Comparison of Gray Values of Cone-beam Computed Tomography with Hounsfield Units of Multislice Computed Tomography: An In vitro Study

Abstract

Purpose: Hounsfield unit (HU) provides a quantitative evaluation of bone density. The assessment of bone density is essential for successful treatment plan. Although, multislice computed tomography (MSCT) is considered as gold standard in evaluating bone density, cone-beam computed tomography (CBCT) is frequently used in dentomaxillofacial imaging due to lower radiation dose, less complex device, and images with satisfactory resolution. Aims and Objectives: The aim of this study is to determine and compare the gray value and HU value of hypodense and hyperdense structures on CBCT and MSCT, respectively. The study also evaluated and compared the gray values in different fields of view within CBCT. Materials and Methods: A total of 20 dry human mandibles were obtained. The gray values and HU values of hypodense structures (extraction socket, inferior alveolar canal, and mental foramen) and hyperdense structures (enamel, cancellous, and cortical bone) were evaluated and compared between CBCT and MSCT images, respectively. The obtained data were statistically analyzed. Statistical Analysis: One-way analyses of variance, ANOVA F-test. Results: The gray value for hypodense structures in large volume CBCT scans resembled the HU value. The study showed statistically significant difference (P < 0.001) in gray values for all the hyperdense structures in CBCT when compared to HU values of MSCT scans. Conclusion: The gray value for hypodense structures in large volume CBCT scan was more reliable and analogous to HU value in MSCT. The determination of grey values in CBCT may not be as accurate as HU value in CT for hyperdense structures.

Keywords: Computed tomography, cone beam computed tomography, field of view, Hounsfield units

Introduction

Imaging is the key investigative tool for many diseases in diagnostic medicine. The development of three-dimensional (3D) imaging has revolutionized diagnosis in Radiology.[1,2] The emergence of multislice computed tomography (MSCT) has pronounced clinical impact, as it captures images rapidly and simultaneously. MSCT is an established system in dentomaxillofacial diagnosis and in assessment of bone density. The evaluation of bone quality is critical for successful treatment plan. Hounsfield units (HU) or CT number provides a quantitative assessment of bone density. HU is the ability to attenuate an X-ray beam and it considered as a standard scheme for scaling the reconstructed attenuation coefficients of CT.[3-5] However, CT cannot be used in routine diagnosis due to its limitations.[6]

The advent of cone-beam computed tomography (CBCT) in maxillofacial imaging is increasingly replacing MSCT for evaluating mineralized structures as CBCT images are of adequate quality with lower radiation dose. In addition, CBCT has reduced cost and limited volume scanning of structures.[4] However, there is no consensus regarding the accuracy of HU in CBCT images for determining bone density. This may be because of scattered radiation and enhancing noise in reconstructed images.[4,5] CBCT does not have a standard system for scaling the gray levels representing the reconstructed values.[4]

The current data on HU in CBCT volumes are limited and there is an acknowledgment that a deficiency exists with CBCT systems that they do not correctly display HU. However, there has been little research conducted to overcome the drawbacks.[4,5]

With this background to understand this knowledge gap, the study was conducted to determine the gray values of hypodense and hyperdense structures on CBCT and MSCT images rapidly and simultaneously.
hyperdense anatomical structures of mandible and compare with the HU values of MSCT. The study also evaluated the gray values among the different field of views (FOVs) within CBCT.

Materials and Methods

Institutional ethical clearance was obtained. Unbroken, intact twenty dry human mandibles were procured for the study. They were sequentially numbered from 1 to 20. Gutta-percha cones as radio opaque marker were placed in the molar region running from buccal to lingual side on each mandible. It was secured with the help of the tape; was used to identify the image slicing. Three-hyperdense areas of enamel, cortical, and cancellous bones and hypodense areas of mental foramen, inferior alveolar canal and extraction socket within the mandible were evaluated. The images were obtained in DICOM format.

The mandibles were mounted in the standard recommended position [Figure 1]. Initially CT images of all 20 mandibles were acquired with MSCT scanner (Asteion, Toshiba Medical Systems, Tokyo, Japan) at an exposure of 120 kV, 100 mA and 0.5 s. The MSCT images were evaluated using Sienet magic view 300 DICOM software [Figure 2].

