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RESEARCH

Effect of object location on the density measurement and Hounsfield conversion in a NewTom 3G cone beam computed tomography unit

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Objectives: The purpose of this study was to determine the effect of an object's location in a cone beam CT imaging chamber (CBCT-NewTom 3G) on its apparent density and to develop a linear conversion coefficient for Hounsfield units (HU) to material density (g cm^{-3}) for the NewTom 3G Scanner.
Methods: Three cylindrical models of materials with different densities were constructed and scanned at five different locations in a NewTom 3G Volume Scanner. The average HU value for each model at each location was obtained using two different types of software. Next, five cylinders of different known densities were scanned at the exact centre of a NewTom 3G Scanner. The collected data were analysed using the same two types of software to determine a standard linear relationship between density and HU for each type of software.
Results: There is no statistical significance of location of an object within the CBCT scanner on determination of its density. A linear relationship between the density of an object and the HU of a scan was $\rho = 0.001(HU)+1.19$ with an R2 value of 0.893 (where density, ρ, is measured in g cm^{-3}). This equation is to be used on a range between 1.42 g cm^{-3} and 0.4456 g cm^{-3}.
Conclusions: A linear relationship can be used to determine the density of materials (in the density range of bone) from the HU values of a CBCT scan. This relationship is not affected by the object's location within the scanner itself.
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Keywords: Hounsfield value; computed tomography; bone density

Introduction

Cone beam CT (CBCT) offers several advantages over traditional CT, including more compact imaging equipment, lower radiation dose and lower costs to operate the equipment.[1]

The data collected by CT and CBCT scanners can be used to determine the density of scanned tissues or objects. Images provide X-ray attenuation information for specific sized image pixels/voxels in terms of Hounsfield units (HU), which are related to the greyscale. While by definition the physical density of air is equivalent to −1000 HU and the physical density of water is equivalent to 0 HU, the relationship is slightly non-linear.[2] Research has shown, however, that over specified ranges a linear approximation can be used to convert HUs to density with a high degree of accuracy.[2–4] Determination of bone density will allow the clinical practitioner to assess bone quality to help choose sites most suitable for implant placement.[5]

The first objective of this study was to determine whether the perceived density (g cm^{-3}) of an object is affected by its location in the scanner imaging chamber. The second objective was to determine a linear relationship between the HU and density for the NewTom 3G.

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Materials and methods

Location effect

Three cylindrical blocks of varying density were constructed from Canadian spruce ($\rho = 0.4456$ g cm^{-3}), nylon ($\rho = 0.955$ g cm^{-3}) and acetal ($\rho = 1.42$ g cm^{-3}). These blocks measured 50 mm in radius and height.

A phantom Plexiglas® box designed to hold water in compartments along its sides was used to provide an artificial attenuation value of soft tissue without modifying the setting of the CBCT machine.[3] All three blocks were placed parallel to the central axis of the box and scanned using a NewTom 3G Scanner (Aperio Services, Verona, Italy) using a 12 inch field of view with an 8 mm aluminium filtration at 110 kV and 6.19 mAs. This process was performed with the block positioned at five different locations in the scanner gantry (centre, left, right, superior and inferior). The last four locations were determined by placing the blocks 3 cm from the centre location within the scanner gantry without interfering with the scanner itself. Determination of HU values has been reported in a previous study.[3]

Data were converted into DICOM format and then analysed using Merge eFilm (Merge eFilm Inc., Milwaukee, WI) and Amira (Amira™, ZIB, Mercury Computer Systems, Berlin, Germany). Merge eFilm is software designed for clinical use, while Amira was developed for research use.

Relationship between HU and apparent density

The method used to determine a linear regression between HU and density for the NewTom 3G Scanner was based on the procedure developed by Lagravère et al[3] and similar to the one used by Kilic et al.[6] Smaller cylinder samples (measuring 20 mm in radius and height) were placed individually in a phantom Plexiglas box. They were scanned one at a time at the exact centre of the scanner gantry, using the same imaging parameters as described previously. Five separate samples were used: acetal ($\rho = 1.42$ g cm^{-3}), acrylic ($\rho = 1.2$ g cm^{-3}), nylon ($\rho = 0.955$ g cm^{-3}), cork ($\rho = 0.127$ g cm^{-3}) and Canadian spruce ($\rho = 0.4456$ g cm^{-3}). The data were again converted to DICOM format and analysed using the Amira and eFilm software.

Images collected were measured in three trials. For all trials, three slices were selected near the centre of each block. Slices were divided into quadrants and four HU measurements were obtained from each quadrant. The 4 values for each quadrant were then averaged, providing 4 data points per image or 12 data points per block.

