Variations of CBCT Hounsfield Units at Different Distances from Single-Placed Dental Implant Due to the Metal-Induced Artifact Effect

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Abstract

Objective of the research was to assess changes of Hounsfield units as representative values of relative bone density at different distances from single-placed dental implant for quantitative demarcation of beam hardening artifact effect zone. Study sample included 76 pairs of CBCT data sets obtained before and right after single implant placement.

Analysis of CBCT images was provided within Planmeca Romexis Viewer software of 5.1.0 version for Windows. Measurements of peri-implant Hounsfield units (HU) were provided by the two approaches: 1) with the use of peri-implant “Verification” instrument within ranges of 1 mm, 2 mm and 3 mm outside the dental implant; 2) by in-detail manual measurement with the use of “Rectangular” instrument from the “Annotation” set within ranges of 1 mm, 2 mm and 3 mm outside the dental implant. Metal artifact effect in means of visually recognizable dark streaking bands (darkening zone) was limited to an average 0.43±0.15 mm around placed dental implants with no statistical difference noted in such installed either at molar or at premolar region ($p > 0.05$). After implant placement statistically significant increase of Hounsfield values was noted at 1 mm ($p < 0.05$), 2 mm ($p < 0.05$) and 3 mm ($p < 0.05$) outside physically placed implants both at molar and premolar regions compared to the values registered before implant placement outside virtually positioned fixtures.

Considering specifics of present study it may be concluded that placement of single dental implant provokes significant variations of CBCT Hounsfield units as representative values of relative bone density through metal artifact effect at distances up to 3 mm from installed fixture.

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Introduction

Due to the Position statement of the American Academy of Oral and Maxillofacial Radiology cone-beam computer tomography (CBCT) with limited field of view (FOV) may be interpreted as imaging modality for pre-operative analysis of future implant site.[1] Analogical indication for CBCT use was presented in the systematic review focused on guidelines, indications and radiation dose risk regarding tomographic examination methods in implant dentistry.[2] Analysis of 600 patients’ data revealed that implant planning was the second most common indication for the CBCT examination (32.7%), while lesion assessment was the first one responsible for the 40.8% cases of CBCT use in clinical dental practice.[3] CBCT provides possibilities for implant placement planning not only considering available geometrical parameters of bone proposal in means of linear measurements, but also taking into account bone quality parameters, including relative bone density.[4]

Even though CBCT represents reliable and accurate method for implant treatment planning, safety margin of 2 mm should be kept in relation to surrounding anatomical structures,

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since diagnostic value of CBCT may be reduced by the influence of metallic objects-artifacts, patient motions, machine-specific exposure parameters.[5]

Presence of dental implants within jawbone associated with beam hardening artifacts, which occur on the obtained CBCT scans after placement of metal fixtures.[4] CBCT study demonstrated that beam hardening artifacts represented by dark bands and streaks are the most prevalent among different types of artifacts registered at the obtained scans with an average incidence level of 38.8%.[3] In the retrospective study beam hardening and streak artifacts were noticed in 67.1% of all analyzed cases.[6] Recent integrative review also reported beam hardening artifact being the most prevalent within the CBCT scans used for implant practice.[7]

Presence of dental implant associated artifacts on received CBCT image may cause suspicion of implant non-integration, visual reduction of real peri-implant defect's sizes and underestimation of buccal bone thickness.[8]

There are no unequivocal conclusions regarding quantitative parameters of beam hardening artifacts' linear expansion at adjacent peri-implant area and distantly from the installed fixture. In most of available cases CBCT metal-induced artifacts caused by dental implants were analyzed under conditions of simultaneous several implants placement within jawbone, which usually causing drastic changes of relative bone density parameters measured in Hounsfield units (HU) at peri-implant area.[9,10] Nevertheless, only few studies presented attempts for quantitative measurement of CBCT implant-associated beam hardening artifact's linear dissemination within surrounding and distant jawbone tissue.[11, 12]

Recent literature review highlighted the need for realization of further studies aimed at improvement of CBCT image quality for correct peri-implant pathology diagnostics, taking into account a fact that peri-implant area is frequently affected by implant-associated artifacts.[13] Moreover, there is a need in developing adapted CBCT exposure protocol, which would enhance image quality even under condition of implant-induced beam hardening artifacts presence.[13] Such approach would be easier to realize if magnitude (spread/dissemination) of dental implant-caused beam hardening artifact could be quantified in absolute units of measurements.

