Journal of Dentomaxillofacial Radiology, Pathology and Surgery

Autumn 2022, Volume 11, Number 4

Research Paper: New Formula for Calculating the Hounsfield Unit in CT Scan of Hard Tissue from Grey Scales in CBCT

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Citation: Ostovarrad F, Boroumand R, Masali S, Alizadeh Shuili A, Tabari-Khomeiran R. New Formula for Calculating the Hounsfield Unit in CT Scan of Hard Tissue from Grey Scales in CBCT. Journal of Dentomaxillofacial Radiology, Pathology and Surgery. 2022; 11(4):7-11. http://dx.doi.org/ http://3dj.gums.ac.ir

Article info
Received: 2022/10/05
Accepted: 2022/10/15

Keywords:
X-Rays
Cone-BeamComputed Tomography
tomography

ABSTRACT

Introduction: HU is a standard numbering system in CT, which is proportional to x-ray attenuation and an indicator of relative tissue density. In CBCT, the x-ray attenuation degree is demonstrated with the grayscale. The present study aimed to determine the correlation between the grayscale in CBCT and HU (Hounsfield Unit) in MDCT.

Materials and Methods: This descriptive-analytical study was approved under the ethics code of IR.GUMS.REC.1398.451. A human dry mandible was immersed in a transparent cylindrical container to simulate soft tissue attenuation. The sample was scanned at three separate imaging centers using three CBCT units with the same brand. The scans were carried out once with standard irradiation conditions and once with high-resolution conditions. The mandible was scanned with a CT scan unit. The grayscale and HU of the enamel, dentin, cortical, and spongy bone were evaluated and compared with each other. Pearson's correlation coefficient was used for data analysis at a significance level of 5% ($P<0.05$).

Results: In two standard and high-resolution conditions, there was a significant correlation ($P<0.001$) between the grayscale and HU. Given the positive values of the mean differences, it could be concluded that the gray level in CBCT has a positive correlation with HU in MDCT.

Conclusion: The grayscale in CBCT and HU in MDCT had a positive correlation, and according to this study, it is possible to calculate the HU from the gray level.

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Introduction

CBCT is a new imaging technique that eliminates superimpositions by producing detailed images of bone structures. Compared to MDCT, the CBCT system imposes a lower dose and cost on the patient, and the ease of access is one of its benefits.(1) CBCT has some shortcomings; it has limitations for imaging soft tissue details, and its Hounsfield Unit (HU) is not reliable compared to MDCT.(2) HU is a standard numbering system for body tissue density in MDCT. HU is the unit of measurement of X-ray attenuation assigned to each pixel.

HU is used to determine bone quality for implant insertion, implant stability, pathologic lesion evaluation, determine its nature, and evaluate airways.(3) Although CBCT shows a grade of x-ray attenuation with a voxel value (the gray scale), its number is varied in different types of CBCT units.(4) Previous studies have shown a correlation between HU in MDCT and the grayscale in CBCT.(5,6)

In MDCT, HU has a range of -1000 for air, +3000 for dental enamel, 0 for water, and +1000 for bone. These numbers show the differences in x-ray attenuation in tissues.(2,7,8) On the other hand, some studies have considered a grayscale range for bone from -1500 to +3000 in different tissues and reported it is not accurate in soft tissues.(8)

Detecting changes in bone density and hard tissues in radiographic images is very important because changes outside the normal range may indicate disease. A large number of studies have reported the existence of a relationship between Hounsfield Unit in CT and gray index in CBCT.(9) In 2017, in Shiraz, Khojaste pour et al.(7) conducted a comparative evaluation between Grer scale in intraoral digital radiographs and Hounsfield Unit in CT, the results of which indicated that there is a positive relationship between Hounsfield Unit and average Grey value. Also, Razi et al.(3) in 2014 investigated the relationship between Hounsfield Unit in CT and gray value in CBCT and showed that no significant difference was observed between gray scale in any of the three brands of CBCT and Hounsfield Unit obtained from CT.

Based on this, considering the lower dose and cost that CBCT systems impose on the patient, and considering the shortcomings and contradictions in relation to the relationship between Gray Scale in CBCT and Hounsfield Unit in CT and the gap in the Pixel value standard in CBCT of different devices, this study aimed to evaluate the relationship between the grey scale in CBCT and Hounsfield Unit in CT scan of hard tissues.

Materials and Methods

A dry human mandibular bone with all the needed anatomical features was used. It did not have any metal filling for avoiding metal artifacts. There was no pathologic condition in the mandible, and it had intact teeth.

