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Understanding and Addressing Implant Artefacts in Cone Beam Computed Tomography: A Review

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Abstract

For various dental techniques, including implant implantation, cone-beam computed tomography (CBCT) has gained popularity. However, the quality and dependability of the pictures may be harmed by implant artefacts in CBCT. Dental implants and abutments are examples of metallic or radiopaque materials that can absorb X-rays and result in streaking or shadow abnormalities, which are known as implant artefacts. The accuracy of the diagnosis, treatment planning, and implant placement can all be impacted by these artefacts. Therefore, it is crucial to comprehend the sources and effects of implant artefacts and to put the right measures in place to reduce or remove them. The point of this article is to give an outline of the causes, impacts, and likely answers for embed curios in cone-bar registered tomography (CBCT) imaging. The article aims to help clinicians and researchers improve the accuracy and reliability of CBCT imaging for implant placement and other dental applications.

Keywords: Beam hardening, Scanner related artefacts, stair step artefact, zebra artefacts, aliasing artefacts, motion artefacts

Full-length review article*Corresponding Author*, e-mail: atultink@gmail.com

1. Introduction

The NewTom-9000 was the first CBCT device designed specifically for imaging of the maxillofacial region (Quantitative Radiology, Verona, Italy). Cone beam computed tomography (CBCT) is a relatively novel An imaging method that has become a crucial instrument in dentistry for diverse purposes, such as implant positioning. However, like other imaging techniques, CBCT has its limitations and challenges. One such challenge is the presence of implant artefacts, which can significantly affect the accuracy and reliability of the images. When there is a difference between the CT values in the reconstructed image and the actual attenuation coefficients of an object, it is known as a "CT artifact". This difference is considered to be precise dissimilarity [1]. Unfortunately, the CBCT technique produces artefacts due to the presence of dim level nonuniformities. By and large, a relic is an item found during an examination that isn't normally present yet happens because of the preparative strategy [2]. Implant artefacts are caused by the presence of metallic or radiopaque materials, such as dental implants and abutments, which can absorb X-rays and lead to streaking or shadow artefacts in the images. These artefacts can interfere with accurate diagnosis, treatment planning, and implant placement accuracy, leading to potential complications or failures. Therefore, it is crucial to understand the causes and effects of implant artefacts and implement appropriate solutions to minimize or eliminate them [2].

1.1. Benefits of CBCT over CT

- Picture exactness
- Fast sweep time
- Portion decrease
- Diminished picture curios [3].

2. Review and Discussion

2.1. Beam Hardening

Beam hardening artefact is a common artefact that occurs in Computed Tomography (CT) imaging, including in Cone Beam Computed Tomography (CBCT) imaging employed in the field of implant dentistry. Photons with a lower frequency are absorbed at a faster rate compared to the higher-frequency photons, leading to the beam becoming "harder" as it passes through an object, indicating an increase in its average energy[4]. The mean energy of the X-ray beam increases. As a result of the selective intake of photons with less energy as opposed to those with higher energy levels, resulting in the appearance of beam hardening artifact.

By employing iterative reconstruction, these can be minimized. This impact may produce one of two kinds of artefacts. The emergence of obscure stripes or marks encircling solid entities in the picture, as well as the occurrence of 'cupping artifacts. Diminishing the field of vision is advised in clinical practise to avoid scanning areas that could be affected by beam hardening (such as metallic dental restorations or implants). This should be possible by collimation, altering the placement of the patient, or alternatively the division of the dental arches. Filtration, alignment amendment, and programming for Beam solidifying rectification are used by manufacturers to reduce beam hardening.

a)Filtration

The beam is "pre-hardened" by sifting through the lower-energy parts on a level piece of constricting material, normally metallic, before it enters the patient. The margins of the Beam are additionally solidified by a second "bowtie" channel, permitting it to go through the patient's more slender regions.

b)Calibration correction

By adjusting the calibration by using phantoms of various sizes, manufacturers calibrate their scanners.

c)Software for beam solidifying amendment

While reproducing pictures of hard districts, an iterative adjustment approach may be utilized. By applying an appropriate filter, the visibility of dark bands in non-uniform cross-sections can be reduced, along with the obscuration of boundaries between bone and delicate brain tissue in neuroimaging.

d) Aversion of beam solidifying by the administrator

At times it is feasible to abstain from filtering hard regions by either moving the patient or shifting the gantry.

e)By using Blu-Mousse® and polyvinyl siloxane dental material[5].

i. Cupping Artefacts

At the point when a uniform barrel shaped object is imaged, the cupping effect artefact is displayed. As a result of the increased quantity of material the beam must penetrate, X-rays passing through the center of a massive entity become more rigid compared to X-rays traversing its periphery, creating cupping abnormalities. The resultant profile of the linear attenuation coefficients has the appearance of a **"cup"** since the beam becomes more enthusiastically in the item's middle [6].

ii. Streaks and Dark Bands

They are visible between two substantial items. This happens because, at some tube positions, the component of the beam that goes through both objects is harder than the portion that goes through only one of the things at those other cylinder positions. Axial planes 3D reconstruction images provide for a more precise view of the photographs.