Following this, CBCT scans were obtained using Planmeca Promax 3D Max, CBCT unit. 3D imaging data were acquired at 100 kV, 10 mA and 9.6 s for a 360° rotation. CBCT images of the mandibles were obtained in all three FOV; the width and height were 55 mm × 50 mm, 100 mm × 90 mm and 160 mm × 130 mm. CBCT images were analyzed using Romexis Viewer version 2.5.1 R (Promax 3D, MAX, M/s; Planmeca OY, Finland) [Figure 3]. The images corresponding to the gutta-percha marker in the axial section were considered the central image. HU for extraction socket was obtained by placing the cursor in the middle portion of the socket. The Inferior alveolar canal was obtained at the course of the canal in the molar region, mental foramen at the exit of the foramen. The HU for hyperdense structures were obtained by placing the cursor at the area of increased trabeculation for cancellous bone, outer portion of cortical plate for cortical bone and occlusal tip of the tooth for enamel. The mean, standard deviation, minimum and maximum values were calculated for all obtained gray values and HU values. One-way analyses of variance were used to test the difference between groups. When comparing more than two means, an ANOVA F-test was used.

Results

Comparison of gray values of cone-beam computed tomography with Hounsfield unit values of multislice computed tomography for hypodense and hyperdense structures

Table 1 shows a significant difference in radio density for extraction socket and Inferior alveolar canal between MSCT and CBCT images. However, the gray value resembled HU value for mental foramen. For all the hyperdense structures, there was significant difference in mean gray values of CBCT with HU values of MSCT.

Comparison of gray values of individual field of views in cone beam computed tomography with Hounsfield unit values of multislice computed tomography

Table 2 shows significant difference in gray values of inferior alveolar canal and extraction socket in small FOV.
Comparison of gray values for different field of views of cone-beam computed tomography images

The ANOVA F-test indicated that there was significant difference in gray values for all the three-hyperdense structures, extraction socket and mental foramen between different FOV’s of CBCT images (P < 0.001). However, the attenuation coefficient of Inferior alveolar canal had resemblance between different FOV’s of CBCT scans [Table 5].

Discussion

MSCT images are frequently used imaging modality to determine mineral density of craniofacial bone.[7] The introduction of dentomaxillofacial CBCT scanners is being used more frequently in the field of dentistry for several advantages.[3] However, bone density in terms of gray value on CBCT scanners vary widely.[5] Thus, this study was conducted to evaluate and compare the gray values on CBCT with HU values for hypodense and hyperdense structures.

HU in CT is proportional to degree of X-ray attenuation and it is assigned to each pixel in the image that represents the tissue density, whereas in CBCT the degree of X-ray attenuation is shown as gray scale (voxel value).[8] With MSCT, the values of X-ray tissue absorption can be accurately measured with a standard HU scale. HU in MSCT are considered as gold standard. The possible explanation for CT units being consistent in displaying HU could be due to the values of X-ray tissue absorption

(55 mm × 50 mm) on CBCT images; had no difference for mental foramen. The HU values differed for all hyperdense structures. Note Table 3 shows similar results for FOV (100 mm × 90 mm), CBCT scans on large FOV (160 mm × 130 mm) showed similarity in radio density for three hypodense structures whereas, hyperdense structures showed statistically significant difference between CBCT and MSCT [Table 4].

Table 1: Comparison between gray values of cone beam computed tomography with Hounsfield unit of multislice computed tomography

| Anatomical structures | Images | Mean    | SD     | Mean difference | SE difference | t      | P       |
|-----------------------|--------|---------|--------|----------------|---------------|--------|---------|
| Extraction socket     | CT     | −870.05 | 46.939 | −126.700       | 7.446         | −17.015| 0.001*  |
|                       | CBCT   | −743.35 | 19.749 |                |               |        |         |
| Inferior alveolar canal | CT    | −559.55 | 93.634 | 167.550        | 16.765        | 9.994  | 0.001*  |
|                       | CBCT   | −727.10 | 52.444 |                |               |        |         |
| Mental foramen        | CT     | −436.75 | 45.751 | 15.517         | 13.488        | 1.150  | 0.253   |
|                       | CBCT   | −452.27 | 54.162 |                |               |        |         |
| Cancellous bone       | CT     | 344.45  | 20.531 | −67.267        | 11.829        | −5.687 | 0.001*  |
|                       | CBCT   | 411.72  | 51.370 |                |               |        |         |
| Cortical bone         | CT     | 1828.50 | 60.421 | 229.283        | 29.906        | 7.667  | 0.001*  |
|                       | CBCT   | 1599.22 | 128.687|                |               |        |         |
| Enamel                | CT     | 2492.65 | 186.396| 725.067        | 33.424        | 21.693 | 0.001*  |
|                       | CBCT   | 1767.58 | 104.718|                |               |        |         |

