Understanding artifacts in cone beam computed tomography

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Abstract

Cone beam computed tomography (CBCT) is an established technology in the present era of Dentistry. It is the modern third dimension which is applied, with lower radiation dose compared to conventional CT in field of oral maxillofacial region. Artifacts can seriously degrade the quality of computed tomographic (CBCT) images, sometimes to the point of making them diagnostically unusable. Every dentist must be familiar with these limitations while interpreting CBCT images. To optimize image quality, it is necessary to understand why artifacts occur and how they can be prevented or suppressed. This article highlights the causes of artifacts on CBCT images.

Keywords: CBCT; Artifacts; Metal Artifacts

Introduction

In present state-of-the-art, cone beam computed tomography (CBCT) units produce excellent high resolution, three dimensional images of oral anatomy making dental implant planning and surgical placement simple and reliable. The introduction of new technology in dentistry is rapidly changing the diagnostic landscape, allowing dentists to now diagnose in three dimensions. Patients have benefited since the advent of CBCT by receiving enhanced treatment planning, better diagnostics, and ultimately, safer and more foreseeable surgeries. This also facilitates better patient education, understanding, and treatment acceptance. With innovation in computers and developments in scanning technology, it has become one of the important diagnostic modalities to the practicing dentists and researchers in the rapidly changing field of digital dentistry. Also the role of CBCT in oral & maxillofacial surgery, orthodontics, temporomandibular joint disorders, endodontics, airway assessment, and periodontics is widely described lately.[1-3] The required radiation dose for CBCT is lower than that of CT if we consider images made for the same purposes.[4] In reconstructed CBCT images, the presence of grey level non-uniformities contributes to artifact formation.[5] These artifacts may contribute to image degradation and can lead to inaccurate or false diagnoses.This article aims to present a pictorial essay describing the various CBCT faults and artifacts, which may also help to understand the factors causing image deterioration in CBCT. To further simplify, we are also presenting a classification of these artifacts.

Faults and Artifacts

It is important to understand the basic concept of a fault and an artifact. Fault is an imperfection, error or mistake, where flaws will hinder interpretation of the radiograph. Whereas, an artifact is any distortion or error in the image that is unrelated to the (tissues/organs of the) subject being studied. According to their cause the artifacts can be classified.[6] For a radiologist it is important to understand the cause, recognize and diagnose the faults and artifacts in the image and, thus preventing their occurrence in subsequent images.

Classification of Artifacts

A. Beam-related artifacts
   1. Beam hardening artifacts
   2. Cone-shaped beam-related faults
   3. Scatter
   4. Exponential edge gradient effect (EEGE)
   5. Photon deprivation
   6. Full mouth restoration (metallic) artefact
B. Patient-related artifacts
   1. Unsharpness
   2. Double image
C. Scanner-related artifacts
   1. Image noise
D. **Beam-related artifacts**
   1. The beam-related artifacts include:

Beam hardening artefact: This type ofartifacts are the most prominent artifacts seen in CBCT images.[7] Because of their higher density, they are made by heavy metal restorations. Beam hardening artifact is seen because the mean energy of beam increases as the lower energy photons are absorbed more in comparison to higher energy photons.[6] This shows effects in the distortion of metallic structures as a result of disturbance in the reconstruction process. This phenomenon produces two types of artifacts:

a) **Cupping artifacts:** 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 of the object due to the greater amount of material the beam has to penetrate. Because the beam becomes harder in the center of the object, the resultant profile of the linear attenuation coefficients appears as a "cup".[5]

b) **Streaks and dark bands:** They can be seen between two dense objects[8]. In dental imaging, this type of artifact can be seen between two implants located in the same jaw that are in close proximity toeach other. This occurs because the portion of the beam that passes through both objects at certain tube positions becomes harder than when it passes through only one of the objects at other tube positions. The images are more precisely seen in the axial planes and 3D reconstruction images.

