axis of the blocks was orientated vertically. Maxillary and mandibular blocks were both mounted with the alveolar bone crest facing the top of the plexiglass box. The orientation of the specimen blocks was governed by the desire to have all 64 positioning indicator rods and impending implant fixtures being aligned parallel to each other in both mesio-distal and bucco-lingual dimensions. The spatial
positioning of the specimen blocks on the 6 shelves throughout the box was made in a manner to minimize and equalize attenuation of adjacent bones, thereby providing the most accurate density readings. For this, the specimen blocks were spread at 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 2-4 mm coronal to the bony crest. A 2 mm diameter twist drill guided by a paralleling device was used.

The specimen holding device was modified to fit the specificities dictated by the three dimensional computerized machine. Each shelf with its specimen blocks was cut in half, as a consequence, each half contained one row of 3 specimen blocks (Fig 1, page 10). Then, each half of shelf with 3 specimen blocks was put in plastic container 14 cm diameter and 27 cm high filled with formalin. In order to position the shelf towards the center of the container, the shelf was sat over a plexiglass table 20 x 8.5 x 0.9 cm with 4 small legs 2.5 x 1.2 x 0.9 cm (Fig 2, page 11), (Fig 3, page 12). Then, each container was placed in a vacuum chamber for 30 minutes to remove air bubbles, as trapped air would incorporate errors in the density evaluation.

Acquisition of NewTom images and bone density evaluation

Each container containing specimens was placed on the NewTom table in a position so the specimen blocks were parallel to the axis of the table. The slices to be obtained were perpendicular to this axis and parallel to the indicator rods. Alveolar bone density within the edentulous areas of the jaws were scanned by the NewTom. The
regions of interest were the areas 1 mm immediately mesial and distal to the indicator rods.

The data was then transferred to an AGFA PACS (picture archiving communication system) (Impax DS 3000 Version 4.1 SP2; AGFA, Ridgefield Park, NJ, USA) for easy access and analysis. The images were sequentially examined to identify each of the 64 aluminum rod indicators. For each of the sites, an image representing a 1 mm bucco-lingual slice immediately mesial to the rod and an image representing a 1 mm bucco-lingual 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, 1 mm wide, and separated by 2 mm (the diameter of the aluminum rod). Often, however, depending on the position of the rods within the box in relation to the cross section images obtained throughout the box, the aluminum rods would be seen on 3 sequential slice images. This means that the adjacent mesial and distal images selected for analysis were occasionally separated by 3 mm.

Bone density measurements

The selected 128 images mesial and distal to the aluminum rods were analyzed using the Impax software systems. This software includes an application to map the bone within a defined area, and to provide the average bone density within this area in Hounsfield units (HU). A rectangular area, 4.1 mm x 10.5 mm, was first mapped onto each image and placed over the image in a position where the impending implant would be inserted. The positioning of the rectangle was guided by 1) the direction of the aluminum rod as observed from the adjacent image, and 2) the desire to have the entire
impending implant inserted in bone without exposure of implant threads. Bone density readings were then obtained from 3 equal portions of the 4.1 x 10.5 mm rectangular area: a coronal 1/3, a middle 1/3 and an apical 1/3, each 4.1 x 3.5 mm. In addition, a reading of the top 1 mm layer of the coronal 1/3 portion was accomplished. Moreover, 20 images were randomly selected for repeat readings to check reproducibility of CBCT machine.

Subjective bone density evaluation

Prints using 1.5 x magnification were obtained for each of the selected images mesial and distal to the aluminum rods used for the measurements. Two independent examiners with extensive clinical dental implant experience rated the bone density of these images for the designated implant sites.

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

*Comparison of bone density between QCT and CBCT.* All bone density measurements in Hounsfield units (HU) of CBCT were compared to those of QCT by using Intraclass Correlation Coefficient. First, the data was graphed in descending order according to QCT values for each vertical area and mesial or distal slice. Then, CBCT readings from the same specimens were matched to those of QCT readings. To measure the correlation of the readings between the two machines, Intraclass Correlation
Coefficient was then applied. Moreover, Spearmans rho was applied to determine the relation between two lines: one line represented every reading of QCT, another estimated most of the readings of CBCT.

**Correlation between CBCT bone density (HU) and CBCT subjective readings.** Mean bone density of mesial and distal part of each specimen was calculated. Mean mesial bone density of each specimen was calculated from bone density of mesial coronal 1/3, middle 1/3, and apical 1/3. Also, mean distal bone of each specimen was calculated from bone density of distal coronal 1/3, middle 1/3, and apical 1/3. The relationship between CBCT bone density values and the Lekholm and Zarb ratings was determined by Spearmans rho. For these correlation, the average CBCT value for the entire implant area was used. The relationship between CBCT bone density values in each separate area: coronal third, middle third, and apical third area, and the subjective readings were also studied.

