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ARTIFACTS- THE STUMBLING BLOCK IN CONE BEAM COMPUTED TOMOGRAPHY

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Abstract: Following the discovery of X-rays by Sir Wilhelm Conrad Roentgen in 1895, 2-D radiology formed the backbone of imaging for many years. It did however, come with a set of limitations. Eventually 3-D imaging evolved to meet the demands of advancing technology. One such modality that has been embraced successfully in the field of oral and maxillofacial radiology is Cone Beam Computed Tomography (CBCT). With the benefits of having a lesser physical footprint, lower radiation exposure and a comparatively lower cost to its medical counterpart, CBCT has made a sizeable impact in the field of dentistry. CBCT uses radiation in a similar manner as conventional diagnostic imaging and reformats the raw data into DICOM data. This DICOM data are imported into viewing software that enables the manipulation of multiplanar reconstructed slices and three-dimensional volume renderings. The apt use of sophisticated software and computerized algorithms has truly revolutionized the way oral and maxillofacial imaging is performed. However, on the other side of the fence we do find certain factors which impair the quality of the image and thereby hamper the diagnosis and treatment planning. This factor that impairs the CBCT image quality is an artifact. This article aims to discuss the most notable artifacts identified in scientific literature and review the existing knowledge on these artifacts.

Index terms: Artifacts, Cone Beam Computed Tomography, Beam Hardening

INTRODUCTION:

Cone beam computed tomography (CBCT) is a radiographic imaging method that allows accurate, three-dimensional (3D) imaging of hard tissue structures. It is the most significant among the recently emerged medical diagnostic imaging modality. [1] It has the potential to transform all aspects of dental imaging.

The cone beam scanners are based on a cone- shaped beam of x-rays rotating around the object of interest giving a volume of data using a 2-dimensional extended digital array as an area detector. The technique involves a single 360-degree scan in which the X-ray source and area detector synchronously move around the patient's head. [2] The projection data obtained is read by software and interpreted by the operated.

Due to its ability to provide cross sectional images at lower radiation doses as compared with computed multislice computed tomography, CBCT has widened diagnostic possibilities in dentistry. [3]

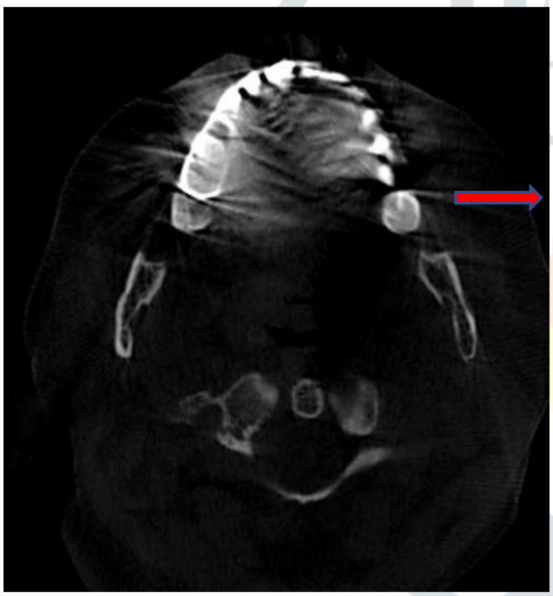
However, on the other side of the fence, we often find certain factors which impair the quality of the image and thereby hamper the diagnosis and treatment planning. This factor that impairs the CBCT image quality is an image artifact.

Artifacts in radiographic imaging are discrepancies between the reconstructed visual image and the actual content of the subject being studied. In radiographic imaging, this means the grayscale values in the image do not accurately reflect the attenuation values of the subject. [4]

CBCT images have more artifacts than conventional CT images majorly due to the lower energy spectra used and the cone-beam geometry of the beam. [5]

ARTIFACTS IN CBCT:

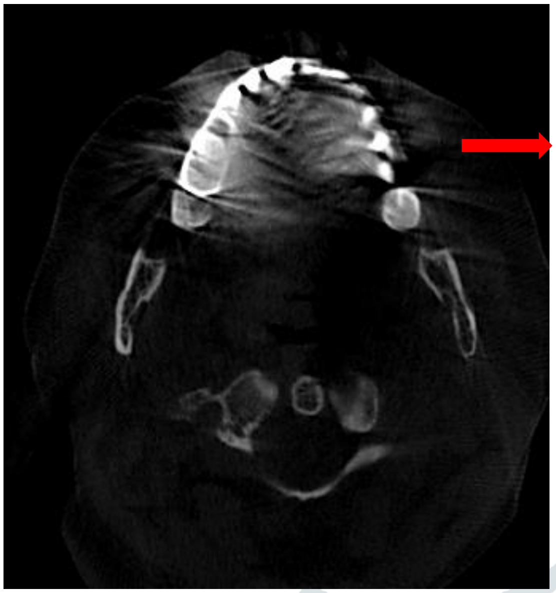
1. BEAM HARDENING:
   Beam hardening is the phenomenon that occurs when an x-ray beam comprised of polychromatic energies passes through an object, resulting in selective attenuation of lower energy photons. [6] The attenuated X-ray beam exits this object with a higher mean energy than the incident or primary beam resulting in distortion of the beam. [7]
   If the emitted spectrum contains more relatively lower-energetic rays than that recorded on the detector (i.e., the beam is hardened), a non-linear error (relatively too much energy recorded in the beam path behind highly absorbing materials) is induced in the recorded data. In the 3D reconstruction, the error is back projected into the volume, resulting in darks streaks. [8]