To simulate the soft tissue around the bone, the mandibular bone was placed in a cylindrical container, measuring 19 cm in width and 15 cm in height, filled with water (Fig.1).(6)

Figure 1: Mandibular bone, placed in a cylindrical container, measuring 19 cm in width and 15 cm in height, filled with water

CBCT examinations were carried out with an Xmind Trium unit (ACTEON, Italy) in a private office. The CBCT images were acquired with two different standard qualities (mAs: 60, kVp: 90, mA: 10) and high resolution (mAs: 90, kVp: 90, mA: 10). OnDemand3D Dental (Cybermed, Seoul, Korea) software was used for data collection. Pixel size was set to 250 µm for all the scans. The reconstruction of images in the mandible cross-sections was performed with 2.5 steps in the areas of teeth 6, 7, and 8 on the left side of the mandible, and the gray scales of enamel, dentin, cortical bone, and spongy bone were measured.(Fig.2,3)

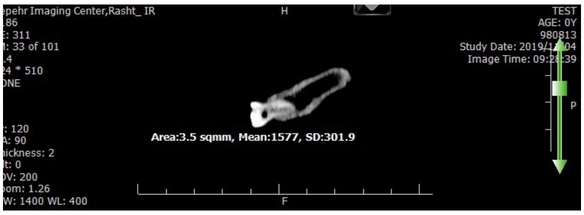

Figure 2: Measuring the Gray scales of dentin by Ondemand software


Figure 3: Measuring the Gray scales of cortical by Ondemand software

Afterward, MDCT scans were carried out with a helical 8-channel CT scanner (Ingenuity; GE Healthcare). The CT parameters included a slice thickness of 1.25 mm, a tube voltage of 140 kVp, a tube current of 300 mA, and the bone reconstruction algorithm (window width/window level of 2000/400). Two-dimensional reconstructions were obtained in the coronal and sagittal planes. The gray value and HU of specific points in mandible scans were evaluated by a maxillofacial radiologist.

In this study, the data collected from the samples were analyzed using SPSS 21.

In this study, descriptive statistics, such as central and dispersion indicators, were used to describe the samples. Then, Pearson's correlation test was used at a significance level of 5% ($P<0.05$).

It should be noted that normality of variance was studied with Kolmogorov-Smirnov, Shapiro-Wilk, and Levene's tests. To study the relationships between the research variables, Pearson's and Spearman's correlation tests were used for normal and abnormal cases, respectively.

According to the descriptive statistics of each device, 24 images of the dry mandible were prepared, 12 of which were of high resolution and 12 of which were of standard CBCT resolution. Each part's grayscale (enamel, dentin, cortical bone, and spongy bone) was measured in 18 points.

The HU of these points (enamel, dentin, cortical bone, and spongy bone) was measured with the MDCT unit.

Depending on the grayscale in CBCT and HU numbers in MDCT, there was a correlation between these numbers ($P<0.001$). An increase in grayscale number was associated with an increase in HU. The conducted linear equation for grayscale in CBCT and HU in MDCT is: $y=a\ \ e^{b/x}$

Spearman's correlation test was used to determine the correlation between the grayscale and HU in each CBCT unit, and the results are summarized in the Table below.

Discussion

Determining the changes in bone density and hard tissues is vital in radiographic images because it could indicate disease if it is out of the normal range. Early diagnosis is important for the patient's health. Diagnosis of bone density changes in all kinds of extraoral radiographs depends on the brightness and darkness of images, i.e., HU in the MDCT and grayscale in CBCT.(10)

Although CBCT can provide an accurate and subtle scale in millimeters at a shorter time and a lower dose, and it has a more reasonable price in comparison with MDCT, it has some limitations, like producing more scattered x-rays, noise, the heel effect, and beam hardening artifact, and it does not have real HU like MDCT.(11,5) Many studies have shown a correlation between HU in MDCT and grayscale in CBCT.(5,12) This study evaluated the correlation between the grayscale of CBCT and HU in dry human mandibles. In this research, three Acteon Xmind Trium CBCT units were used to evaluate the grayscale in six areas of enamel, dentin, cortical bone, and spongy bone. CBCT images were taken with two standard qualities: mAs: 60 kVp: 90, mA: 10, and mAs: 90, kVp: 90, mA: 10. Therefore, there were 36 images for evaluating the grayscale in CBCT. These 6 points of enamel, dentin, and cortical bone were also used for evaluating the HU in MDCT. The mean HU scale of MDCT for

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enamel, dentin, cortical bone, and spongy bone was 1469.75±692.98, and the mean grayscale of CBCT was 1390.03±838.52. This study showed a correlation between the grayscale of CBCT and the HU of MDCT (P<0.001). This correlation is positive; an increase in the grayscale is associated with an increase in HU.