**Comparison of CBCT subjective readings between two examiners.** Cross-tabulation listed numbers of accordance in each category of Lekholm and Zarb classification between two examiners performing CBCT readings from the same sites. Kappa statistics was then used to measure the agreement between the two readings.

**Comparison of subjective readings between QCT and CBCT.** Cross-tabulation listed numbers of accordance in each category of Lekholm and Zarb classification between subjective readings of QCT and CBCT from the same sites. Kappa statistics was then used to measure the agreement between the two readings.

**Comparison of reproducibility between QCT and CBCT subjective scoring.** The results of repeat classification using the Lekholm and Zarb system of 20 images from
QCT were collected from previous study. The results of repeat classification of the same 20 images from CBCT were also collected. Sign-test was used to compare the reproducibility between subjective scoring of these 2 machines.
Fig 1. A Plexiglass shelf displaying 3 specimens.
Fig 2. A plexiglass table 20 x 8.5 x 0.9 cm.
Fig 3. A plastic container filled with a plexiglass table and a shelf of bone specimens.
RESULTS

CBCT bone density

Examples of individual images with Lekholm and Zarb Classification are provided in Fig 4-7 (page 18-21). When 20 scans were repeated to test for reproducibility, the intraclass correlation coefficient for absolute agreement was 0.99.

The means, standard deviations, and ranges for the differences between mesial and distal scans and between subdivisions are reported in Table 1 (page 16). Mesial scans were consistently and significantly denser than those values obtained from sites located 2-3 millimeters distal. These differences ranged from 16 to 112 HU, averaging 76 HU. In spite of the magnitude of difference, the correlation for the total recipient site was 0.98. The subdivision demonstrating the highest density was the coronal 1 mm followed in order by coronal, middle and apical thirds. The magnitude of mean differences between subdivisions approximated 100 HU with substantial standard deviations.

Comparison of bone density (HU) between QCT and CBCT

Assuming that standard computerized tomography is the gold standard for graded bone radiopacity, QCT and CBCT bone density values were plotted separately for mesial and distal, coronal to apical subdivision according to descending QCT HU values (Fig 8-15, page22-25). The NewTom CBCT device produced bone density values that were generally higher than those recorded with the QCT machine. The magnitude of these differences ranged from -148 to +397. The mean differences were 133.6 HU ± 96.0 for the 4.1 x 10 mm mesial scan and 93.7 ± 75.8 HU for the total distal scan. The largest
average difference was found in the mesial mid 1/3 subdivision, amounting to as much as 212.1 HU, and as little as 15.4 HU in the distal coronal 1 mm.

Intraclass correlation coefficient values comparing bone density derived with QCT versus the CBCT machine for the four vertical areas from the mesial and distal slices ranged from 0.73 to 0.99 (Table 2, page 16). The coronal one millimeter sites were most consistent followed by the coronal third, apical third and least consistent in the middle third area. The data was graphed in descending order according to QCT values for each vertical area and mesial or distal slice (Fig 8-15, page 22-25).

Correlation between CBCT bone density (HU) and CBCT subjective readings

A scatter plot illustrated the relationship between the CBCT bone density values in Hounsfield units and the Lekholm and Zarb subjective ratings for all 4.1 mm x 10.5 mm images (Fig 16, page 26). Only three of the 127 slices were judged as type 1 bone ("homogenous compact bone"). The three densities were between 701 and 921 HU. The range of HU for the corresponding subjective bone types 2, 3, and 4 were 364-939, 143-907, and 140-758 respectively. Although the mean values of the respective subjective groups were aligned almost in linear descending relationship, a large standard deviation explains the overlap seen between groups. Not surprisingly, type 1 and type 4 bone images were clearly separate. In addition, the bottom range reported for type 2 bone was 364 HU, a magnitude difference of 221 HU from the bottom range of 143 HU reported for type 3 bone. In a similar manner, the top of the range for type 3 bone was 907 HU, a 149 HU difference from the 758 HU upper boundary for type 4 bone. A coefficient of
correlation amounting to 0.5 was observed for the relationship between CBCT bone density (HU) and the Lekholm and Zarb classification for all images.

When bone density values in separate areas were studied, Spearmans rho values were highest in the coronal third, apical third and least in the middle third area (Fig 17 – Fig 19, page 27-29)

Comparison of CBCT subjective readings between two examiners

The comparison for subjective readings of CBCT images between two examiners was reported in Table 3 (page 17). The agreement in subjectively grouping bone types was 55 percent. Of the 54 images not classed in agreement, only 3 were separated by 2 bone groups. Sixty-three percent of the disagreements were found between type 2 and 3 bone groupings. An agreement K-value of 0.32 was found.

