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Impact of artifacts on the diagnostic accuracy of CBCT scans - A retrospective study

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Abstract

Purpose: The purpose of the study was to assess the prevalence of the artifacts on Cone Beam Computed Tomographic (CBCT) scans and their impact on the diagnostic accuracy of images.

Methods: A total of 1050 CBCT images were retrieved from the archival records of a private CBCT diagnostic Centre. The images were divided into four categories Degree 0 (G0), Degree 1 (G1), Degree 2 (G2) and Degree 3 (G3) based on presence of artifacts. The impact of these artifacts on diagnosis was evaluated by two maxillofacial radiologists. The inter observer variability was evaluated using Kappa statistics.

Results: In our study, 856 images (81.5%) presented with artifacts, out of which degree 1 (G1) was present in 421 images (40.1%), degree 2 (G2) was present in 154 images (14.7%) and degree 3(G3) was present in 269 images (25.6%). Amongst these images with artifacts 75 % of images were diagnosable whereas 25% of images hindered diagnostic accuracy.

Conclusion: It is necessary for a maxillofacial radiologist to have a sound knowledge of artifacts to overcome diagnostic challenge. Selection of appropriate method for its correction is also important to reduce need for rescan and unwanted patient exposure.

Keywords: Artifacts, Cone beam computed tomography, Diagnostic accuracy.

Introduction

Advanced imaging modalities have revolutionized dental diagnosis and treatment planning. One such modality is Cone-beam computed tomography (CBCT) which has emerged as a major diagnostic aid in dentistry in a very short span of time [1].

CBCT ranks extremely high when considering the balance between high diagnostic yield, low cost, and low radiation risk to the patient. It has been frequently considered as the "gold standard" imaging of the oral and maxillofacial area [2]. It also provides clinician an improved therapeutic efficiency in the medical and dental fields with image- guided operative and surgical procedures.

Despite a growing trend of CBCT in dentistry, it has some disadvantages like the presence of visible artifacts in the final reconstructed images [3]. An artifact is a distortion or error in an image that is not related to the subject being studied (Scarfe and Farman 2008). It is a discrepancy between the reconstructed visual image and the actual content of subject which degrade the quality of CBCT image, making them diagnostically challenging [4&5]. Beam-hardening and extinction artifacts caused by high-density objects (e.g., metal), and motion artifacts caused by patient's movement contribute to image degradation and can lead to inaccurate or false diagnosis [6]. Clearly, the increasing spread of the technique is accompanied by the challenging demand for the user to correctly diagnose the volume data sets in presence of artifacts.

Whatever the source or appearance of image artifacts, their presence impairs the image quality, increase the interpretation time by covering anatomical structures in the region of interest and reduce the diagnostic accuracy or even prevent it [7].

It is therefore beneficial to be aware of the presence of artifacts and their impact on the interpretation of the data and be familiar with their characteristic appearances in order to enhance the extraction of diagnostic information from cone beam images [8].

On this background, the aim of this retrospective study was to analyze the prevalence of the artifacts on CBCT scans and their impact the diagnostic accuracy of images.

Materials and methods

The study was carried out in the department of Oral Medicine and Radiology in collaboration with a CBCT diagnostic centre. The study was approved by the ethical committee of the institution. The data of radiographic images of those subjects were retrieved from the archival records whose prior consent in view of future research purposes was already obtained during the making of CBCT. 1050 subjects who had undergone CBCT screening in a span of 5 years of the maxilla, mandible, both arches, whole cranium and sectional (specific section of either maxilla or mandible) were inspected for the presence of artifacts in them. CBCT scans of patients subjected to dental and craniofacial CBCT examination irrespective of gender, disease, treatment and clinical query were included in the study.

A single dental arch (226 maxillary and 203 mandibular arches), both arches, sectional, and the whole cranium were studied in 429, 541, 29, and 51 patients, respectively.

Radiographic images of subjects were grouped based on age into: -

6-10, 11-18, 19-60, 61-80 years

Image acquisition

The CBCT images obtained using the three-dimensional (3D) CS9300 Carestream CBCT machine with following parameters; tube voltage of 90 Kvp, tube current of 10 mA. A single 360-degree scan were used.