Objective

To assess changes of Hounsfield units as representative values of relative bone density at different distances from single-placed dental implant for quantitative demarcation of beam hardening artifact effect zone.

Materials and methods

Present study represented retrospective analysis of CBCT data sets of patients, who undergone procedure of single implant placement. Original pool of CBCT data sets was formulated from CBCT database available at VitRus Dental Clinic (Uzhhorod, Ukraine), which represents clinical base for professional training of dental interns during postgraduate education at Faculty of Dentistry (Uzhhorod National University, Ukraine). All the CBCT examinations were provided on Planmeca ProMax® 3D Classic CBCT machine (anode voltage – 60–90 kV, anode current – 1-14 mA, focal spot – 0.5 mm (fixed anode), image detector – flat panel, image acquisition – single 200 degree rotation, scan time – 9-37 seconds, typical reconstruction time - 2–25 second, maximum volume with a single scan – Ø8 x 8 cm, standard resolution (voxel size) – 200 μm).

Primary CBCT database included 1623 data sets of dental patients. Considering specific objective of present research following parameters were used as inclusion criteria to formulate corresponding study sample of CBCT data sets: 1) patients who undergone procedure of single implant placement at the mandible; 2) availability of CBCT data sets of patient before and right after the implantation (as control imaging modality for checking correct implant positioning); 3) high quality of available CBCT data objectified due to the generally accepted criteria; 4) absence of artifacts related with positioning and/or preparation of patient for the CBCT examination, provoked by non-adequate CBCT machine calibration or associated with metal or highly radiopaque objects present within oral cavity (in addition to single placed dental implant); 5) absence of periapical pathologies, bone defects and signs of endodontic treatment at the area of the teeth adjacent to the implant placement zone; 6) realization of high/maximum metal artifact reduction (MAR) algorithm during CBCT examination; 7) agreement of patients who's CBCT data corresponded to the criteria 1-6 to provide further analysis of their dental records with full anonymization of personal data and only in research objective; 8) availability of patients dental records for anonymized analysis of clinical data, anamnesis and diagnosis; 9) absence of any disease or pathological conditions evidenced by available clinical, anamnestic and diagnostic information that potentially may have pronounced impact on bone condition of the mandible.

Next parameters were used as exclusion criteria: 1) presence of any other metal object or highly radiopaque objects within oral cavity except installed dental implant; 2) single implant placement at maxilla region; 3) presence of artifacts related with non-correct patients positioning and/or non-adequate preparation of patients for CBCT examination; 4) presence of artifacts that potentially may be related with deficient calibration of CBCT machine; 5) patients disagreement for their anonymized dental record analysis aimed at specification of patient's clinical data, anamnesis and diagnosis; 6) clinical, anamnestic or any diagnostic data that evidence bone pathology or any diseases that potentially may have impact on mandibular jawbone condition; 7) presence of periapical pathologies and/or bone defects at the projection of the teeth adjacent to the implant placement zone; 8) endodontic treatment of teeth adjacent to the implant placement zone; 9) realization of other than high/maximum MAR algorithm during CBCT examination.

Considering above-mentioned inclusion and exclusion criteria the final study sample of CBCT paired data sets (received before and right after implantation) was formed, which consisted of 76 pairs of images. No additional CBCT examinations were provided to support present study and no CBCT scans obtained immediately after implant placement were originated specifically for present study objective. Present research followed retrospective design and was aimed at analyzing only the scans already present within original pool of CBCT data sets.

Analysis of CBCT images was provided within Planmeca Romexis Viewer software of 5.1.0 version for Windows (Planmeca OY, Helsinki, Finland).[14] Measurements of peri-implant Hounsfield units (HU) were provided by the two approaches. First approach included the use of peri-implant "Verification" instrument due to which it was possible to measure mean values and standard deviation of Hounsfield units within ranges of 1 mm, 2 mm and 3 mm outside the dental implant. Such verification was provided before implant placement by using virtual implant positioning and after implant placement by assuring same virtual implant superimposition over the physically installed implant (Figure 1 and Figure 2). Specific care was taken to ensure full correspondence of physically installed implant position with such provided during virtual positioning.

