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RESEARCH

Density conversion factor determined using a cone-beam computed tomography unit NewTom QR-DVT 9000

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Objective: The purpose of this study was to determine a conversion coefficient for Hounsfield Units (HU) to material density (g cm^{-3}) obtained from cone-beam computed tomography (CBCT-NewTom QR-DVT 9000) data.
Methods: Six cylindrical models of materials with different densities were made and scanned using the NewTom QR-DVT 9000 Volume Scanner. The raw data were converted into DICOM format and analysed using Merge eFilm and AMIRA to determine the HU of different areas of the models.
Results: There was no significant difference ($P = 0.846$) between the HU given by each piece of software. A linear regression was performed using the density, ρ (g cm^{-3}), as the dependent variable in terms of the HU (H). The regression equation obtained was $\rho = 0.002H - 0.381$ with an R^2 value of 0.986. The standard error of the estimation is 27.104 HU in the case of the Hounsfield Units and 0.064 g cm^{-3} in the case of density.
Conclusion: CBCT provides an effective option for determination of material density expressed as Hounsfield Units.
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Keywords: Hounsfield value, computerized tomography, bone density

Introduction

Three-dimensional (3D) analyses and related procedures in dentistry have been attempted through several different approaches since the mid 1970s.[1–3] Advances in 3D imaging software have permitted major improvements in the perception of craniofacial structures.[4,5] One of the new techniques consists of digital volume tomography, also known as cone-beam computerized tomography (CBCT).[6] Compared with traditional cephalometric radiographs, the CBCT produces images which are anatomically true (1 to 1 in size) 3D representations from which images can be displayed from any angle in any part of the skull. Presently, 3D volumetric imaging provides useful information for clinicians in identifying teeth and other structures for diagnostic and descriptive purposes.[7]

With respect to osseous structures, the type and architecture of bone is known to influence its load bearing capacity, and it has been demonstrated that poorer quality bone is associated with higher failure rates in different dental treatments. Fanuscu and Chang[8] mention that bone mass, structural and material properties form the bone quality that is used frequently in implant dentistry.

Assessment of bone quality has been made using densitometry,[9] bone biopsies[10,11] and ultrasound.[12] Although these techniques present reliable bone quality measurements, they are not of practical clinical use for surgeons and other dental practitioners.

Since the use of CBCT is increasing in dentistry, assessment of bone quality from CBCT data may have practical implications. The purpose of this preliminary study was to determine a conversion coefficient for Hounsfield Units (HU) obtained from CBCT images to material density (g cm^{-3}).

Materials and methods

Cylindrical models, 20 mm in diameter and 20 mm in height, were made from six different materials with known densities. The materials used were Acetal (1.42 g cm^{-3}),

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Acrylic (1.2 g cm^{-3}), Nylon 6/6 (0.955 g cm^{-3}), Cork (0.127 g cm^{-3}), Celfortic Pink Foam (0.001 g cm^{-3}) and Spruce (0.4456 g cm^{-3}).

A CBCT scan was taken of these models using the NewTom QR-DVT 9000 Volume Scanner (Aperio Services, Verona, Italy) at 110 kV, 15 mAs and 8 mm aluminium filtration. Since the cylinders have no soft tissue component, the images obtained from the CBCT machine would be too dark to be analysed. Thus, a phantom Plexiglass box (26 cm × 24.6 cm × 22 cm) was manufactured in which the models were placed. The box had divisions at the base (5.1 cm wide) and sides (2.5 cm/each wide). The box was filled with water and non-coloured gelatin (Knox Gelatin) to simulate soft tissue around the models. This box design gave an artificial attenuation value of soft tissue without modifying the setting of the CBCT machine (Figures 1 and 2).

Once collected, the raw data were converted into DICOM format. This DICOM formatted data was exported into Merge eFilm (Merge eFilm Inc., Milwaukee, WI) and AMIRA (AMIRA™; ZIB, Mercury Computer Systems, Berlin) software which use linear filters to analyse and determine the HU of the different areas of the models.

Results

Three slices of the model images were selected and each model was divided into four segments. In each segment, four measurements of HU were obtained and averaged. This was done in each of the three slices selected, thereby giving a total of 12 HU values for each model. The procedure was done using both types of software.