Comparison of subjective readings between QCT and CBCT

When the Lekholm and Zarb subjective bone type readings of CBCT and QCT images were compared, an agreement of 57 percent was recorded (Table 4, page 17). Only 4 of the readings were separated by 2 bone groups. The inter-machine K-value was 0.36. There was no statistically significant difference between reproducibility of QCT and CBCT subjective scoring.

Comparison of reproducibility between QCT and CBCT subjective scoring

Sign-test showed p-value > 0.05. Therefore, there was no statistically significant difference between reproducibility of QCT and CBCT subjective scoring.
Table 1. Bone density (HU) mean ± SD and Spearman’s rho for each mesial and distal subdivision and total 4.1 X 10 mm implant recipient site.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Mesial</th>
<th>Distal</th>
<th>Difference</th>
<th>rho</th>
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<td>651±231</td>
<td>72</td>
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<tr>
<td>Coronal 1/3</td>
<td>714±251</td>
<td>629±238</td>
<td>85</td>
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</tr>
<tr>
<td>Middle 1/3</td>
<td>633±226</td>
<td>521±218</td>
<td>112</td>
<td>0.93</td>
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<tr>
<td>Apical 1/3</td>
<td>537±214</td>
<td>521±191</td>
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<td>628±226</td>
<td>552±211</td>
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Table 2. Intraclass Correlation Coefficient values (ICC) and Spearman’s rho for QCT and CBCT.

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</table>

Table 3. Comparison of CBCT subjective readings between 2 examiners (by % of sites)

<table>
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<th>4</th>
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<td></td>
<td></td>
<td></td>
</tr>
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</tr>
<tr>
<td>Total</td>
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<td>44</td>
<td>33</td>
<td>17</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4. Comparison between QCT and CBCT subjective readings (by % of sites)
Fig 5. Image of a designated mandibular implant site (right molar area). This site was classified as Lekholm and Zarb type 2 bone density by both examiner 1 and 2.
Fig 6. Image of a designated mandibular implant site (right molar area). This site was classified as Lekholm and Zarb type 3 bone density by both examiner 1 and 2.
Fig 7. Image of a designated maxillary implant site (right molar area). This site was classified as Lekholm and Zarb type 4 bone density by both examiner 1 and 2.
Fig 8. Comparison of bone density (HU) between QCT and CBCT in mesial coronal 1 mm area.

Fig 9. Comparison of bone density (HU) between QCT and CBCT in mesial coronal third area.
Fig 10. Comparison of bone density (HU) between QCT and CBCT in mesial middle third area.

Fig 11. Comparison of bone density (HU) between QCT and CBCT in mesial apical third area.
**Distal C 1 mm**

![Graph](Distal C 1 mm graph)

- Distal C 1 mm (QCT)
- Distal C 1 mm (CBCT)
- Linear Distal C 1 mm (CBCT)

ICC = 0.99

Spearmans rho = 0.99

**Site**

Fig 12. Comparison of bone density (HU) between QCT and CBCT in distal coronal 1 mm area.

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**Distal C 1/3**

![Graph](Distal C 1/3 graph)

- Distal C 1/3 (QCT)
- Distal C 1/3 (CBCT)
- Linear Distal C 1/3 (CBCT)

ICC = 0.94

Spearmans rho = 0.95

**Site**

Fig 13. Comparison of bone density (HU) between QCT and CBCT in distal coronal third area.
Distal M 1/3

Fig 14. Comparison of bone density (HU) between QCT and CBCT in distal middle third area.

Distal A 1/3

Fig 15. Comparison of bone density (HU) between QCT and CBCT in distal apical third area.
Fig 16. A scatter plot to illustrate the relationship between the Mean CBCT bone density values in Hounsfield units and the Lekholm and Zarb ratings for all images (Spearman's rho = 0.5, N = 127). Mean ± standard deviation and ranges of CBCT bone density in Hounsfield units for each type of bone by Lekholm and Zarb Classification were also shown.
Fig 17. A scatter plot to illustrate the relationship between the CBCT bone density values in Hounsfield units of coronal third of specimens and the Lekholm and Zarb ratings for all images (Spearmans rho = 0.55, N = 127). Mean ± standard deviation and ranges of CBCT bone density in Hounsfield units for each type of bone by Lekholm and Zarb Classification were also shown.
Fig 18. A scatter plot to illustrate the relationship between the CBCT bone density values in Hounsfield units of middle third of specimens and the Lekholm and Zarb ratings for all images (Spearman’s rho = 0.3, N = 127). Mean ± standard deviation and ranges of CBCT bone density in Hounsfield units for each type of bone by Lekholm and Zarb Classification were also shown.
Fig 19. A scatter plot to illustrate the relationship between the CBCT bone density values in Hounsfield units of apical third of specimens and the Lekholm and Zarb ratings for all images (Spearman's rho = 0.4, N = 127). Mean ± standard deviation and ranges of CBCT bone density in Hounsfield units for each type of bone by Lekholm and Zarb Classification were also shown.
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 identifying 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 compare assessment of bone density from cone-beam computed tomography to that of conventional computed tomography.