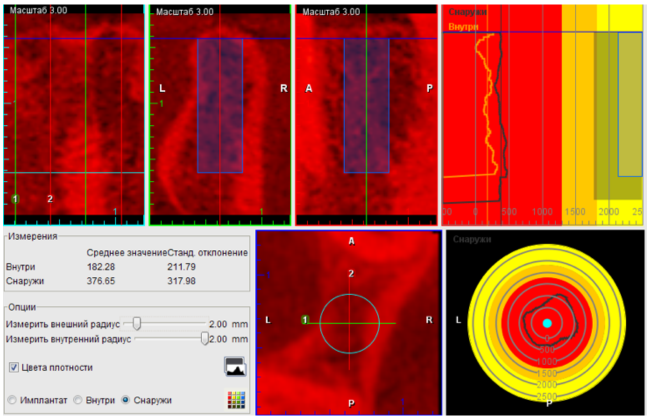

Figure 1. Analysis of HU at different distances outside virtually positioned dental implant in the adapted software using peri-implant "Verification" instrument.

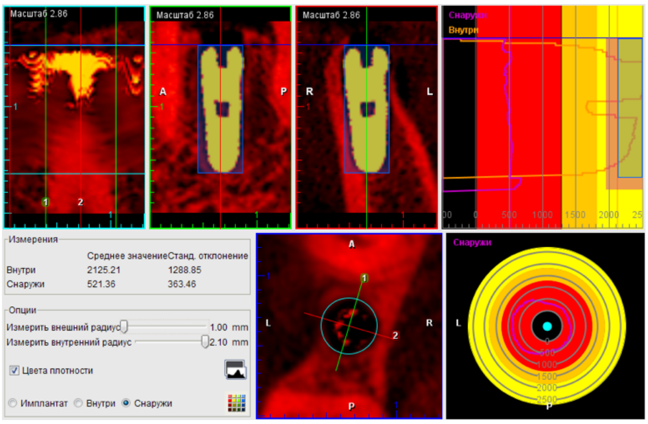

Figure 2. Analysis of HU at different distances outside physically placed dental implant in the adapted software using peri-implant "Verification" instrument (notice the full correspondence with position provided during virtual positioning).

Second approach included in-detail manual measurement of peri-implant Hounsfield units with the use of "Rectangular" instrument from the "Annotation" set at different ranges of outside-implant areas (1 mm, 2 mm and 3 mm) within the same Planmeca Romexis Viewer software (Figure 3).[15]

Figure 3. Analysis of HU at different distances outside physical placed dental implant in the adapted software using “Rectangular” instrument from the “Annotation” set.

Impact of beam hardening artifacts (BHA) was measured due to the previously described rating system, which originally was developed to asses quality of obtained CBCT images: 5 points – no signs of BHA; 4 points – minimal BHA with more than 90% of dental implant structure imaged in the correct manner; 3 points – moderate BHA with more than 75% of dental implant structure imaged in correct manner; 2 points – pronounced BHA with more than 50% of dental implant structure imaged in correct manner; 1 point – severe BHA with less than 50% of dental implant structure imaged in correct manner.[16]

Statistical analysis

Hounsfield units at different ranges outside placed dental implants were measured in the form of mean values and standard deviations. All the numerical data was systematized and statistically process within Microsoft Excel software version 16.0 (Microsoft Office 2019, Microsoft Corporation India Pvt. Ltd., New Delhi, India) with the use of XSTAT add-in (Addinsoft Inc., Long Island, USA). The normal distribution of data was assessed using the Shapiro-Wilk test. Differences in Hounsfield units measured outside installed fixture before and after implant placement at different ranges were statistically affirmed only under condition of $p < 0.05$ (significance level of 0.95), while Student’s t-test was used for comparison of obtained data. Inter-method agreement focused on measuring the concordance between two sets of HU measurements, obtained by two approaches listed in the Material and Methods sections, was assessed with Cohen’s kappa.

Ethical aspects

Design of present study and its conformity with relevant ethical standards was approved by Institutional Review Board of Faculty of Dentistry at Uzhhorod National University (Ukraine). Provided research is a part of complex scientific research work of the Department of Restorative Dentistry at Uzhhorod National University (Ukraine) dedicated to the implementation of modern materials and technologies into the dental practice.

Results

Out of formed study sample consisted of 76 paired CBCT data sets (received before and after implant placement), 56.58% (43 paired sets) belonged to male patients who undergone single implant placement procedure, while 43.42% (33 paired sets) – to female patients.