The FOVs used were 5 × 5 cm and 10 × 5 cm (small FOVs), 10 x 10 cm and 17 × 13cm (large FOVs), adopted as follows:

- FOV 8 × 8 cm in 29 images
- FOV 10 × 5 cm, in 429 images (226 maxillary and 203 mandibular arches)
- FOV 10 × 10 cm, in 541 images
- FOV 17 × 13 cm, in 51 images

The acquisition time (AT) was variable (9, 10, 11, 12 s) based on age and anatomical area: -

- 9 s; 38 images; low dose
- 10 s; 56 images; low dose
- 11 s; 92 images; high dose
- 12 s; 864 images; high dose

The reconstructed sagittal, coronal and axial sections of image obtained from the projection data with thickness of the image slice 1 mm and the distance between slices 1mm were analysed. All images were assessed under optimal viewing conditions with appropriate image viewing software (Carestream 3D imaging software).

Evaluation methods

The sagittal, coronal, axial sections of image reconstructed from the projection data were basically used for detection of presence, type of artifacts and their effect on the diagnosis of the image. This was evaluated separately by two maxillofacial radiologists (two observers) with an experience of over 10 years. The patient information was blinded for both the observers.

Once the presence and type of artifacts were detected they were categorized into four groups depending on the severity of artifacts and inability to extract diagnostic information in them.[10]

- Degree 0 (G0): absence.
- Degree 1(G1): not significant presence. An excellent image analysis is achievable
- Degree 2(G2): significant presence. A diagnostic image analysis is achievable
- Degree 3(G3): remarkable presence. A reliable opinion cannot be expressed

To analyze the effect of artifacts on diagnostic accuracy; the diagnosis of 40 images (10 random images from each group/degree) provided by observers were compared with the diagnosis given in patients scan report.

The data obtained was tabulated and subjected to statistical analyses. There was a good interobserver agreement - Kappa value 0.76.(TABLE 1)

Results

Among all the 1050 images examined, 194 images (18.5%) were in G0 category [without any artifacts]. Of the 856 images examined, 421 images (40.1%) were in degree 1 (G1) category, 154 images (14.7%) in degree 2 (G2) and 269 images (25.6%) were in degree 3(G3) category. (TABLE 2) [FIGURE 1,2,3, &4] Of 856 images with artifacts (G1+G2+G3), there were four types of artifacts detected, motion artifacts in 390 images (37.1%), metal artifact (beam hardening) in 416 images (39.6%), ring artifacts in 23 images (2.2%) and aliasing artifacts in 27 images (2.6%). Among the four artifacts detected metal artifact (beam hardening) was the most common type of artifact.

Among the 40 random images (10 images from each degree) both the observers could diagnose 75% (G0, G1, G2) of the images correctly whereas 25% (G3) of the images had inaccurate or incomplete diagnosis when compared with the diagnosis given in patients scan report due to presence of artifact obscuring the image. (TABLE 3) [FIGURE 5 &FIGURE 6]

Inter-observer agreement for the diagnosis of 40 random images was analyzed using chi square test and was found to be statistically significant (p=0.001). It was found that there was a good inter-observer agreement for images that belong to G0, G1 and G2 whereas poor inter-observer agreement was noticed for images of G3 category. (TABLE 4)

Discussion

CBCT images are inherently more prone to artifacts than conventional radiographs because the image is reconstructed on the order of a million independent detector measurements [6]. In our study out of 1050 images, 856 images (81.5%) presented with artifacts; metal artifact (39.6%), being the most common type of artifact among them followed by motion artifact (37.1%).

Artifacts related to CBCT can be divided into three main categories, physics-based, patient- based and scanner-based [9].

Physics- based artifacts include noise, scatter and aliasing.