Once the HU were collected, these were inserted into a statistical software (SPSS 13.0; SPSS Inc., Chicago, IL) where the respective tests were applied. It was found that there was no significant difference ($P = 0.846$) between the HU obtained by each software. A linear regression was performed using the density, ρ (g cm^{-3}), as the dependent variable in terms of the HU (H). The regression equation is:

$$\rho = 0.002H - 0.381$$

Figure 1 Cylinder models inside phantom box with water and gelatin attenuation elements

Figure 2 Phantom box inside cone-beam computed tomography (CBCT) imaging area

with an R^2 value of 0.986. The standard error of the estimation is 27.104H in the case of the Hounsfield Units and 0.064 g cm^{-3} in the case of density.

Discussion

There is a need for clinicians to have an appreciation of bone quality pre-operatively for some treatments. For example, this knowledge may be useful prior to placing implants. This would serve as a predictor of expected outcome helping the clinician to adequately inform and advise the patient regarding the prognosis of treatment. Several classification systems have been developed to assess bone quality and prognosis prediction. Some of these involve invasive procedures such as analysing bone fragments obtained from implants.[10,11,13] Norton and Gamble proposed an image based bone density classification that uses grey-scale values (HU) from CT. They suggested that this pre-operative measurement could serve as an indicator to objectively and quantitatively provide bone quality information.[14] Although this method provides a bone mass classification, it has limitations concerning structural and material properties.[8]

The use of CT in dentistry is growing; nevertheless, there is still concern about the radiation dose.[14] Several studies[15–18] have reported on the higher mortality risk obtained from the radiation absorbed with CT. A suggestion for lowering this risk is to reduce the radiation output of the CT unit without affecting the clarity of the images obtained, by lowering tube potential and tube current settings.[19] Staniszewska et al state in their study that CT radiation dose may be reduced up to three times without having significant image quality loss.[20]

The dose from the NewTom 9000 can be as low as 50 μSv,[21] similar in range to that from a dental periapical full mouth series. CBCT uses one rotation of the patient, similar to the panoramic radiography. The data are collected for either a complete dental/maxillofacial volume or limited regional areas of interest.[21] Depending on the machine used, the scan time with CBCT is approximately 40–75 s for the complete volume and 17 s for specific areas.[21,22]

Once the image is obtained, measurements concerning material density can be obtained. Using spiral CT, Norton and Gamble[14] analysed the quality of the bone by assessing its density. Their results showed that the anterior maxilla had a mean density value of 696.1 HU while the posterior maxilla had a value of 417.3 HU. They defined the HU value of the anterior maxilla as a thick layer of compact bone surrounding a core of dense trabecular bone and the HU value of the posterior maxilla as the poorest bone quality being a thin layer of cortical bone surrounding a core of low density trabecular bone. It should be taken into consideration that in their study, a conventional CT scanner was used (GE ProSpeed helical scanner; General Electric, Slough, UK). This scanner uses a Hounsfield Unit scale ranging from −1500 HU to +4000 HU where −1000 HU would be air density, 0 HU equals water density and a metallic dental restoration would be >+3000 HU. The authors have suggested that in their measurements bone density may vary. They recommend the use of ranges when verifying bone density in the anterior mandible (>+850 HU), posterior mandible/anterior maxilla (+500–850 HU), posterior maxilla (0–500 HU) and tuberosity region (<0 HU). This system is more flexible in helping the clinician categorise bone quality as a diagnostic predictor. In the present study, determination of a density conversion factor is attempted using structures composed of materials of known density. Once this is achieved with experimental models which are encased in soft tissue equivalent material, more studies using models that more closely simulate a clinical condition can be performed.

The regression equation obtained for the purpose of this paper was determined using material of known densities with range including the densities established for bone. Thus, this equation would only be applied for densities under the range of materials used for this study. For this reason, this equation can not be extrapolated to include values for water and air.

It should be noted that these quantities are not applicable for every type of CT scanner. The Hounsfield scale will vary according to the scanner used.[14] Thus, there is a need for a conversion factor to use a similar methodology for bone classification for other CBCT machines. In this study, this conversion factor was determined for the NewTom QR-DVT 9000 Volume Scanner, thus its use is applicable only for this particular machine. Conversion factors for other machines can be determined using similar methodologies as the one used in this study. It should also be considered that when using low doses, noise can affect the image quality and mask the trabecular pattern making CBCT and conventional CT give similar images at similar doses.

Another limitation of this study is that the objects imaged presented uniform densities, while trabecular bone does not.

In conclusion, density conversion factors can be determined for a given CBCT machine. Establishment of HU to material conversion coefficients for CBCT will give clinicians new possibilities for pre-operative evaluation of bone density.

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