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Comparison of radio density between cone beam computed tomography (CBCT) and multi slice computed tomography (MSCT) scan – an in vitro study

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Abstract

Aim: The aim of the study was to compare the radio densities of four objects (soft tissue, bone, dental implant and aluminum) between cone beam computed tomography and multi slice computed tomography scan.

Materials and method: A polymethyl methacrylate (PMMA) phantom was custom made containing objects of different densities: a titanium dental implant, soft tissue, aluminum and bone. The phantom was scanned on 2 CBCT devices and 1 MSCT device. Correlations between CBCT gray values and CT numbers were calculated.

Results: Mean and Standard deviation was calculated. Parametric test – one way ANOVA was performed. Gray scale values of CBCTs were converted to the Pseudo Hounsfield unit and compared with the Hounsfield unit of CT scan. One way ANOVA was done; the density was different between three machines – 2 CBCT (Kodak and Sirona) and CT (Siemens). It is understood that the Hounsfield unit (HU) from CBCT is not as reliable as multi slice CT. Irrespective of the machines and its brands or parameters, there is no significant difference observed between CBCTs.

Conclusion: This study revealed a significant difference in the Hounsfield unit (HU) in comparison between CBCT and CT. However, there is not much of a difference evident between two CBCT machines.

Keywords: Cone beam computed tomography, gray value, Hounsfield unit, implant, multi slice computed tomography

Introduction

Maxillofacial imaging is an important investigatory modality in dentistry. Even today, the usage of two-dimensional radiographs namely, intraoral periapical radiographs or OPG etc., are the first line of investigations to be carried out in ruling out abnormalities. Advancements in maxillofacial imaging have paved the way for three-dimensional radiographic scans in recent times, namely, cone beam computed tomography (CBCT) in dentistry. CBCTs are extensively used in orofacial areas as it allows for the acquisition of true volumetric images at a high spatial resolution. [1] With the ability of the cone-beam scanners to rotate 360^{o}, multiple slices (more than 600 slices) can be acquired at one time with minimal radiation exposure pertaining to the head and neck region. [2]

CBCT has numerous applications which can be used for making accurate measurements for dental implants, in identifying and measuring the sizes of pathologies, in locating the anatomical structures, in evaluating abnormalities of oral airways or maxillofacial bones, and also aids in analyzing odontogenic anomalies. [3]–[6] Evaluating the bone tissue characteristics such as width, depth, density and structure, and in dental implants, linear and volumetric measurements at potential implant sites in the jaw bones at submillimeter accuracy can be assessed using CBCT. [7]–[9] For a successful implant treatment, it is also mandatory to analyse the quality of the bone in which the implant is to be placed along with good height and width. However, the degree of calcification of jaw bone can be better evaluated in Hounsfield Unit (HU), which is a standard index used widely in Multi Slice Computed Tomography (MSCT) scans. [10]–[12] MSCT scanners are also extensively used for determining the densities of objects like air, water, metals etc., Due to standard HU index tissue density assessments are best appraised in MSCT. [13]

Most of the CBCT devices are found to use 12-bit images (i.e., 4096 gray values) which are scaled in an HU-like fashion ranging between 21000 and +3000. Taking these into account, many researchers have assumed that CBCT gray values cannot be calibrated as precisely as HU due to presence of various artefacts, the relatively large amount of noise (i.e., signal - to - noise ratio), the cone beam geometry, the limited field of view (FOV) size, type of device, positioning of the objects inside the FOV, etc. These factors are said to affect the tissue or object density assessments and CBCT image quality. Knowledge about these internal factors can help in minimising the errors and helps in better CBCT image quality. [10], [14]–[16] [1]

The primary objective of this study was to compare the radio densities of four objects (soft tissue, bone, dental implant and aluminum) between two different commercially available cone beam computed tomography devices with different FOVs.

The secondary objective of this study was to compare the radio densities of the four objects (soft tissue, bone, dental implant and aluminum) in a multi slice computed tomography scan and in analysing the overall radio densities of the objects between the CBCT and MSCT devices.

Materials and Method

Study design: In vitro study.

Phantom: A custom made radiographic phantom was prepared using polymethyl methacrylate (PMMA). The phantom is created with indentations designed accordingly to each object. The four materials taken for analysis of radio densities were aluminium, soft tissue, dental implant

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and bone. The materials used were - for aluminium, a thin foil measuring 5x4mm was used; for dental implant, a titanium coated implant (Straumann, Basel, Switzerland) measuring 3.5mm in diameter and 10mm in length was used ; for bone, goat bone of size 2x3mm was used and for soft tissue, 0.5cm of tissue taken from buccal mucosa was used. (Figure 1 and 2)