Noise is defined as an unwanted, randomly and/or non-randomly distributed disturbance of a signal that tends to obscure the signal's information content from the observer. Noise affects images produced by cone-beam CT units by reducing low contrast resolution making it difficult to differentiate low-density tissues, thereby reducing the ability to segment effectively [10]. [FIGURE 7]

Scatter, on the other hand, is caused by those photons that are diffracted from their original path after interaction with matter. Scatter is well known to further reduce soft-tissue contrast and it also affects the density values of all other tissues [6]. [FIGURE 8]

Aliasing in CBCT lies in the divergence of the cone beam. In each projection, the voxels close to the source will be traversed by more than those close to the detector. This causes aliasing which represents itself as line patterns (moire patterns), commonly diverging toward the periphery of the reconstructed volume [11]. [FIGURE 9]

Scanner based artifact include ring artifact

Ring artifacts are seen as concentric rings centered on the location of the axis of rotation that result from imperfections in scanner detection or poor calibration [10]. [FIGURE 10]

Patient based artifacts include metal artifact (beam hardening) and motion artifacts.

According to R Schulze et al beam hardening is one of the most prominent sources of artifacts in CBCT [FIGURE 11]. Beam hardening occurs when the X-ray beam runs into a metal with a low atomic number, such as in the case of titanium (Z = 22) and of steel (Z = 26), used in implantology and in orthodontics. Therefore, the lower energy radiations are mostly absorbed than the higher energy ones and the emerging beam becomes rich in high-energy photons ("harder"). This kind of artifact appears as hypodense streaks which gradually diminish from the metallic region towards the periphery [12]. Scatter causes streak artifacts in the reconstruction that are very similar to those caused by beam hardening [6].

Second most common artifact is the motion artifact caused by patient's movement during CBCT scan. Reasons for motion artifacts is thought to belong to scan time or screening time. Patient anxiety can be suggested as a reason for patient movement. The patient's position in the CBCT scanning (supine, sitting or standing) and the fixing status of the head may also affect the patient's movement [13]. [Figure 12]

Artifacts degrade the value of diagnostic image by overlapping the important anatomical structures, while others can mimic pathological changes. In our study, 81.5% images presented with artifacts out of which 25.6% artifacts were of significance. According to the study conducted by Nardi et al on diagnostic evaluation of images with artifacts, 1.9 % cases out of 41.5% cases had motion artifacts that compromised the diagnosis [14].

K. Babalola and A. Tadinada conducted a study to assess root canal morphology and anatomy from CBCT scans with metallic artifacts and found that 6% of the images in the study were not adequate for assessment due to significant presence of artifacts in them [15]. In a study conducted by Donaldson et al revealed that 99.5% of images were diagnostically acceptable without the need for any retakes [16]. In our study, 75 % of the images with artifacts were diagnosable and 25% with significant artifacts had inaccurate or incomplete diagnosis.

Images that become diagnostically unusable might require a rescan. In a previous study from Donaldson 0.5% of the images needed a rescan for diagnostic reasons [16]. A study by Spin-Neto reported that 6.4% of the examinations needed to be redone due to presence of artifacts [17]. The European Commission Directorate for Energy in 2012 stated that for dental and maxillofacial CBCT scans, a maximum of 5% of CBCT images might be in need of a retake due to the presence of artifacts [18]. In a study conducted by Yasamin Habibi et al the most common reason for a rescan was due to 46% motion artifacts [19].

Today CBCT is an indispensable component in maxillofacial imaging. Issues like artifacts need to be considered with the help of artifact correction or reduction software that are currently under investigation. In a study by Bechara et al., the metal artifact reducing (MAR) algorithm reduced the effects of the beam hardening and scattering caused by a metallic structure [20]. Zhang et al. introduced a three-step computer algorithm to reduce artifacts in CBCT images and stated that the artifacts caused by dental amalgam fillings had been significantly reduced [21]. Computational geometric methods are effective in decreasing metal artifacts in the CBCT images. For head and neck imaging, along with head and neck stabilization if whole body stabilization is also incorporated, it may automatically help in some motion artifact reduction during the reconstruction.