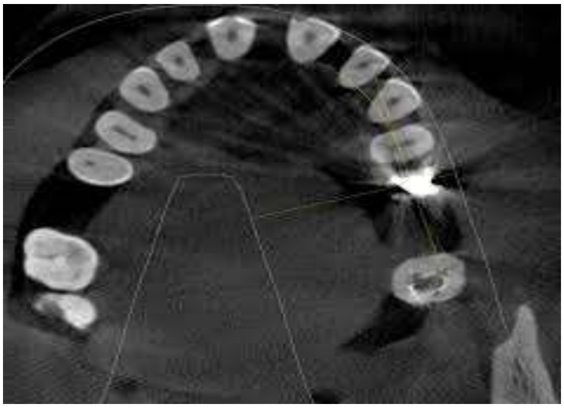

Fig. 1: Image showing: cupping effect, streaks, and. dark bands seen as a result of beam hardening

Cone-shaped beam-related faults: The cone beam projection geometry and the image reconstruction method produce three types of artifacts:

a) Partial volume averaging: When the selected voxel resolution of the scan is greater than the spatial or contrast resolution of the object to be imaged. Partial volume averaging artifacts occur in regions where surfaces are rapidly changing in the *z*-direction (e.g. in the temporal bone).
b) Under sampling: This is a type of aliasing artifact. It is seen when very few basis projections are provided for the reconstruction.
c) Cone beam effect: This type of artifact is seen in the peripheral portions of the scan and is seen because of the divergence of X-rays in those areas. The outcome of cone beam effect is image distortion, streaks, and peripheral noise.[6,8]

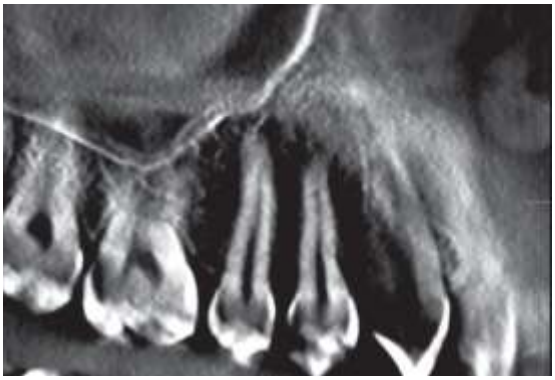

Fig. 2: Under sampling due to insufficient basic projections

Scatter: In radiographic imaging, only photons traveling directly from the source to the detector are measured. Scatter is caused by those photons that are diffracted from their original path after interacting with the object being imaged. The larger the detector, the higher the probability that scattered photons incites it, the researchers noted.[9]

"Scatter is the really big one, and this is where the big difference between CBCT and medical CT occurs". "In a CBCT image, the whole area you are looking at is the entire image, so when you get scatter, it scatters all through the image. In medical CT, the scatter is significantly less because the detector is very small."[1]

Exponential edge gradient effect: This effect is caused because of the sharp edges of the metallic crown borders producing high contrast, as it reduces the computed density value.[10] As sharp edges of high contrast may commonly occur in the oral cavity, e.g. at metallic crown borders, this artifact also has to be considered in dental CBCT. The EDGE is known to cause streaks tangent to long straight edges in the projection direction.[9]

Photon deprivation: This is a result of severe beam hardening, generally seen next to titanium implants or other heavy metal restorations. Due to the high density of metallic restorations, when sufficient photon unable to reach the detector and a complete void exists in the image, which is known as photon starvation.[11]

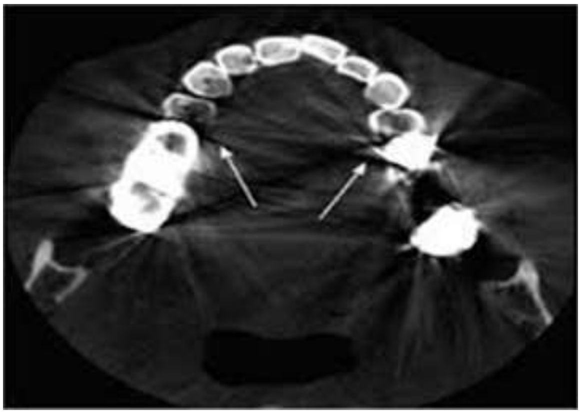

Fig. 3: Photon Deprivation

Patient-related artifacts: Patient motion can cause cause faulty registration of data within the image. Because of the relatively long acquisition times (compared to conventional radiography) and volumetric image acquisition, motion artifacts are common in CBCT. These artifacts can be attributed to improper patient stabilization. Small motions cause image blurring and larger physical displacements produce artifacts that appear as double images or ghost images. This results in poor overall image quality.