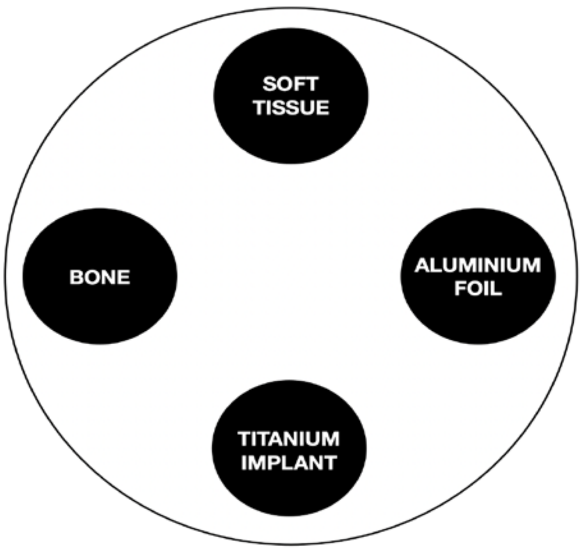

Figure 1 : shows the diagrammatic representation of the phantom with the representation of the four materials taken for study.

Figure 2: shows the PMMA phantom with materials used for analysis.

Devices and software

2 cone beam CTs with different fields of view were used and the phantom was scanned accordingly. First the phantom was scanned in Orthophos XG (Dentsply sirona, Pennsylvania, USA) with a small FOV of 5x5.5cm and with a large FOV of 8x8cm at 5-8mA and 120kVp. The phantom was then scanned in Carestream (Kodak) with a small FOV of 5x5.5cm and large FOV of 17x13.5cm at 5-8mA and 120kVp.

Multi slice CT scan which can take 128 slices at one time from Somatom definition AS (Siemens, Germany) was used. The phantom was used at a constant FOV of 17x11cm at 110kVp. The exposure parameters, as well as the software used for image acquisition in MSCT, were the same throughout the study inorder to maintain proper standardization and to avoid variability in the HUs.

The phantom was placed at the centre of the FOV and the long axis of it was perpendicular to the plane of X-ray beam. The datas acquired were reconstructed with the respective CBCT softwares.

The reconstructed datas of CBCT were then imported as DICOM (Digital Imaging and Communications in Medicine) files via the OnDemand3D software v1.010.7510 (Cybermed Inc., Korea). The gray values were rescaled by the software to ensure the same method of analysis of the data and to avoid errors created due to various software applications. To calculate the mean gray values, 10 regions of interest (ROI) were used. (Figure 3)

Figure 3 shows the CBCT reconstructed image of a dental implant placed in the phantom.

The Hounsfield Unit (HU) values were calculated using Clear Canvas Workstation software (Clear Canvas,

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Canada) in the same above mentioned way. Two primary researchers were involved in the study. (Figure 4)

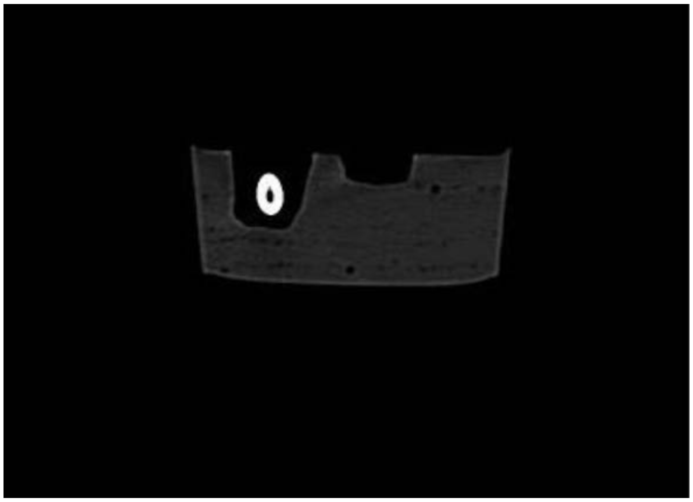

Figure 4: shows the CT reconstructed image of a dental implant placed in the phantom.

Statistical analysis

The statistical analysis was performed using SPSS v20.0 software (SPSS Inc., USA). Mean and standard deviation were calculated. Parametric t - test was done for comparing the two CBCT values. ANOVA was carried out to compare the values of each material. Comparisons of the 3 devices were made using the Tukey post hoc test. The level of significance was kept at 0.05 (p = 0.05). Inter examiner agreement was calculated using Kappa statistics and the value of Kappa was found to be 96% denoting the strong level of agreement.

Results and Discussion

Table 1 explains the detailed statistical analysis obtained from comparing the materials using 2 CBCTs and 1 MSCT. The mean and standard deviation were calculated. Parametric t- test and ANOVA were also calculated using the SPSS software. Table 2 explains the comparative analysis of the three devices (2 CBCTs and 1 MSCT) using Tukey post hoc test.