Most of the algorithms under investigation can be categorized as projection interpolation, iterative reconstruction and filtering algorithms, using different approaches or combinations to limit the effect of metal objects in the image (Wang et al. 1999; Watzke & Ka lender 2004; Bal & Spies 2006; Zhang et al. 2007; Prell et al. 2009) [22]. However, the cone beam geometry provides additional challenges in artifact reduction compared to parallel or fan beam reconstruction. It may take several more years before iterative MAR algorithms for CBCT are implemented in routine clinical practice.

More recently, dental CBCT manufacturers have introduced artifact reduction technique algorithms within the reconstruction process (e.g., Scanora 3D; SOREDEX, Helsinki, Finland) [22]. These algorithms reduce image noise, metal and motion-related artifacts and require fewer projection images, and therefore may allow for a lower acquisition dose. However, they are computationally demanding and require increased reconstruction times

Figures and tables

Table 1: inter observer agreement for the grading of artifacts.

Degree 0, 1- Degree 1, 2- Degree 2 and 3- Degree 3

Observer 1	**Observer 2**				**Total**
	0	1	2	3	
0	187	10	2	7	206
1	1	294	122	4	421
2	0	10	141	3	154
3	1	7	14	247	269
Total	189	321	279	261	1050
Kappa statistic=0.76					

Table 2: grading of artifacts by observer 1 and observer 2

0-Degree 0, 1- Degree 1, 2- Degree 2 and 3- Degree 3

Observer 1		
Grade	Number of images(N)	Percentage (%)
0	206	19.6
1	421	40.1
2	154	14.7
3	269	25.6
Total	1050	100.0

Observer 2		
Grade	Number of images (N)	Percentage (%)
0	189	18.0
1	321	30.5
2	279	26.6
3	261	24.9
Total	1050	100.0

Table 3: comparison of diagnosis of 40 images given by two observers with the diagnosis in patients scan report.

	Observer-1		Observer 2	
	Number of subjects(N)	Percentage (%)	Number of subjects(N)	Percentage (%)
Almost same diagnosis as given in patients scan report	30	75.0	30	75.0
Inaccurate / Incomplete diagnosis compared to diagnosis given in patients scan report.	10	25.0	10	25.0

Table 4: inter- observer agreement with the diagnosis in patients scan report.

Degree	Observer 1		Observer 2	
	Number of images out of 10 (n)	Percentage (%)	Number of images out of 10 (n)	Percent age (%)
G0	10	100	10	100
G1	9	90	9	90
G2	8	80	7	70
G3	3	30	2	20
	Chi- square - 15.4 p - 0.001*		Chi- square – 18.1 p - 0.001*	

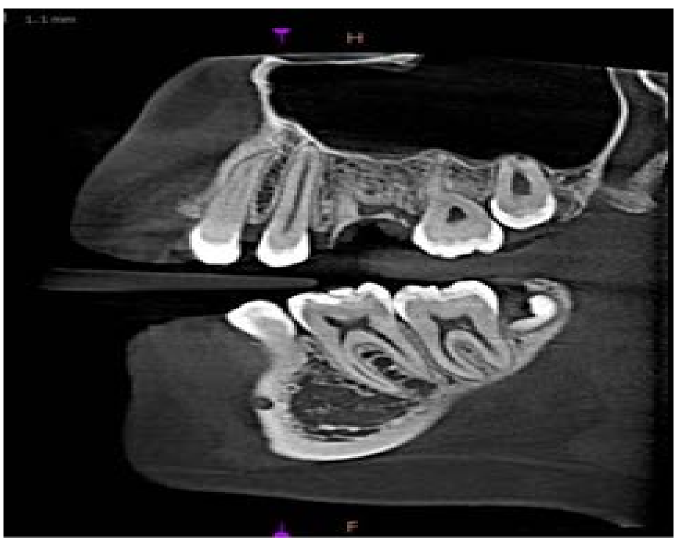

Figure 1: sagittal section of image showing grossly decayed 16 with periapical rarefaction. Absence of artifacts noticed. degree 0 (g0).