*Statistically significant. CBCT=Cone-beam computed tomography, CT=Computed tomography, SD=Standard deviation, SE=Standard error

Table 2: Comparison of gray values of cone beam computed tomography in field of view of 55 and 50 mm with Hounsfield unit of multislice computed tomography

| Anatomical structures | Images | Mean    | SD     | t      | P       |
|-----------------------|--------|---------|--------|--------|---------|
| Extraction socket     | CT     | −870.05 | 46.939 | 134.634| <0.001*|
|                       | CBCT   | −736.65 | 20.982 |        |         |
| Inferior alveolar canal | CT    | −559.55 | 93.634 | 40.443 | <0.001*|
|                       | CBCT   | −707.50 | 45.359 |        |         |
| Mental foramen        | CT     | −436.75 | 45.751 | 6.255  | 0.017   |
|                       | CBCT   | −402.55 | 40.577 |        |         |
| Cancellous bone       | CT     | 344.45  | 20.531 | 20.624 | <0.001*|
|                       | CBCT   | 357.60  | 29.941 |        |         |
| Cortical bone         | CT     | 1828.50 | 60.421 | 209.210| <0.001*|
|                       | CBCT   | 1496.65 | 82.928 |        |         |
| Enamel                | CT     | 2492.65 | 186.396| 296.366| <0.001*|
|                       | CBCT   | 1694.25 | 90.961 |        |         |

*Statistically significant. CBCT=Cone-beam computed tomography, CT=Computed tomography, SD=Standard deviation

Table 3: Comparison of gray values of cone-beam computed tomography in field of view of 100 and 90 mm with Hounsfield unit of multislice computed tomography

| Anatomical structures | Images | Mean    | SD     | t      | P       |
|-----------------------|--------|---------|--------|--------|---------|
| Extraction socket     | CT     | −870.05 | 46.939 | 12.223 | <0.001*|
|                       | CBCT   | −737.20 | 16.691 |        |         |
| Inferior alveolar canal | CT    | −559.55 | 93.634 | 45.839 | <0.001*|
|                       | CBCT   | −717.40 | 45.871 |        |         |
| Mental foramen        | CT     | −436.75 | 45.751 | 2.510  | 0.121   |
|                       | CBCT   | −458.35 | 40.306 |        |         |
| Cancellous bone       | CT     | 344.45  | 20.531 | 106.927| <0.001*|
|                       | CBCT   | 409.65  | 19.329 |        |         |
| Cortical bone         | CT     | 1828.50 | 60.421 | 75.487 | <0.001*|
|                       | CBCT   | 1581.80 | 111.688|        |         |
| Enamel                | CT     | 2492.65 | 186.396| 256.958| <0.001*|
|                       | CBCT   | 1752.70 | 88.728 |        |         |

*Statistically significant. CBCT=Cone-beam computed tomography, CT=Computed tomography, SD=Standard deviation
being accurately measured with a standard HU scale. The calibration factor to calculate HU is based on the assumption that the total amount of X-ray passing through the object is unchanged even when seen from any of the 360° of the scan direction.\(^4\)\(^,\)\(^5\)\(^,\)\(^9\)

In conventional MSCT, scanning of maxillofacial region a large FOV encompassing the entire head is usual and the total volume of projection data is constant during a complete rotation for data acquisition.\(^9\) In the limited-volume CBCT imaging of a part of the dental arch and with a rotation of 360° for data acquisition, it is inevitable that the X-ray will change at various points in the scan. That is, the attenuation of the X-ray beam becomes maximized and minimized at various points in the scan. The effect of this phenomenon may be to reduce the overall density value in a limited imaging volume. In addition, there is significant use of lower effective energy in CBCT machines than medical CT.\(^7\)\(^,\)\(^8\)

The scattered radiation entering the two-dimensional detector in CBCT cannot be prevented when compared with MSCT. The later uses an anti-scatter grid. The resultant beam hardening effect, partial volume averaging, under sampling, cone-beam effect results in change in gray value in CBCT.\(^3\) In a presentation by Armstrong\(^9\) concluded that HU sampled from identical anatomic areas with CBCT and MDCT are not identical. Miles and Danforth\(^10\) concluded that CBCT gray levels are inaccurate to rely on for decisions on implant placement.