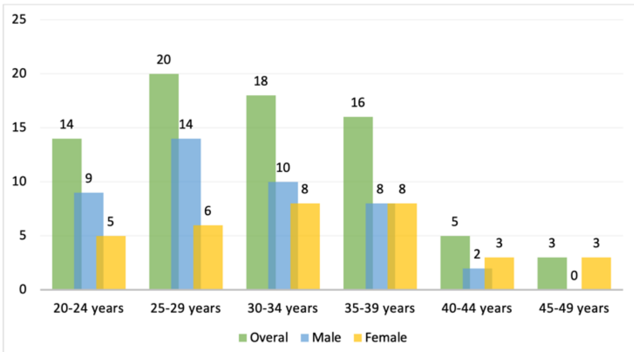

Figure 4. Age and gender distribution of the patients who’s CBCT data sets were collected into the study sample.

Distribution of the patients considering age and gender parameters was presented by the following pattern: 20-24 years old – 14 patients/18.42% (9 males/11.84% and 5 females/6.58%), 25-29 years old – 20 patients (14 males/18.42% and 6 females/7.89%), 30-34 years old – 18 patients/23.68% (10 males/13.16% and 8 females/10.53%), 35-39 years old – 16 patients/21.05% (8 males/10.53% and 8 females/10.52%), 40-44 years old – 5 patients/6.58% (2 males/2.63% and 3 females/3.95%), 45-49 years old – 3 patients/3.95% (all females) (Figure 4).

In 23.68% (18 images) of analyzed CBCT scans no visual signs of beam hardening artifacts were noted even though the dental implant was present; while 71.05% (54 images) of CBCT scans demonstrated minimal visual signs of beam-hardening artifacts with more than 90% of dental implant structure imaged in the correct manner. Only 5.26% of analyzed tomographic images (4 scans) were characterized with moderately presented signs of beam hardening artifact and more than 75% of dental implant structure imaged in correct manner.

Metal artifact effect in means of visually recognizable dark streaking bands (darkening zone) was limited to an average 0.43±0.15 mm around placed dental implants with no statistical difference noted in such installed either at molar or at premolar region ($p > 0.05$) (Figure 5).

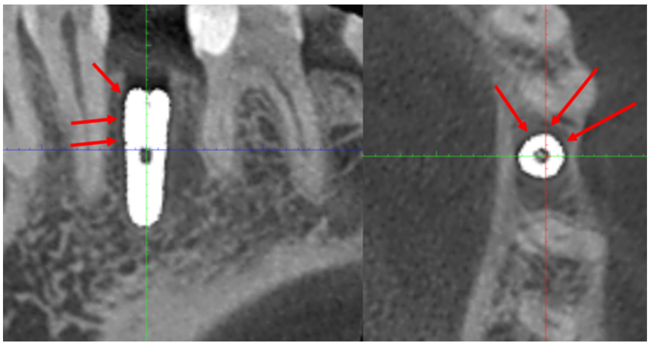

Figure 5. Minimal visually recognizable signs of beam hardening effect in means of dark streaking bands (darkening zone) around single placed dental implant

	Before implant placement			After implant placement		
	1 mm outside virtually positioned implant	2 mm outside virtually positioned implant	3 mm outside virtually positioned implant	1 mm outside physically placed implant	2 mm outside physically placed implant	3 mm outside physically placed implant
HU at molar region	329.71	341.26	389.75	564.57	517.28	510.83
SD	313.18	330.49	345.73	386.14	395.24	406.31
HU at premolar region	368.58	367.73	393.60	525.49	497.45	493.41
SD	327.07	314.43	353.45	353.27	363.15	382.14

Table 1. Mean HU values registered at different distances outside virtually positioned and physically placed dental implants.
HU – Hounsfield units, SD – standard deviation

Before implant placement mean Hounsfield values in the molar region 1 mm outside virtually positioned implant corresponded to 329.71±313.18 units, 2 mm outside virtually positioned implant – to 341.26±330.49 units, and 3 mm outside virtually positioned implant – to 389.75±345.73 units; while at premolar regions such Hounsfield values equaled to 368.58±327.07, 367.73±314.43 and 393.60±353.45 at 1 mm, 2 mm and 3 mm outside virtually positioned implant respectively (Table 1).