Figure 2: sagittal section of image showing evident bone loss with respect to 45 and 46 regions. Image also has motion artifact. Degree1 (g1)

Figure 3: sagittal section of image showing mesiodens in palatal aspect of 11 region. Image also has significant presence of motion artifact. Degree 2 (g2).

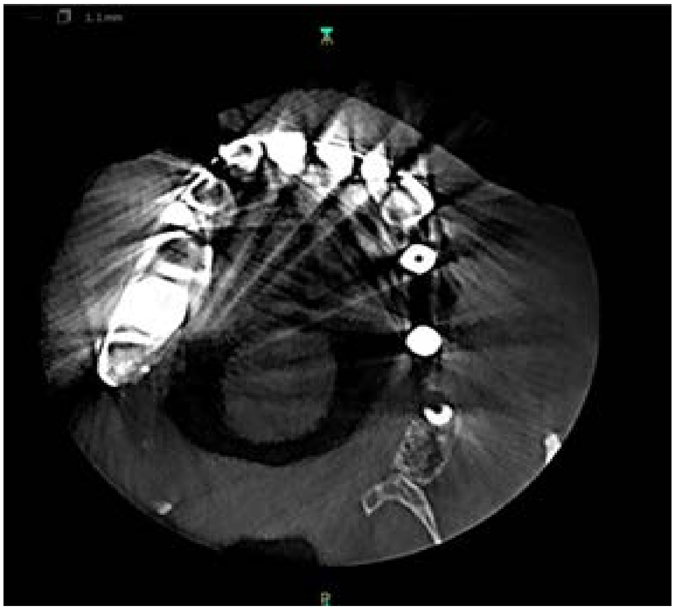

Figure 4: axial section of image showing significant presence of metal artifact. diagnosis not achievable degree 3 (g3).

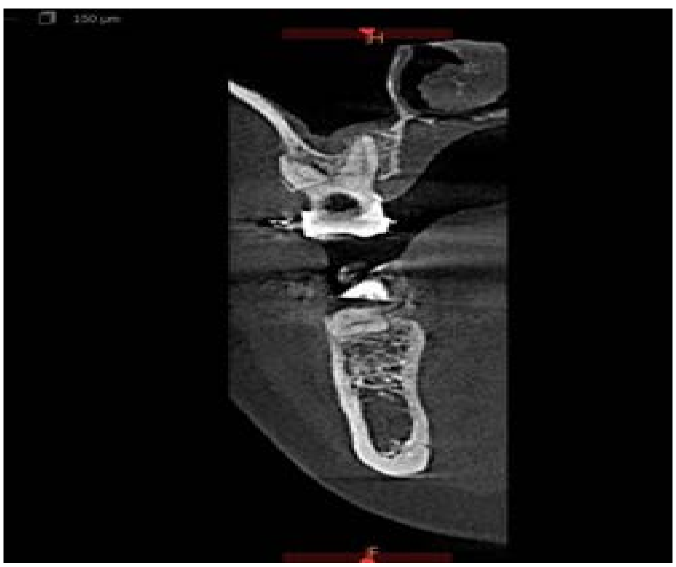

Figure 5: coronal section of image showing significant presence of metal artifact. Reliable opinion cannot be expressed on 16 for dental caries or cupping artifact from metal crown. Degree 3 (g3).