2.2. Artefacts related to the patients

Patient movement can bring about information misregistration, which shows up as un-sharpness in the remade picture. This un-sharpness can be decreased by exercising a head self-control and filtering as fast as could really be expected**.** As a result, the overall image quality is poor.

a*) Aversion of metal artefacts by the administrator*

Prior to checking, patients are typically approached to eliminate any removable metal articles, like adornments. For nonremovable things like dental fillings, prosthetic gadgets, and careful clasps, occasionally gantry inclination can be employed to eliminate metallic inserts from scans of adjacent anatomy.

b) Motion artefacts–misalignment artefacts

Back projection is inconsistent when one or more concerning the triad of components (emitter, subject, and sensor)are out of alignment, which is why Both of these potential causes of inaccuracy are so interconnected. Mis-registration artefacts in the image can be caused by patient motion. Assuming an article moves during the examining system, the remaking doesn't represent that development on the grounds that no development data is incorporated into the reproduction cycle.

c) Aversion of movement artefacts by the administrator

In most patients, for preventing voluntary movement, placement aids are sufficient. To mitigate distortions in areas of the body susceptible to motion during the scanning process, it is advisable to employ the briefest scan duration feasible. If patients are capable of sustaining breath-holding for the entire duration of the scan, this can aid in minimizing respiratory motion. The image's sensitivity to motion artefacts is determined by the motion's orientation. As a result, It is more desirable for the commencement and conclusion positions to have the orientation of the tube coincide with the direction of the principal movement.

2.3. Cone-shaped beam related artefacts

Three types of artefacts are produced by the structure of the cone beam projection and the picture reconstruction techniques

a) Fractional volume averaging

At the point when the output's chosen voxel goal is more prominent than the spatial or contrast goal of the item to be imaged.

b) Under sampling

This is an illustration of an associating relic. It seems when a couple of premise projections for the remaking are given.

c) Cone shaft impact

This kind of artefact is seen in the scan's peripheral areas and is caused by X-ray divergence in those areas. Image distortion, streaks, and peripheral noise are the results of the cone beam impact.

d) Correction of Cone shaped beam related artefact

It very well may be diminished by setting the locale of interest adjoining the even plane of the x-beam pillar and selecting an appropriate field of view.

2.4. Scanner related artefacts

a) Ring artefacts

As a result of flaws in scanner recognition or unfortunate alignment, concentric rings seem based on the area of the pivot of revolution.These anomalies manifest as circular bands within the planes that are parallel to the plane of progression of the source (known as axial planes in CBCT), resulting from the circular trajectory and discrete sampling technique.When a dexel within the finder component is flawed or not properly aligned with the x-beam source, it can result in the creation of ring artifacts. This is because the dexel produces an imperfect image projection as it travels around the subject's curve, which ultimately leads to the appearance of ring-shaped artifacts[7].

b) Avoidance and software corrections

Opting for the appropriate scan field of view and utilizing calibration data that is closely aligned with the patient's anatomy can help in reducing artefacts. While Solid State detectors are used in contemporary scanners, their potential for producing ring artifacts can be mitigated through software that characterizes and corrects variations in the detector.

c) Image noise

In the context of a signal, noise refers to a stochastic or non-stochastic disruption that is unwanted and has the potential to obscure the pertinent information in the signal from an observer. Within cone beam CT scanners, noise can hamper the ability to discern low-density tissues, leading to reduced resolution in low contrast regions and hindered effectiveness in tissue segmentation. In reconstructed CBCT images, there exist two forms of noise: additive noise arising from electrical or round-off errors, and photon count noise.In projection images, noise manifests itself as irregular attenuation values, resulting in a "grainy" appearance on the image.

2.5. Extinction artefacts

These are frequently referred to as "**missing value artefacts**. "In cases where the object being examined includes materials with high absorption rates, such as gold restorative prosthetics, the signal captured by the detector pixels situated beyond the material could become insignificant or possibly zero.

a) ***Correction***

The use of post-processing image filters can aid in rectifying the raw data in regions of low photon count. This involves identifying segments of the technique involves utilizing the unprocessed projection data, which experiences a disproportional loss of X-ray signal, and then utilizing a regional 3D filter that generates a smoothing outcome to lessen the occurrence of image noise and streak artifacts.[8]

b) Scatter

The deflection of photons from their initial trajectory, brought about by their interaction with matter., is what leads to scatter. During the reconstruction phase, scatter has the potential to generate streak artifacts that are akin to those produced by beam hardening. This phenomenon is well-known for reducing the contrast of delicate tissues and affecting the density measurements of all other tissues.