This study demonstrated that the bone densities for hyperdense structures in different FOV on CBCT showed significant difference. The difference in densities could be attributed to different FOV dimensions. The inconsistencies and discrepancies in gray values could be due to various reasons. X-ray beams are polychromatic in nature. The linear attenuation coefficient for the selected anatomical structure alters accordingly.\(^4\) Furthermore, at low kV and mA settings on CBCT machines, quantum noise interferes with estimation of actual gray level.\(^10\) This would contribute to possible inaccuracies in HU values from resulting gray value.

The reduced values of density in small FOV on CBCT scans could be due to the reduction in the diameter of X-ray beam irradiating the limited volume. This beam limitation may increase the penetration of X-rays by removing the low energy photons causing reduction in attenuation of

### Table 4: Comparison of Hounsfield unit between the 160 and 130 mm field of view of cone-beam computed tomography with multislice computed tomography

| Anatomical structures      | Images | Mean | SD  | t    | P     |
|----------------------------|--------|------|-----|------|-------|
| Extraction socket          | CT     | −870.05 | 46.939 | 10.474 | 0.018 |
|                           | CBCT   | −756.20 | 15.213 |       |       |
| Inferior alveolar canal    | CT     | −559.55 | 93.634 | 6.018  | 0.011 |
|                           | CBCT   | −756.40 | 54.515 |       |       |
| Mental foramen             | CT     | −436.75 | 45.751 | 2.291  | 0.008 |
|                           | CBCT   | −495.90 | 34.545 |       |       |
| Cancellous bone            | CT     | 344.45  | 20.531 | 325.662| <0.001*|
|                           | CBCT   | 467.90  | 22.681 |       |       |
| Cortical bone              | CT     | 1828.50 | 60.421 | 26.035 | <0.001*|
|                           | CBCT   | 1719.20 | 74.340 |       |       |
| Enamel                     | CT     | 2492.65 | 186.396| 210.348| <0.001*|
|                           | CBCT   | 1855.80 | 61.801 |       |       |

*Statistically significant. CBCT=Cone-beam computed tomography, CT=Computed tomography, SD=Standard deviation

### Table 5: Test of ANOVA to assess F value

| Anatomical structures      | Different FOV’s of CBCT (mm) | Mean   | SD    | F     | P     |
|----------------------------|------------------------------|--------|-------|-------|-------|
| Extraction socket          | 55 and 50                    | −736.65| 20.982| 7.824 | 0.001*|
|                           | 100 and 90                   | −737.20| 16.691|       |       |
|                           | 160 and 130                  | −756.20| 15.213|       |       |
| Inferior alveolar canal    | 55 and 50                    | −707.50| 45.359| 5.622 | 0.006 |
|                           | 100 and 90                   | −717.40| 45.871|       |       |
|                           | 160 and 130                  | −756.40| 54.515|       |       |
| Mental foramen             | 55 and 50                    | −402.55| 40.577| 29.652| <0.001*|
|                           | 100 and 90                   | −458.35| 40.306|       |       |
|                           | 160 and 130                  | −495.90| 34.545|       |       |
| Cancellous bone            | 55 and 50                    | 357.60 | 29.941| 102.373| <0.001*|
|                           | 100 and 90                   | 409.65 | 19.329|       |       |
|                           | 160 and 130                  | 467.90 | 22.681|       |       |
| Cortical bone              | 55 and 50                    | 1496.65| 82.928| 30.412| <0.001*|
|                           | 100 and 90                   | 1581.80| 111.688|       |       |
|                           | 160 and 130                  | 1719.20| 74.340|       |       |
| Enamel                     | 55 and 50                    | 1694.25| 90.961| 20.106| <0.001*|
|                           | 100 and 90                   | 1752.70| 88.728|       |       |
|                           | 160 and 130                  | 1855.80| 61.801|       |       |

*Statistically significant. FOV’s=Field of views, CBCT=Cone-beam computed tomography, SD=Standard deviation
X-rays and subsequently gray values. Another factor that may be related to the variability of HU values in CBCT is the position held by the region of interest within the FOV. The variability in density at various places of homogenous structures occurs, as the same object will be scanned repeatedly in different position within the FOV under same exposure condition and with more intensity.\textsuperscript{[11]}