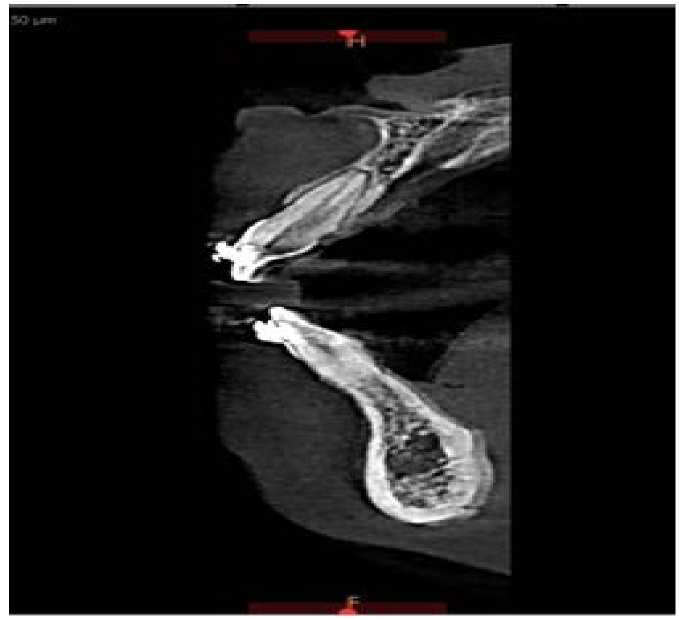

Figure 6: sagittal section of image showing significant presence of motion artifact. Reliable opinion cannot be expressed on 11 for two root canals or double image from patient motion. Degree 3 (g3).

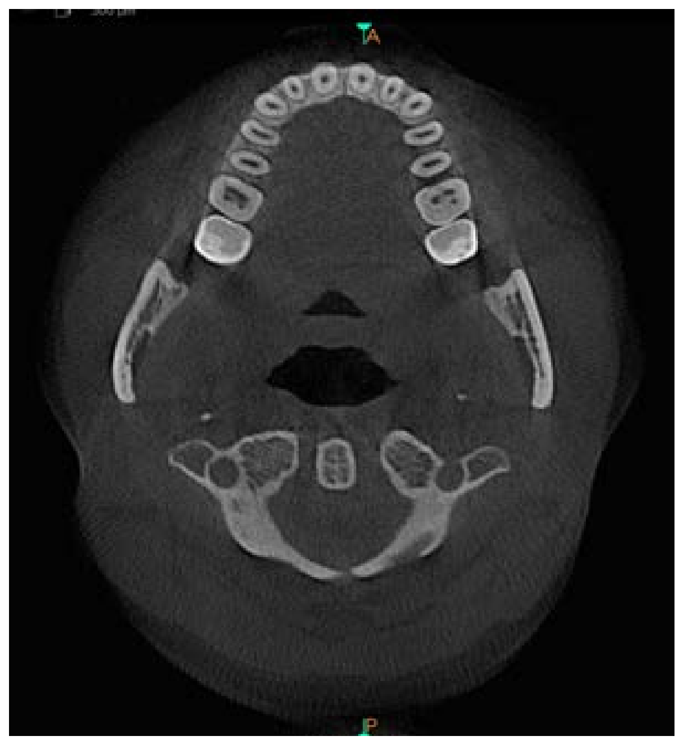

Figure 7: axial section of image showing noise artifact (yellow arrow)

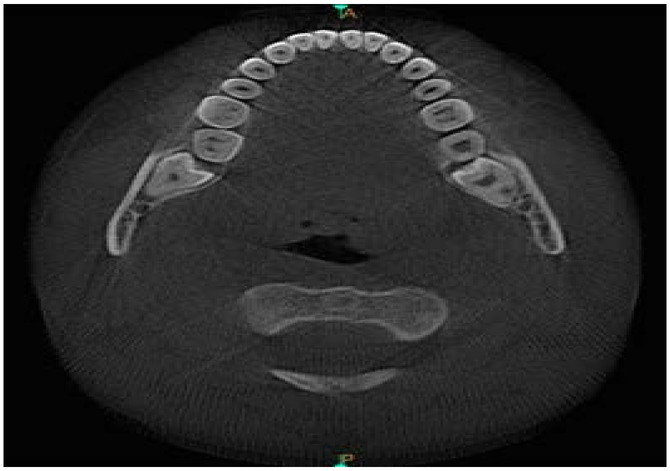

Figure 8: axial section of image showing scatter (streak artifact) {yellow arrow}

Figure 9: axial section of image showing alaising artifact (fine lines radiating towards periphery)