Results

Location effect

Average HU values obtained from the three cylinders using both types of software at every location is shown in Table 1. Arbitrarily, measurements from Trial 3 were chosen for comparison between the two types of software in registering HU values, obtaining a *P*-value of 0.985 when using a paired *t*-test. Also, the average HU value obtained from Amira was compared with the average HU value obtained from eFilm using a paired *t*-test. A *P*-value of 0.17 was obtained, meaning that there was no significant statistical difference between the types of software when determining HU values.

The data were split into the three different blocks and a repeated measures analysis was performed for the values obtained from both Amira and eFilm analyses. For Amira, when analysing the HU values obtained for the different trials for the different positions of the blocks, it was found with the Wilks' lambda test that they were not statistically significant for Canadian spruce, nylon and acetal (0.868, $P = 0.803$; 0.821, $P = 0.54$; 0.803, $P = 0.439$, respectively). Since these values were not significant, no further testing was done. The same procedure was repeated for the values obtained from eFilm software. Similar results were obtained for Canadian spruce, nylon and acetal (0.873, $P = 0.824$; 0.84 $P = 0.65$; 0.765, $P = 0.258$ respectively). When comparing results from both types of software, no statistical significance was found for each material analysed ($P > 0.05$).

Relationship between HU and apparent density

The data collected from different locations in the CBCT scanner were plotted against their objects' known densities and sorted by both location and the analysis software used. A linear regression was then fitted to each dataset using Excel software and its linear regression command.

The average linear regression obtained from the eFilm software was:

Table 1 Average Hounsfield units for both eFilm and Amira software using samples taken at various locations

		Centre		*Right*		*Left*		*High*		*Low*	
Material	*Software*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Canadian	Amira	−989.7	44.5	−1074.7	90.7	−1004.8	47.7	−1021.7	61.2	−1055.6	51.9
Spruce	E-film	−1037.5	43.7	−1015.8	75.6	−993.8	68.6	−923	96.5	−1068.1	78.4
Nylon	Amira	104.3	22.4	231.7	39.8	160.1	41.4	216.3	53.7	146.9	29.1
	E-film	−171.2	147.1	−98.3	185.7	−171.3	130.8	−105.4	161.7	−234.6	213.3
Acetal	Amira	337.7	92.4	551.5	63.5	514.8	54.9	497.2	48.5	477.3	83.5
	E-film	201.2	212.5	271.9	194.3	214.8	184.7	229.5	231.7	161.8	218.4

SD, standard deviation

Table 2 Average Hounsfield units for both eFilm and Amira software using 20 mm radius and height samples

Material	*Software*	*Mean*	*SD*
	Amira	−850.4	28.6
Canadian Spruce	E-film	−993.4	87.6
	Amira	140.1	34.6
Nylon	E-film	−159.4	94.8
	Amira	395.8	29.1
Acetal	E-film	213	150.4
	Amira	89.1	17.7
Acrylic	E-film	75.7	24.3

SD, standard deviation

$$\rho = 0.001(HU) + 1.022(\rho - \text{apparent block density g cm}^{-3}) \quad (1)$$

where standard deviations on the slope and intercept $\sigma_{\text{Slope}} = 0$ and $\sigma_{\text{Intercept}} = 0.01$. The coefficient of correlation for Equation 1 was $R^2_{\text{Avg}} = 0.855$.

For the Amira software, the average linear regression obtained was:

$$\rho = 0.001(\text{HU}) + 1.013 \quad (2)$$

where standard deviations on the slope and intercept $\sigma_{\text{Slope}} = 0$ and $\sigma_{\text{Intercept}} = 0.01$. The coefficient of correlation for Equation 2 was $R^2_{\text{Avg}} = 0.897$.

The CBCT scanner did not pick up the less dense cork with any level of accuracy; therefore, the data regarding that sample were discarded (Table 2). A linear regression was fitted to the data and the following relationship was obtained:

$$\rho = 0.001(HU) + 1.019 \quad (3)$$

The coefficient of correlation for Equation 3 was $R^2_{Avg} = 0.893$.

Discussion

During the process of data collection, it became evident that the apparent densities of the blocks were not constant (Figure 1), despite the attempt to use only homogeneous blocks in the procedure. This anomaly has two possible and likely combined causes. Firstly, as it is virtually impossible to construct truly homogeneous blocks, it is probable that at least some of the discrepancies arose from the non-uniform nature of the blocks themselves. The manufacturing and cutting of the blocks could also cause higher densities at the outer edges, especially for nylon and acetal, which present greater standard deviations compared with their means. For example, Figure 1 shows what appears to be the grain of the Canadian Spruce. Additionally, there is the possibility that the less powerful CBCT scanner could not completely penetrate the blocks (particularly when larger blocks were used). The extent to which each of these factors affects the final values collected is yet to be determined.