Khojastepour et al (2017) compared the grayscale in intraoral digital radiography with HU in MDCT in Shiraz. In that study, a sheep's mandible whose soft tissue was reduced was used. The results showed a positive correlation between HU and meant grayscale, consistent with the present study.(7) Razi et al (2014) evaluated the relation between HU of MDCT and the grayscale of CBCT. In that evaluation, a sheep's head and three CBCT units (NewTom VG, Planmeca Promax, and Scanora Sordex), and a Somatom Sensation CT scan (Siemens Germany) were used. In that study, spongy and cortical bone, fat, muscle, cartilage, enamel, dentin, and sinus spaces were evaluated. The mean gray scales of CBCT units were 373±616, 353±619, and 341±633, and the mean of HU in MDCT was 407±685. Razi et al reported no significant differences in the gray scale between the three brands of CBCT units and HU of MDCT. There was a strong correlation between HU in MDCT and the grayscale in CBCT. Although Razi's results support our hypothesis, in this study, one brand of CBCT was used, and only hard tissue was evaluated, while Razi et al evaluated the hard and soft tissues, which explains the different results in the evaluated means of grayscale and HU.(3) Silva et al evaluated HU in MDCT and the grayscale in CBCT (Classic i-CAT scanner) in Brazil in 2012, reporting that the bone density evaluation by HU of CBCT units is not reliable, which is different from our study. The reason for this contrast can be the difference between brands of CBCT units and the method of studies.(2) Mah et al evaluated the correlation between the grayscale and HU of CBCT units. Mah et al used eight materials with different densities and components and carried out 11 CBCT and two MDCT scans. The materials were located in translucent acrylic phantoms and scanned under three conditions (dry, low, and a large amount of water). Furthermore, at last, the selected samples were placed in water to mimic the soft tissue. Their findings showed that the HU could approximately be determined by the gray level in CBCT, and it could be more accurate if the brand of units were the same as in this study.(9) Nackaert et al (2011) performed a study to compare the differences in intensity by computed tomography and cone-beam tomography. The study aimed to investigate the differences in the grayscale in CBCT imaging compared to the computed tomography (CT) units (also known as Hounsfield Units) to evaluate the reliability of CBCT in calculating density.(4) In their study, five CBCT units and one CT unit were used. The results showed that the HU values were reliable; however, the grayscale values can differ depending on the CBCT device used in this study. The correspondence of CT HUs and CBCT gray scale values was consistent between the three devices.

Conclusion

Under the existing limitations, it can be concluded that the grayscale of the cone-beam computed tomography (CBCT) corresponds with the HU of the CT scan. According to this study's results, the formula below can be used to calculate the HU from the gray value, in which, instead of the letter X, the value of the grayscale, instead of the letters a, b, and the Neperian number (e), the defined scale, and instead of the letter (y), the Hounsfield unit are placed and calculated.

$y=aeb/x$

Coefficients:

$a = 2.98024702341E+003$

$b = -7.62212417721E+002$

Result

The grayscale in CBCT and HU in MDCT had a positive correlation, and according to this study, it is possible to calculate the HU from the gray level.

Table 1. Mean and standard deviation of Hounsfield unit and Gray scale

Scale	Mean ± SD
Hounsfield unit	1469.75±692.98
Gray scale	1390.03±83852

Table 2. The correlation between the gray scale and HU in each CBCT unit

CT \ CBCT	CBCT1	CBCT2	CBCT3
HU	0.851	0.802	0.801
P-value	P<0.001	P<0.001	P<0.001

Table 3. The correlation between HU and gray scale value at the standard condition

	Gray scale	HU
Gray scale	1	-
HU	R=0.810, P<0.001	1

Table 4. The correlation between HU and gray scale value at the high-resolution condition

	Gray scale	HU
Gray scale	1	-
HU	R=0.831, P<0.001	1

Acknowledgments

None

Authors' contributions

Farzane Ostovarrad: Conceptualization, Methodology, Writing - Review & Editing **Rabieh Boroumand:** Resources, Investigation, Visualization **Sadra Masali:** Methodology, Visualization **Ashkan Alizadeh Shuili**: Writing - Original Draft, Data **Rasoul Tabari Khomeiran:** Funding acquisition, Project administration, Supervision

Conflict of Interests

The authors declare no conflict of interest.

Ethical declarations

IR.GUMS.REC.1398.451

Financial support

None

Availability of data and material:

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

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