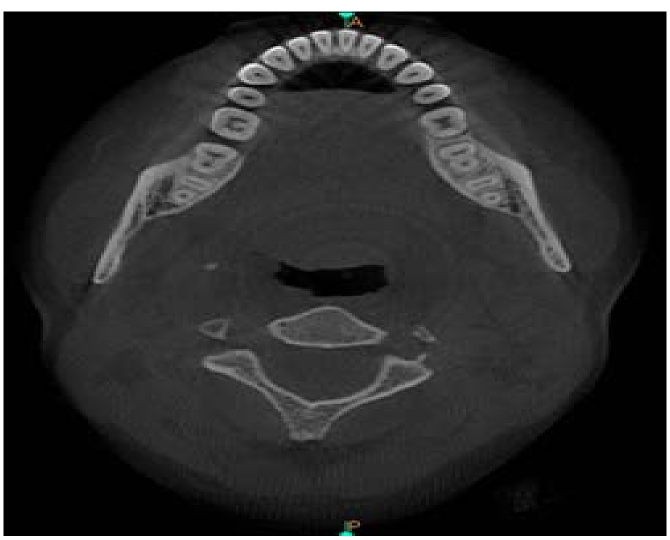

Figure 10: axial section of image showing ring artifact.

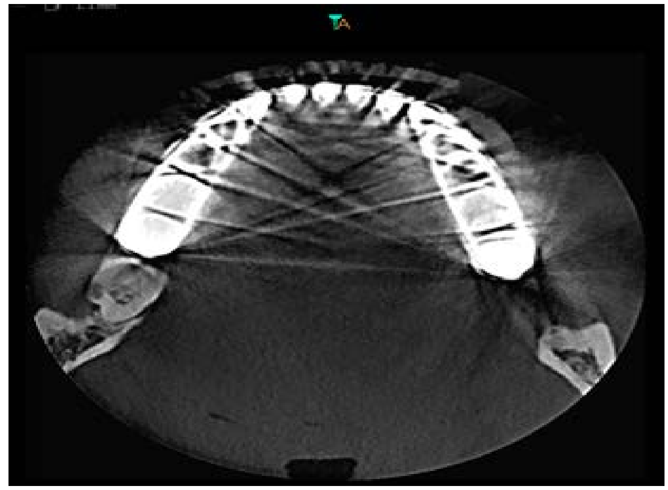

Figure 11: axial section of image showing beam hardening artifact.

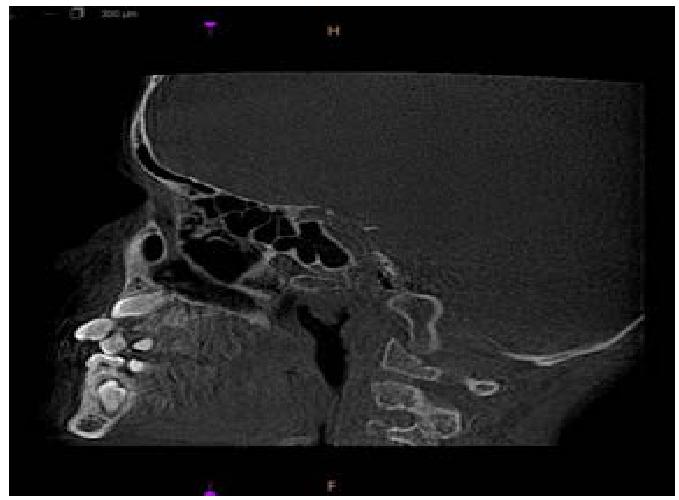

Figure 12: sagittal section of image showing motion artifact (double images of teeth).

Conclusion

In our study, considerable number of images presented with artifacts that affected the diagnostic quality of the image. 75 % of images with artifacts were diagnosable whereas 25% of images with significant presence of artifacts had diagnostic inaccuracy as per the observers. Being a maxillofacial radiologist, it is essential to be familiar with the characteristic appearance of artifacts in order to correctly diagnose cone beam images because false diagnosis based on corrupt images can directly influence the treatment protocol. It is also important to be aware about various artifact correction software's as these artifacts not only degrade the quality of image but also warrant a need for rescan and thereby increasing radiation exposure to patient.

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