Beam Hardening

Beam hardening results in 2 types of artifacts:

a. Cupping artifact-
   Cupping artifacts from beam hardening occur when X-rays passing through the center of a large object become harder than those passing through the edges due to greater amount of material the beam has to penetrate. The resultant profile of the linear attenuation coefficients as a "cup".[9] This effect is most prominent when a cylindrical object is imaged. It can be minimized by using energy minimizing algorithms and anti-scatter grids.



Cupping artifact

b. Missing artifact-

If the object under study contains highly absorbing material like a prosthetic gold restoration, then the signal recorded by the detector pixels behind that material may be close to zero or zero. [5] Reducing the field of view, adjusting the patient position, or separating the dental arches to avoid scanning the regions susceptible to beam hardening. One should also remove the metallic objects such as jewelry to reduce further artifacts.

Metal artifact reduction (MAR) tools are post processing algorithms developed by the manufactures of some CBCT devices to improve the image quality during the reconstruction process by reducing beam hardening artifacts. [10]

2. CONE SHAPED BEAM RELATED ARTIFACT:

The cone shaped beam results in the production of 3 types of artifacts:

a. Partial volume averaging-

A micro-CT slice is comprised of voxels. Partial volume averaging occurs when materials of different density (i.e., bone and air) occupy the same voxel. The CT (grey) value assigned to each voxel represents an average of the linear attenuation coefficients (i.e., density). This leads to a blurring of the bone non-bone boundary. [11] it is most commonly seen in regions where the surfaces are rapidly changing in the z direction like the temporal bone. It can be reduced by using smaller and more sharply defined voxels. [12]

b. Under sampling

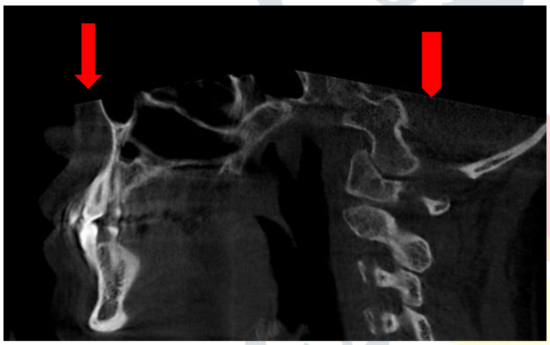
Due to the divergent nature of the cone beam, the voxels close to the source will be traversed by more recorded rays than those that are close to the detector. This results in under sampling which can appear as aliasing artifacts also known as Moiré artifact. Another probable source of this artifacts is the small size of the detector elements. [5,13]

They appear as multiple linear radiating stripes towards the periphery.

Moiré artifact

c. Cone beam effect

Because of the divergence of the x-ray beam as it rotates around the patient in a horizontal plane, structures that are at the top and bottom of the image are exposed only when the source is on the opposite side of the patient. This appears as image distortion, streaking artifacts and a greater peripheral noise. [14]



Cone beam effect

3. SCATTER

Scatter refers to the off-axis low-energy radiation that is generated in the patient during image acquisition. It corresponds to the contribution to photon influence at the detector not attributable to the incident primary beam. [15] this scattered radiation does not reflect the actual attenuation of the object and leads to an increased noise and a reduced contrast resolution of the image which appears in the form of streak artifacts. [16]

One way to avoid the impact of scattered radiation in a CBCT scan is to prevent the detection of scattered photons at first place. This can for instance be done by increasing the object detector distance, a stronger collimation, the use of bow-tie filters and anti-scatter grids. [17]

4. EXPONENTIAL EDGE GRADIENT EFFECT

The exponential edge-gradient effect must arise in any X-ray transmission CT scanner whenever long sharp edges of high contrast are encountered. While the most common effect is lucent streaks emerging from single straight edges, it is demonstrated that dense streaks from pairs of edges are possible. [18] A couple of correction algorithms are made available in order to reduce this particular artifact.