After implant placement statistically significant increase of Hounsfield values was noted at 1 mm ($p < 0.05$), 2 mm ($p < 0.05$) and 3 mm ($p < 0.05$) outside physically placed implants both at molar and premolar regions compared to the values registered before implant placement outside virtually positioned fixtures.

Differences of mean HU values observed at 1 mm, 2 mm and 3 mm outside virtually positioned implant both at molar and premolar regions were not statistically approved ($p > 0.05$); HU values noticed at 1 mm, 2 mm and 3 mm outside physically placed implant were also not significantly different between each other ($p > 0.05$).

No statistically affirmed relations of registered HU changes with an age ($p > 0.05$) or gender ($p > 0.05$) parameters of the patients were noted.

Meanwhile specific trend was noted during processing of obtained data: mean HU values tended to increase while moving from 1 mm to 3 mm outside virtually positioned implant, and on the other hand – mean HU values registered on the range of 1-3 mm outside physically placed implant demonstrated decreasing pattern while moving from metal fixture. Due to the above-mentioned trend differences in mean HU values noticed at the same distances outside virtually positioned implant and outside physically placed implant characterized with descending order: at 1 mm from implant – 234.86 HU, at 2 mm from implant – 176.02 HU, at 3 mm from implant – 121.08 HU for molar region; and at 1 mm from implant – 156.91 HU, at 2 mm from implant – 129.72 HU, at 3 mm from implant – 99.81 HU for premolar region.

Concordance between sets of HU measurements, one of which was obtained using "Verification" instrument of peri-implant area and another was determined by manual instrument of "Rectangular" marking along implants' axis, equaled to 0.87 for cases before implant placement, and 0.81 for cases after implant placement.

Discussion

Basic CBCT image quality assessment relies on the verification of following four principal parameters: spatial resolution, contrast, noise and artifacts.[3] Artifacts noticed on the received CBCT scans could be caused by unit-related, patient-related or object-related factors.[3] Development of beam hardening artifacts associated with the absorbance of low energy protons and increase of mean energy of the beam due to the passage of high energy protons.[3,4,7,9] If two metal objects with the high density like dental implants located one near other it can cause development of streaks and dark bands, while also cupping artifact effect may have place.[9,10] Beam hardening artifacts are more pronounced on the received CBCT images compare to CT scans due to the heterochromatic nature and lower kilovoltage peak energy of CBCT beams.[17] Also beam hardening artifacts are ones of the most frequently noticed during the use of CBCT as image modality in implant practice. In present research visual signs of beam hardening artifacts were registered among 76.31% of all analyzed CBCT images, which is in full correspondence with outcomes of retrospective study provided by Mahesh et al.[6], who reported 67.1% prevalence of such.

One of the laboratorial studies revealed that single titanium dental implants do not cause significant black streaks arising, except areas closely related to the long axis of fixture.[18] In present study obtained results were in full correspondence with outcomes of Fontenele et al. study,[18] since significant visual signs of beam hardening artifact in the means of dark streaking bands (darkening zone) was limited only to 0.43±0.15 mm zone around placed fixture. On the other hand significant but not visually recognizable HU changes were noted after dental implant installation at the distance up to 3 mm from placed fixture, which also may be interpreted as deterioration of CBCT image caused by metal object. The latter effect may be not visualized on the first place during image observation without any additional analysis provided, but obviously it represents outcome of beam hardening phenomenon. Study of Fontenele et al. also revealed that image deterioration effect caused by the beam hardening artifacts associated with placed dental implant may reach distance of up to 3.5 cm, which is in accordance with results obtained in present research.[18] In contrast several other researches demonstrated significant value of image deterioration around titanium dental implants, which may be caused by the presence of few, but not one installed fixture, CBCT machine parameters and features of exposure.[7,8,9,10]

Expressiveness of beam hardening artifacts was greater at peri-implant areas of fixtures placed into low density bone (IV) compared to such noted around the implant installed into the bone of I, II and III types.[19] Lower magnitude of beam hardening artifact within the frontal mandibular area may be potentially associated with its relatively higher density, due to which low-energy beams got absorbed by the bone itself, while high-energy beams reached metal fixture.[7] In present research no statistically related differences were noted in beam hardening artifacts expression at mandibular molar and premolar areas, which may be caused by the analogical relative initial density of those regions.