Materials	Devices	Mean ± Std. Deviation	T- Test	Anova
Implant	Sirona	2214 ± 268.55	0.014	0
	Kodak	2447.30 ± 395.9	0.01	0
	Siemens	3078 ± 31.04	-	-
Bone	Sirona	338.20 ± 77.330	0.04	0.01
	Kodak	376.10 ± 127.484	0.08	0.01
	Siemens	662.60 ± 101.02	-	-
Aluminium	Sirona	-606.06 ± 37.351	0.3	0.01
	Kodak	-732.80 ± 62.71	0.64	0.01
	Siemens	680.40 ± 118.24	-	-
Soft Tissue	Sirona	-732 ± 68.2	0.16	0.06
	Kodak	842 ± 82.431	0.14	0.06
	Siemens	687.94 ± 130.0	-	-

Table 1: shows the Gray values of each material and comparative tests for the 2 CBCT devices and HU values of each material in MSCT, t- test and ANOVA.

Materials	Devices Compared		Post Hoc Test
Implant	Siemens	Sirona	<0.05
	Kodak		<0.05
	Sirona	Kodak	Not Significant
	Siemens		<0.05
	Kodak	Sirona	Not Significant
	Siemens		<0.05
Bone	Siemens	Sirona	<0.05
	Kodak		<0.05

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	Sirona	Kodak	Not Significant
	Siemens		<0.05
	Kodak	Sirona	Not Significant
	Siemens		<0.05
Aluminium	Siemens	Sirona	<0.05
	Kodak		<0.05
	Sirona	Kodak	Not Significant
	Siemens		<0.05
	Kodak	Sirona	Not Significant
	Siemens		<0.05
Soft Tissue	Siemens	Sirona	<0.05
	Kodak		<0.05
	Sirona	Kodak	Not Significant
	Siemens		<0.05
	Kodak	Sirona	Not Significant
	Siemens		<0.05

Table 2: shows the comparison of 3 devices using the Tukey post hoc test.

From the mentioned tables it is observed that the soft tissue evaluated between the CBCTs showed no statistical significance. Also there was not much of significant difference evident between the two CBCT devices however there was statistically significant difference between the 2 CBCTs and MSCT seen on comparison of them using the Tukey post hoc test.

Less radiation exposure, three - dimensional viewing of the bone, surrounding structures and pathologies, lesser exposure time, wider range of viewing of the maxillofacial area are some of the indications of using CBCT in dentistry. However, there is no evidence of unanimously accepted universal protocols to be followed while using CBCT. [11], [13], [17], [18]

CBCT reconstructed images produce gray values that are unable to display the actual HUs like MSCT as they are not arbitrary gray levels and are uncalibrated. Furthermore the radio densities are variable due to many factors such as the artifacts, increased scattering levels, image acquisition settings, object to be exposed is in field of view, size of the FOV are proven to affect the gray values. In case of implant planning, it is necessary to evaluate the bone quality. [11], [18]–[22] To check them, it is mandatory to compare them with a standard index like HUs using MSCT.

In our study, a radiographic phantom was created with four inserts each representing the most commonly encountered materials in the orofacial area. The materials taken into the study are utilised in dentistry on a daily basis. Titanium are used majorly in dental implants and hence it is necessary to assess them [23]. Since the MSCT has a standard value (HU), we assumed this as a constant and compared the obtained CBCT values. Thus to rule out the significance of each material when exposed in CBCT. The titanium dental implant used in analysis showed a significant difference in the density in MSCT than in the CBCTs. However, the different FOVs used played a difference. The smaller FOV was proven to show better image acquisition when compared with the larger FOV. Assessing the bone, MSCT showed an overall good correlation. Shokri et al. (2018) studied the 4 different types of materials (Cerabone, nanobone, water and cenobone) placed in a radiographic phantom built using PMMA to evaluate the bone densities. He concluded in his study that the size of the FOVs significantly altered the gray values of the materials tested except for the Cerabone. [10] It is understood that till date no

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manufacturer of CBCTs have given standardized gray values for evaluation of bone density.

Various studies have been conducted in the past to prove that smaller FOVs can improve the resolution of the image and can increase the variability of gray values. [20], [21], [24]–[26] Irrespective of different FOVs used to evaluate the soft tissue, it showed the least quantitative significance of all the four materials. It is also important to emphasise that smaller FOVs showed remarkable reduction in the radiation exposure administered to the patients. [20]

Pauwels et al. (2013) studied about 6 different materials using 13 CBCT devices and 1 MDCT device. In his study, he concluded that even though most CBCT devices showed a good overall correlation with CT, large errors were found during the quantitative analysis. [1] On the contrary, the materials exposed with MSCT with different FOVs did not affect the HU values significantly. [11], [27], [28] Keeping this in mind, our study was carried out with a single constant FOV in MSCT throughout.

Conclusion

To conclude, the two CBCTs devices did not show any significant differences between them, however an accountable significant difference was seen between the CBCTs and MSCT. All the materials were differentiable in all the three devices helping us for comparison. This also proves that the type of device, FOVs and location of the material inside the FOVs have a huge role to play.

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