Fig. 4: Fault due to patient movement

Scanner-related artifacts: These artifacts typically present as circular or concentric rings centered on the location of the axis of rotation.[6] If one of the detectors is out of calibration on a scanner, the detector will give a consistently erroneous reading at each angular position, resulting in a circular artifact. A scanner with solid-state detectors, where all the detectors are separate entities, is in principle more susceptible to ring artifacts.[9] However, they can impair the diagnostic quality of an image, and this is particularly likely when central detectors are affected, creating a dark smudge at the center of the image. Currently there is no evidence of ring artifacts on CBCT machine in dental radiology literature.

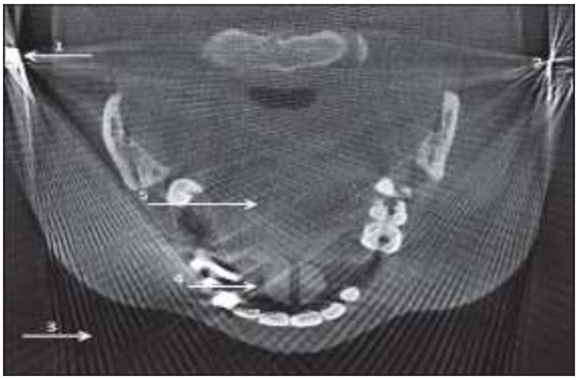

Fig. 5: Image deterioration due to heavy metal. Image also shows the metal earrings, streaks, bands, mouth block, and ring artifact

Image Noise: This is an important image deteriorating factor. It is the result of inconsistent attenuation values in the projection images.[9] Noise is considered one of the most common artifacts in CBCT imaging. There are two types of noise in reconstructed CBCT images: additive, stemming from round-off errors or electrical noise, and photon count. Noise represents itself in inconsistent attenuation values in the projection images -- a "graining" on the image.[1] Because of the use of an area detector, much of this nonlinear attenuation is recorded and contributes to image degradation seen as a noise.

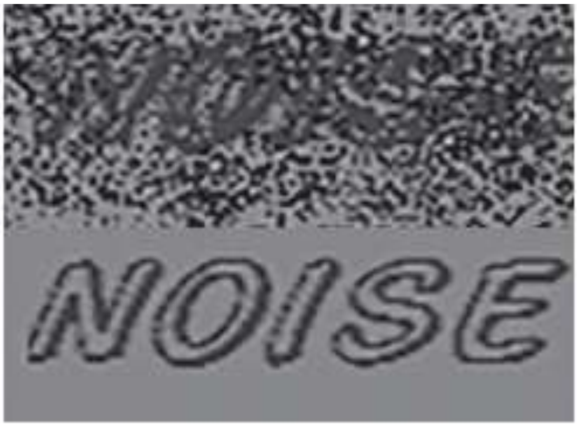

Fig. 6: Noise

Methods to reduce these Drawbacks: With the advancement in image reconstruction, and scanning, computer technology, artifacts occur less frequently in comparison with earlier machines. As to enhance the image quality and to reduce the drawbacks they are summarized in [Table 1]. In a study by Bechara *et al.*,[12] the metal artifact reducing (MAR) algorithm reduced the effects of the beam hardening and scattering caused by a metallic structure.

Drawbacks	Measures to minimize them
Beam hardening artifact	Reduce Field of View (FOV) and modify the arch selection to avoid scanning regions susceptible to beam hardening (such as metal objects) Use of better artifact reduction technique software introduced by manufacturers
Cone-shaped beam-related errors	Select the smallest acquisition voxel to reduce the partial volume averaging error Newer cone beam reconstructions introduced by manufacturers can minimize the cone beam effect Operator can reduce it by positioning the region of interest adjacent to the horizontal plane of X-ray beam and selecting appropriate FOV
Patient-related fault	This can be corrected by shorter scan times and proper patient counseling
Foreign object	Removal of heavy metal jewellery during scanning
Noise and scatter	These are suppressed by using more sophisticated projection and back projection techniques

Conclusion

In day-to-day clinical practice, CBCT imaging is essential imaging modality.To know the effective use of this technology, it is necessary to know the advantages as well as its limitations. Artifacts originate from a range of sources and can de- grade the quality of a CBCT images to varying degrees. The newer technology with artifact reducing software and with high definition has reduced all these limitations. However, as this advancement in technology continues, we can hope for better images leading to a better diagnosis.

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