2.5.1. Correction methods

i) Scatter Correction Algorithms

Using scatter correction algorithms during the reconstruction process is one of the most common ways to reduce scatter artefacts.

ii) By using 2D anti scatter grid[9]

In Cone Beam Computed Tomography (CBCT), By allowing only a small fraction of scattered radiation to reach the detector through the 2D grid, its usage results in a noteworthy reduction in scatter intensity.

iii) Scatter correction based on empirical methods[10]

iv) Moire-free anti scatter grid[11]

2.6. ***ALIASING ARTEFACT***

Aliasing in CBCT is a result of the cone beam's divergence. As the recorded "rays" traverse through each projection, the voxels that are closer to the origin will encounter a greater number of detected rays that are further away from the sensor, as compared to those recorded in closer proximity. This creates a line pattern, commonly known as moire patterns, which tend to diverge towards the outer edges of the reconstructed volume.[12]

a) Exponential edge gradient effect

When there are when neighboring structures exhibit sharp edges with high contrast, it may lead to the emergence of the EEQE effect. This is because the measured intensity is summed over a finite beam width (and consequently, a finite focal spot width), whereas the reconstruction mathematics assumes zero width. Streaks in the projection direction that are tangent to long straight edges are known to be caused by the EEQE effect. In the oral cavity, sharp edges of metallic FPD with high contrast, such as those found at metallic crown borders, are quite common.

2.7. Stair step artefacts

Employing broad collimations and non-overlapping intervals for reconstruction may give rise to stair-step artifacts near the borders of structures in multiplanar and 3D reformatted images. However, with thin section data acquired using modern multi-section scanners, multiplanar and 3D reformatted images effectively eliminate stair-step artefacts.

2.8. Zebra artefacts

The helical interpolation process can cause inconsistencies in noise distribution along the z-axis, resulting in the appearance of faint stripes in images that are multiplanar or have been reformatted into 3D, acquired via helical scanning. The "**zebra**" effect, which is more noticeable distant from the rotation axis, becomes more pronounced as noise inhomogeneity worsens off the axis. (Table 1) summarizes the appearance of different types of artefacts in CBCT scans, while (Table 2) details methods to reduce these artefacts.(Table 3) provides information on post-implant complications and ways to minimize and correct them.

Table 1: Artefact Appears in CBCT

Sr. #	Author (Year)	Artefact	How The Artefact Appearsin CBCT
i.	Nagarajappa et al (2015)	1. BEAM HARDENING ARTIFACT	
		a) Cupping Artefact	Exhibits a typical cupped form artefact
		b) Streaks Artefact	Appears as the image displays dense entities with dark stripes or bands in between.
		2. PATIENT-RELATED ARTIFACT	Un-sharpness in the reconstructed image
		3. RING ARTIFACT	It's noticeable that circular bands encircle the point where the rotational axis is situated.
		4. IMAGE NOISE	In areas where uniform absorption is expected, there are regions with either elevatedstandard deviations or shades of grey.
		5. SCATTER	In the reconstruction, scatter produces streak artefacts that resembles those brought onby beam hardening.
		6. EXTINCTION ARTEFACT	Appears as streaks or shadows
		7. EXPONENTIAL EDGE GRADIENT EFFECT ARTEFACT	This effect is the most noticeable at the edges that contrast sharply with nearby structures.
		8. ALIASING ARTEFACTS	Expresses itself as line patterns (moiré patterns) which typically diverge at the volume's outer edge.
		9.STAIR STEP ARTEFACTS	In multiplanar models , stair step artefacts are visible around the margins of structures.
		10.ZEBRA ARTEFACT	The usage of helical interpolation technique can result in non-uniform noise distribution in the z-direction, leading to the emergence of subtle parallel lines, commonlyknown as "FAINT STRIPES," in helical data-derived 3D reconstructions and multiplanar images.
ii.	Abhishek Sinha et al (2016)	1.BEAM HARDENING ARTIFACT	
		a)Cupping Artefact	As the beam width reduces and the center of the object becomes denser, the shape of the linear attenuation coefficient profile takes on the form of a "cup"
		b) Streaks and dark bands Artefact	Appears as streaks or dark band between two implants that are closely spaced from one another in the same jaw
		c) Scatter Artefact	Streak artefacts result from scatter
		d) Cone-shaped beam-related Artefacts	The utilization of a cone-shaped beam leads to the deformation of the image,the appearance of stripes, and noise at the edges
		e) Exponential edge gradient effect	In the projection direction, make streaks tangent to long straight edges
		f) Photon deprivation	Appears to be a complete void
		g) Patient-related Artifacts	Image blurring is caused by small movements, and artefacts like double images or ghost images are created by bigger physical displacements
		h) Scanner-related Artifacts	Usually appear as concentric or circularbands located at the point where the rotational axis is situated.
		i) Image Noise	Shows as graining on the image