Analysis of beam hardening artifact among CT images of dental implants placed in *in vitro* conditions revealed that Grade 4 implants were associated with more pronounced artifacts compared to Grade 5 dental implants, while severity of artifacts may be lowered through high kVp parameter.[10] Based on provided study it was proposed to use changes of CT Hounsfield units to quantify beam hardening artifact impact.[10] The same approach was used in present study, while we analyze variations of CBCT Hounsfield units as indirect indicators for beam hardening artifact magnitude. Even though CBCT-derived HU do not represent real bone density values, changes of such itself demonstrate the impact of metal fixture caused artifacts, and magnitude of such at peri-implant area may be interpreted as an extent of beam hardening effect.

Nevertheless it should be kept in mind that quantitative values of CBCT Hounsfield units may vary in significant manner, and it should be generally avoided to use them for the different cases comparison.[20,21] CBCT device features, exposure parameters, the position within field of view which may be either central or peripheral may impact the indicators of Hounsfield units and cause their variations even during repetitive examination of the same patient.[20, 21] In present study it was intended to provide research within standardized clinical conditions, due to which all patients were prepared for CBCT scanning by the same roentgenologist, no additional objects that potentially may cause beam hardening effect were present within the oral cavity of patient, CBCT data with signs of artifacts induced by patient's movement or scanning specifics were primary excluded from the study sample.

Recent *in vitro* research demonstrated that such factors as presence of cover screw and presence of another implant may affect implant blooming effect, while also such effect was more pronounced for zirconium implants compared to titanium ones.[8] Experimental study demonstrated analogical trends: artifacts generated because of zirconium implants were more pronounced with gray values variations that those generated because of titanium fixture.[23]

Several techniques have been proposed to minimize effect of metal artifacts on possibility of accurate diagnostics, while some of them have been already approbated in clinical conditions, and other underwent laboratorian approval.[23, 24, 25] Previously it was noted that the use of high metal artifact reduction algorithms with 96 kVp and low resolution supports minimum artifact effect around posts manufactured of different materials and inserted into the root canals.[17] Integrative review systematized that beam hardening effect associated with placed dental implants may be lowered by the following CBCT parameters: smaller field of view, larger voxel size and higher kV peak.[7] In present research maximum effort was applied to minimize artifact expression magnitude, which included following measures: usage of maximum metal artifact reduction algorithm, application of small FOV, exclusion of scans with signs of non-correct patients positioning and/or non-adequate preparation of patients for CBCT examination, while also images with other metal objects except placed single dental implant were excluded from the study sample.

Significant advantage of present study argumented by the fact that analysis of beam hardening effect was held based on CBCT data from real clinical conditions of patients who have undergone single implant placement, while number of previous studies with analogical objective was realized within experimental conditions.[8,9,10,11,12] Even though CBCT is not recommended as imaging modality for immediate postoperative implant position check, in present study we used immediate postoperative CBCT data to analyze impact of beam hardening artifacts. But it is worth to mention that no additional CBCT examinations were provided to support present study and no CBCT scans obtained immediately after implant placement were originated specifically for present study objective. Provided research followed retrospective design and was aimed at analyzing only the scans already present within original pool of CBCT data sets.

Possibilities to prognose exact magnitude of beam hardening artifact and extract such from obtained 3D scans may be sufficiently used during improvement of various artificial intelligence models in implant dentistry, aimed at prognosis of osseointegration and implant fixture recognition by the provided X-ray features.[26]

Conclusion. Considering specifics of present study it may be concluded that placement of single dental implant provokes significant variations of CBCT Hounsfield units as representative values of relative bone density through metal artifact effect at distances up to 3 mm from installed fixture. Hounsfield units in projection of bone regions directly adjacent to the installed dental implants characterized with pronounced changes after implant placement compared to before-placement situation, while metal artifact effect in means of visually recognizable dark streaking bands (darkening zone) was limited only to 0.43±0.15 mm zone around placed fixture. Nevertheless clinical significance of such outcomes should be interpreted with caution, since observed pattern of Hounsfield units variations at different distances from placed implant may be argumented by specific "ideal conditions" of provided study, which includes correct positioning and strict preparation of patient for CBCT examination, in-time calibration of CBCT machine, usage of maximum artifact reduction algorithms, absence of any other metal structure within oral cavity and usage of limited field of view.

Declaration of Interest

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