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 evaluated various methods to assess bone density, which finally will include histologic examination. It should be kept in mind, that the findings from such a series of studies in cadavers may not correspond to those observed in a living jaw bone. Although no studies exist comparing computerized tomographic images of cadaver bone versus fresh bone, studies have made these comparisons for other purposes. Two such studies evaluated removal torque and insertion torque of endosseous implants in cadaver and fresh bone, reporting mixed outcome results. The availability of cadavers was limited, especially since edentulous sites with sufficient bone volumes were being sought. This resulted in an uneven distribution of subject age groups and designated implant sites. 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.

As our research plan included placement of 4.0 x 10.0 mm fixtures in designated implant sites, a rectangular area of 4.1 x 10.5 mm was chosen as the region of interest.
(the closest fit to the size of the fixtures, 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 was also guided by the desire to have the entire impending implant inserted in bone without exposure of implant threads. This meant that in many sites due to 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 the clinical setting, as in many instances the superior part of a peaked bone crest may be removed during osteotomy in order to optimize implant placement.

The consistency of capability to reproduce the CBCT scan values was very high, The intraclass correlation coefficient for absolute agreement was 0.99. This compares favorably to QCT methods. Bone density values decreased from the 1 mm closest to the alveolar ridge, to the coronal, middle and apical third subdivisions.

Intraclass Correlation Coefficient showed a favorable correlation of bone density in HU between QCT and CBCT machine in most of the areas, except for the mesial middle third area. Intraclass Correlation Coefficient values were consistently higher than 0.8. In spite of the strong correlation, the NewTom CBCT device produced bone density values that were generally higher than those recorded with the QCT machine. The question remains whether the QCT or the CBCT values are closer to the corresponding histologic bone density. This topic will be addressed in a future study relating both QCT and CBCT HU values or insertion torque testing and histologic analysis.

A recent study by Norton and Gamble (2001) established bone density in Hounsfield Units derived from spiral computed tomography images and related these
pictures to the subjective bone quality classification of Lekholm and Zarb. As is the case in the present study, Norton and Gamble reported wide ranges of Hounsfield values within each of the 4 Lekholm and Zarb classes, particular for the ratings used most frequently, bone densities types 2 and 3. 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. It must be noted that the present study did not classify bone density considering the whole piece of bone, but rather used the specific region of interest that would house the implant.

In keeping with the fairly strong correlation of the QCT and the CBCT readings, there was only a modest accuracy in relating bone densities in HU and the Lekholm and Zarb subjective groupings. Similarly, the agreement between the two examiners performing CBCT subjective readings, i.e. intra-machine agreement of subjective readings was also guarded, with Kappa statistics value 0.32 (Kappa value higher than 0.4 indicates a good agreement). Most of sites with disagreement were found in bone type 2 and 3 (Table 3 and 4, page 17). This was in accordance with the study by Trisi and Rao16. They related the Misch14 classification of tactile sensation during drilling to histomorphometric bone density determinations using human trephine core biopsies. They found that the D1 and D4 classes had the highest and lowest histomorphometric density respectively, while D2 and D3 presented overlapping densities.

Sign-test comparing reproducibility between QCT to CBCT subjective scoring showed p-value more than 0.05. This indicated, for better or worse, that images from CBCT could be read as reproducibly as those from QCT.
The risk of radiation exposure is a problem with the conventional computed tomography. Radiation dosage from CT reached 3 mGy, which was much greater than that from panoramic radiographs. In contrast, skin dose of radiation using the CBCT was only 0.62 mGy similar to panoramic radiographs. In panoramic radiographs, the absorbed doses in the skin, the parotid gland, and the thyroid gland were 0.6 mGy, 0.6 mGy, and 0.12 mGy, respectively. In full-mouth X-rays, skin dose was estimated at 3 mGy. The absorbed doses to the parotid gland and the thyroid gland were 3.2 mGy and 0.14 mGy, respectively.

In conclusion, 1) cone-beam computed tomography could be considered as an alternative standard diagnostic tool, especially for implant pre-operative purpose, 2) the image quality appears sufficient for the specific diagnostic needs, 3) the scan time is very short and consequently the absorbed radiation dose is significantly low. These features, added to the cheaper cost of CBCT, make it suitable to be used as a diagnostic tool. Final judgment regarding the accuracy of the CBCT device must await the result of the histologic comparisons.
REFERENCES