Table 2: Artefact Mentioning

Sr. No.	Author (Year)	Artefact Author is Mentioning	Method of Reducing the Artefact
i.	AK Hunter et. al (2011)	Cupping Artifacts	Using Copper Pre-filtration
ii.	Abhishek Sinha et. al (2016)	a) Beam hardening artifacts	By reducing the field of view and modifying the arch selection to avoid the regions which are susceptible to Beam hardening.
		b) Patient related artifact	Can be rectified by more limited examination time and appropriate patient counselling
		c) Noise and Scatter	These are revised by utilizing modern projection and back projection techniques
		d) Cone shaped beam related errors	The practitioner can reduce it by placing the area of interest adjacent to the x-ray beam's horizontal plane and selecting an appropriate field of view (FOV).
iii.	Philip Trapp et. al (2022)	Scatter Artifacts	Empirical scatter can be corrected by using software based approaches (ESC generated the scatter-like reference images from each projection image through convolution.
iv.	Tristan M Gottschalk et. al (2023)	Metal artifact	Suggested a technique for diminishing metal artifacts that unites a convolutional neural network with an approximation of the distance of metal pathways.
v.	Nicole V Hinchy et. al (2022)	Beam hardening and photon starvation	Employing Blu-Mousse® and Polyvinyl siloxane lessens the observable consequences of beam hardening and photon starvation.

Table 3: Artefact Complication

Sr No.	Author (Year)	Complication	Reason of Complication	How to Correct The Complication
i.	Gintaras Juodzbalys et. al (2011)	Damage to the canal of the inferior alveolar nerve while inserting the implant.	1.Direct mechanical injury for example intrude,transection,or cut of the nerve is connected with embed interruption into the mandibular canal 2. Post-implant contamination a)Thermal injury b)Delicate tissue swellings c) Implant embed excessively near mandibular canal 3. Aberrant post usable injury a) Mental nerve pressure brought about by delicate tissue oedema b) Inflammation of bone and IAN with auxiliary ischemia	Re-estimation how much accessible bone after tooth extraction is suggested particularly in instances of nerve closeness since a couple of millimetres of the crestal bone may be lost during extraction
ii.	T. Renton et. al (2012)	Neuralgia of the trigeminal nerve following the implantation.	Iatrogenic implant related nerve injury frequently causes diligent neuropathic pain with critical related useful issues which genuinely influences personal satisfaction	In the event that inferior alveolar nerve injury is clear, the implant ought to be taken out in the span of 24 hours of arrangement
iii.	Hugo Gaeta-Araujo et. al (2020)	Perforation of pertinent anatomical structures caused by the implant.	1. The long axis of the implant is not properly aligned with the alveolar process and is unrelated to bone loss. 2. Penetrations of neighboring structures.	Extra short and short implants can be used to lower the risk of perforating the anatomical structures
iv.	Matheus Souza et. al (2022)	Implant placed into the Canalis Sinuosus	Injury to Canalis Sinuosus during implant insertion	Evacuation the implant/ Replacing the implant with a shorter implant
v.	Yaser Safi et. al (2022)	Accidental displacement of the dental implant into the nasal cavity	Possible reasons may include insufficient skill and knowledge of the dental practitioner, inadequate bone density, excessive implant compression, unaddressed damage to the sinus lining (Schneiderian membrane), or excessive force applied during the procedure.	Removal of the implant

3. Conclusion

Artifacts arise from a scope of starting points and can crumble the nature of CBCT pictures to differing degrees. Thus, more current methodologies endeavor to keep away from reproduction blunders by enhancing either missing data or wrong data in the projection pictures. Notwithstanding, there are many occasions where cautious patient positioning and the ideal choice of sweep boundaries are the main elements in keeping away from picture ancient rarity**.**

Beam hardening artefact is a most common artefact that occurs in Computed Tomography (CT) imaging, including in Cone-Beam Computed Tomography (CBCT) imaging.Three fundamental principles of The ALARA (As Low As Reasonably Achievable) concept;

a)*Time*

Reduced exposure time can directly reduce exposure to radiation and radiation dose. The strength of a radiation field at the same point in time in air is measured as exposure. The amount of energy imparted by ionizing radiation to a given mass of matter is referred to as the absorbed dose.

b) Distance

By increasing the distance between your body and the origin of radiation by a factor of four, you will reduce your exposure to radiation by a factor of four. Correct application of the principles of inverse-square law can result in a significant reduction in radiation exposure for both medical staff and patients.

c) Shielding

Utilizing safeguard materials, for example, lead for X-beams and gamma beams is a successful method for decreasing radiation openings.

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