In CBCT systems that are designed to scan a larger FOV with larger-sized detectors and a relatively high-energy X-ray generator, the influence of artifacts peculiar to limited-volume CBCT imaging might be small and application of HU is possible. With limited-volume CBCT imaging of a jaw with a rotation of 360° for data acquisition, inevitably the X-ray beam will pass through hard tissues outside the FOV.\textsuperscript{[11]} The mass present adjacent and outside the FOV can change the HU, that is dubbed as exo-mass effect.\textsuperscript{[12]} The variability of the gray values associated with the exo-mass may be explained by the projection data discontinuity. This is caused by the variation of the superimpositions of the nonhomogeneous and nonsymmetrical tissues outside the FOV along the rotation of the X-ray beam during image acquisition. Projection data discontinuity caused by this overlap might affect the density of the images.\textsuperscript{[11]}

Katsumata \textit{et al.}\textsuperscript{[11]} reported a significant variation of the gray values when objects of different mass were evaluated with different FOV’s, where the greater FOV provided the elimination of the exo-mass, resulting in less variability of the gray values. van Daatselaar \textit{et al.}\textsuperscript{[13]} suggested that maxillofacial hard tissue structures outside the reconstructed FOV may be the cause of certain artifacts. Ohnesorge \textit{et al.}\textsuperscript{[14]} described peripheral bright-band artifacts near the boundary of the scan FOV.

However, in our study one of the hypodense structures, mental foramen did not show any significant difference between CBCT and MSCT. This could be due to variation in anatomical structures and difference in attenuation of photons.\textsuperscript{[3]} The limitation of this study was use of human cadaver dry mandibles.

**Conclusion**

This study concludes that the larger volume CBCT scans yield more consistent HU values for all hypodense structures in comparison to MSCT. The gray values in CBCT may not be as accurate as HU value in CT, in determination of bone density. CBCT is recommended for its lower radiation dose and cost, compared with CT. Nevertheless, further studies and development of new software are required to analyze the gray values in CBCT to determine the bone density.

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**Conflicts of interest**

There are no conflicts of interest.

**References**

1. BouSerhal C, Jacobs R, Quirynen M, van Steenberghe D. Imaging technique selection for the preoperative planning of oral implants: A review of the literature. Clin Implant Dent Relat Res 2002;4:156-72.
2. Turkylmaz I, Tumer C, Ozbek EN, Tözüm TF. Relations between the bone density values from computerized tomography, and implant stability parameters: A clinical study of 230 regular platform implants. J Clin Periodontol 2007;34:716-22.
3. White SC, Pharaoh MJ. Oral Radiology, Principles and Interpretation: (1e) South Asia Edition. 7\textsuperscript{th} ed. New Delhi: Reed Elsevier; 2014.
4. Mah P, Reeves TE, McDavid WD. Deriving Hounsfield units using grey levels in cone beam computed tomography. Dentomaxillofac Radiol 2010;39:323-35.
5. Reeves TE, Mah P, McDavid WD. Deriving Hounsfield units using grey levels in cone beam CT: A clinical application. Dentomaxillofac Radiol 2012;41:500-8.
6. Fred HL. Drawbacks and limitations of computed tomography: Views from a medical educator. Tex Heart Inst J 2004;31:345-8.
7. Campos MJ, de Souza TS, Mota Júnior SL, Fraga MR, Vitalr RW. Bone mineral density in cone beam computed tomography: Only a few shades of gray. World J Radiol 2014;6:607-12.
8. Razi T, Niknami M, Alavi Ghazani F. Relationship between Hounsfield unit in CT scan and gray scale in CBCT. J Dent Res Dent Clin Dent Prospects 2014;8:107-10.
9. Armstrong RT. Acceptability of cone beam CT vs. multi-detector CT for 3D anatomic model construction. J Oral Maxillofac Surg 2006;64:37.
10. Miles DA, Danforth RA. A clinician’s guide to understanding cone beam volumetric imaging (CBVI). Peer Reviewed Publ Acad Dent Ther Stematol 2008;1:2-13.
11. Katsumata A, Hirukawa A, Okumura S, Naitoh M, Fujishita M, Ariji E, \textit{et al.} Effects of image artifacts on gray-value density in limited-volume cone-beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:829-36.
12. Bryant JA, Drage NA, Richmond S. Study of the scan uniformity from an i-CAT cone beam computed tomography dental imaging system. Dentomaxillofac Radiol 2008;37:365-74.
13. van Daatselaar AN, Dunn SM, Spoelder HJ, Germans DM, Renambot L, Bal HE, \textit{et al.} Feasibility of local CT of dental tissues. Dentomaxillofac Radiol 2003;32:173-80.
14. Ohnesorge B, Flohr T, Schwarz K, Heiken JP, Bae KT. Efficient correction for CT image artifacts caused by objects extending outside the scan field of view. Med Phys 2000;27:39-46.