The data indicate that the location within a CBCT scanner has a statistically insignificant effect on the calculated density of an object. While there is some difference associated with the type of software used, this is likely explained by both statistical error and individual bias of various operators as opposed to software discrepancies such as bugs in the upgrades. Some of the data collected presented negative values, which in some cases meant that the density was less than air (−1000 HU) and water (0 HU). One reason for this is that CBCT scanners differ from the conventional CT scanners that define air and water having specific Hounsfield values. The calibration of the NewTom 3G Scanner provided a standard linear relationship between the density of an object and scanned HU (within the density range of bone). As expected, due to the lack of variation caused by object location within the scanner, this standard regression was very similar to the linear regressions obtained during the previous tests. As the HU scale varies between different scanner models and settings,[4] this relationship can only be considered accurate for this particular model. Therefore, it should be expected that both linear regressions were in themselves different from those obtained by Lagravère et al[3] (density (g cm^{-3}) = 0.002 × HU + 0.381) despite the fact that similar methods were used.

When comparing HU values obtained from CBCT with those obtained from normal CT it has been reported that these tend to be higher in CBCT,

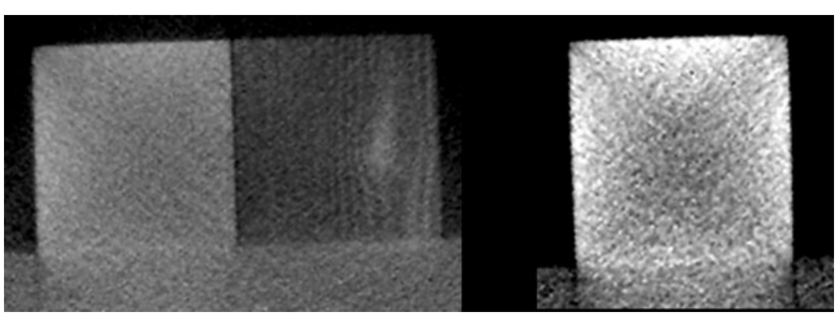

Figure 1 CBCT scan images of blocks constructed of various materials. Bright areas (higher HU) indicate areas of higher apparent density

although determining HU values for each method varies significantly.[7]

Different results have been obtained for each of the software types. One possible explanation is that the software algorithms used to reconstruct the images differ among manufacturers. Another reason is that locating the same points to measure HU units with each type of software was difficult, since eFilm presents the images as axial slices and Amira presents them as vertical slices. Also, the more points used to establish a linear relationship between HU and density of materials, the more precise and reliable this equation will be. Nevertheless, the variation found was not that significant in the study.

There are several immediate implications and applications of this study. Firstly, the knowledge that the location of an object within a CBCT scanner has a minimal effect on the apparent density indicates that density determinations can be made regardless of where the patient is placed in the scanner. Secondly, the calibration of a new CBCT scanner will now allow the scanner to be used in order to accurately determine object density. This should allow for better diagnosis of conditions where information about bone density is important or useful for diagnosis or treatment planning. Also, insertion sites for implants could be chosen based on bone characteristics thereby increasing the potential for implant success.[5,8]

References

1. Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. *J Orthod* 2005; **32**: 282–93.
2. Mull RT. Mass estimates by computed tomography: physical density from CT numbers. *AJR Am J Roentgenol* 1984; **143**: 1101–1104.
3. Lagravère MO, Fang Y, Carey J, Toogood RW, Packota GV, Major PW. Density conversion factor determined using a cone-beam computed tomography unit NewTom QR-DVT 9000. *Dentomaxillofac Radiol* 2006; **35**: 407–409.
4. Lindgren LO. Medical CAT-Scanning: X-ray absorption coefficients, CT-numbers and their relation to wood density. *Wood Sci Technol* 1991; **25**: 341–349.
5. Tolstunov L. Dental implant success-failure analysis: a concept of implant vulnerability. *Implant Dent* 2006; **15**: 341–346.
6. Kilic A, Ozkan L, Engin K. The dosimetric verification of commercial two- and three- dimensional radiation treatment planning systems. *Turk J Med Sci* 2002; **32**: 133–137.
7. Aranyarachkul P, Caruso J, Gantes B, Schulz E, Riggs M, Dus I, et al. Bone density assessments of dental implant sites: 2. Quantitative cone-beam computerized tomography. *Int J Oral Maxillofac Implants* 2005; **20**: 416–424.
8. Norton MR, Gamble C. Bone classification: an objective scale of bone density using the computerized tomography scan. Clin Oral Implants Res 2001; **12**: 79–84.