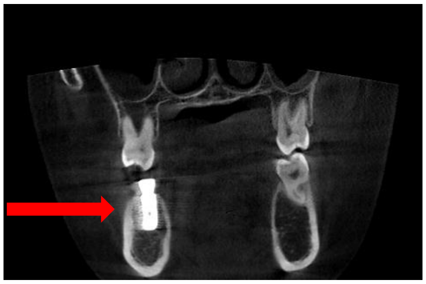
5. PHOTON DEPRIVATION

Photon deprivation or photon starvation results due to insufficient photons reaching the detector owing to high attenuation. This results in the appearance of streak artifacts especially behind metal implants. This can be reduced by automatic tube current modulation and adaptive filtration. [19]

6. METAL ARTIFACT

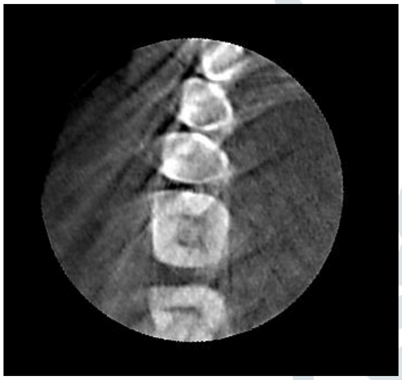
High density objects in CBCT images such as metal implants and dental fillings create a lot of artifacts that appear in the form of white streaks and reduce the image quality, thereby impairing the diagnosis. [20]

It can be avoided by removing metallic objects before the scan, artifact reduction software, and anti-scatter grids.



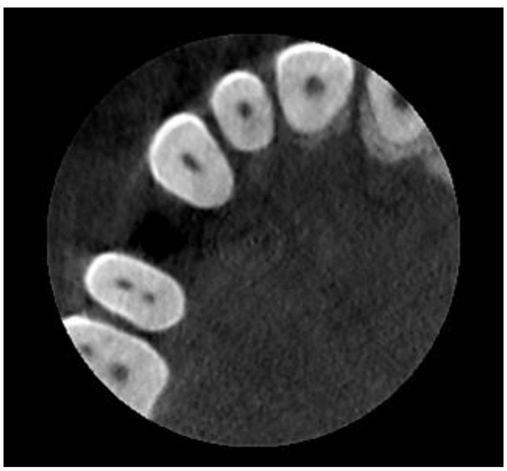
Metal artifact

7. PATIENT RELATED ARTIFACTS:
Patient motion can cause faulty registration of data, which appears as un-sharpness or double image in the reconstructed image. If an object moves during the scanning process, the reconstruction process does not account for that move. [16] The use of a short scan time and head stabilizing devices can minimize this artifact.



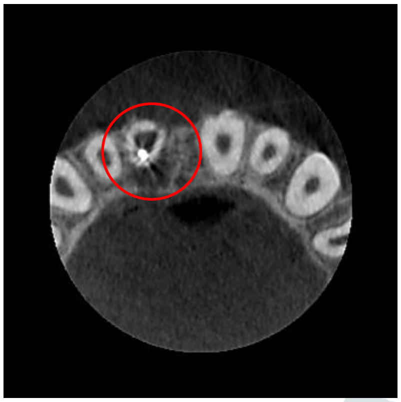
Patient motion artifact

8. RING ARTIFACT
Typically, scanner-related artifacts present as circular or ring-shaped, resulting from imperfections in scanner detection or poor calibration. Either of these two problems will result in a consistent and repetitive reading at each angular position of the detector, resulting in a circular artifact. [21] it appears as a concentric circular ring about the axis of rotation and can be avoided by the proper and periodic calibration of the machine.



Ring artifact

9. FOREIGN OBJECTS
Foreign objects such as earrings, nose rings and any other form of jewelry may result in a shadow on the resultant image due to beam hardening. Such foreign objects which are in the region of the field of view should be removed prior to the scan to avoid image distortion.



Foreign object related artifact

CONCLUSION:

CBCT and its 3D imaging technique tries to overcome the confines of conventional radiography and is a useful accessory to a dentist's armamentarium. Nowadays, CBCT is a well -diagnostic tool for the care of dental patients. [22]

This imaging modality is capable of providing submillimeter resolutions images, a higher diagnostic quality and shorter scan times with lesser radiation doses as compared to conventional CT.

However, it does carries along with it a few challenges in the form of artifacts. The low energy spectra used, the cone shaped nature of the beam and beam hardening effects leads to distortion of the images and artifacts which may hamper the process of efficient and quick diagnosis.

Thus, the use of CBCT as a diagnostic imaging modality should always be attempted with the possibility of artifacts kept in mind. Today, more modern approaches to limit the presence of artifacts are available, but they require massive computational power. We can expect the development of enhanced reconstruction methods in the future which would help us to limit artifacts.

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