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Evaluation of Beam Hardening Artifacts Around Dental Implants: CT Study on Bovine Ribs

SUMMARY

Background/Aim: *The aim of this study was to evaluate beam hardening artifacts generated by Grade 4 and Grade 5 dental implants on computed tomography (CT) images at low and high kilovoltage peaks (kVp).* ***Material and Methods:*** *A total of 16 implants, 8 of which were Grade 4 and 8 were Grade 5, were inserted into bovine ribs. CT images of bovine ribs were acquired using two different exposure protocol: low kVp and high kVp. Beam hardening artifacts generated by Grade 4 and Grade 5 dental implants were calculated by the mean Hounsfield unit (HU) within a standardized region-of-interest (ROI).* ***Results:*** *Artifact in Grade 4 implants were greater than that in Grade 5 implants. Also, artifacts at the high kVp were lower than that at the low kVp.* ***Conclusions:*** *CT scans providing HU values can be used to evaluate the beam hardening artifact. Beam hardening artifacts decreased in the CT images with high kVp. Grade 5 dental implants have an advantage by producing less severe beam hardening artifacts.*

Keywords: Beam Hardening Artifact, Bone Density, Computed Tomography, Dental Implant

Gozde Serindere[1], Ceren Aktuna Belgin[1], Mehmet Serindere[2], Huseyin Berkay Belgin[3], Kaan Orhan[4,5]

[1] Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Hatay Mustafa Kemal University, Hatay, Turkey
[2] Department of Radiology, Hatay Education and Research Hospital, Antakya, Hatay, Turkey
[3] Private Dental Clinic, Hatay, Turkey
[4] Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Ankara University, Ankara, Turkey
[5] Medical Design Application and Research Center (MEDITAM), Ankara University, Ankara, Turkey

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Introduction

Computed tomography (CT) machines are widely used in clinical imaging, thanks to their spatial resolution of up to 2.5 lp/mm and their excellent performance and accurate measurement keeping error in several Hounsfield units (HU)[1,2]. However, high-density materials such as metallic implants will bring strong artifacts and significantly reduce the diagnostic value of CT images[3].

Metal artifacts are frequently observed and result from many mechanisms such as beam hardening, scattering, aliasing, non-linear partial volume and noise, and photon starvation[4]. Beam hardening artifact occurs as follows: When X-ray beam passes through an object, the lower energy photons are absorbed compared to higher energy photons. Beam hardening artifact is frequently caused by high-density objects including metallic restorations and dental implants[5].

Titanium and its alloys are commonly used for dental works, including implants, crowns, bridges, overdentures, and dental implant. Commercially pure titanium is preferably used for endosseous dental implantation operations. Today, there are four commercially pure Ti grades and a titanium alloy specially produced for dental implant. These metals are specified as grades 1 to 5 according to American Society for Testing and Materials. With grades 1 to 4 unalloyed, grade 5 with 6% aluminum and 4% vanadium is the strongest[6]. The aim of this study was to evaluate beam hardening artifacts generated by Grade 4 and Grade 5 dental implants on CT images at low and high kilovoltage peaks (kVp).

Material and Methods

Using an effect size of a difference in an artifact of 16, with a measurement standard deviation of 233, and a significance level of 0.05 for the main effects in a two-way ANOVA, 2 measurements of implant artifact were collected to achieve a power of 0.75.

Fresh bovine rib bones were taken from the local butcher and were of already slaughtered animals. Bovine ribs were prepared to simulate alveolar bone, as previously reported by the studies[7,8]. Two blocks of bone approximately of the same size were prepared. A total of 16 implants, 8 of which were Grade 4 and 8 were Grade 5, were inserted into two bovine ribs. One block belonged to Grade 4 implants and the other block belonged to Grade 5 implants. To distinguish, bone with Grade 4 implants inserted, was marked. On the superior border of each bone block, 8 points at a distance of 1 cm from each other were marked with a pencil to show the implants' position. After implant placement, the rib bone blocks were placed in a plastic container filled with water to simulate soft tissue attenuation.

A 256 slice CT scanner (Revolution CT; GE Healthcare) was used to obtain the images of the bones. The artifacts made by the implants on the CT sections were measured under two different conditions (low kVp - 80 kVp and high kVp - 100 kVp). For each scan, a coronal slice was used to evaluate the beam hardening artifact. HU value was measured with the standardized region-of-interest (ROI) (approximately 0.05 cm^2) from the part adjacent to the implant and with the lowest density (Figure 1). These measurements were performed by an experienced calibrated observer (G.S) using the RadiAnt DICOM Viewer (64 bit) software (Medixant, Poznan - Poland). All evaluations were performed by observer's own laptop (15.6-inch full HD notebook with resolution of 1920x1080 pixels). Same observer (G.S) evaluated all images twice. Intra-observer reliability was estimated between observations performed 2 week apart. Undecided situations were solved by consensus with M.S who was a medical doctor in Radiology Clinic and had nearly 6 years of clinical experience.

Statistical Analysis

Statistical analysis was performed with SPSS 26.0 for windows, through analyzing the Analysis of *variance (ANOVA)*. Due to the presence of two factors, ANOVA two-way was used and because both levels of kVp were repeated for the samples, repeated measurement was used. ANOVA was applied for the second grade of implants under two different conditions. The significance level was set as 0.05 for the main effects in a *two-way repeated-measures ANOVA.*

Results

The reliability was estimated by Intra-class Correlations (ICC) for all observations. Intra-observer ICC values for all observations were excellent (ICCs > 0.85). Descriptive statistics of HU values were shown in Table 1 and 2. Also, Figure 1. illustrates the means as shown in Table 1 as a scatter plot. There was a significant difference between the Grade 4 and 5 and HU values ($p<0.05$). A significant difference was found between two levels of kVp (High and low) and HU values ($p<0.05$). As the ANOVA results and Figure 2. indicate, artifact produced by Grade 4 implant was greater than that of grade 5 implant. Also, the artifact at the high kVp was lower than that at a low kVp.

Table 1. Descriptive statistics (mean and SD)

	Low kVp Mean(SD)	High kVp Mean(SD)
Grade 4	-584.95(233.71)	-517.46(219.67)
Grade 5	-266.53(114.16)	-178.97(43.21)

Table 2. Descriptive statistics (frequency, min, and max)

kVp		Frequency	Min	Max
Low	Grade 4	8	-1024	-239.61
	Grade 5	8	-467.56	-123.30
High	Grade 4	8	-984.76	-332.44
	Grade 5	8	-251.35	-125.67

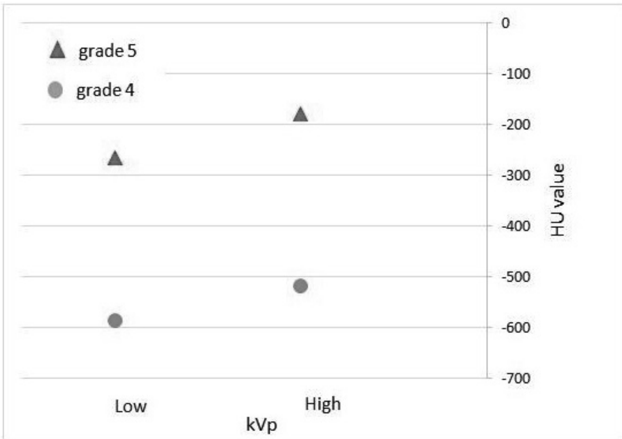

Figure 1. Mean HU values of artifact for Grade 4 and 5 implants in high kVp and low kVp

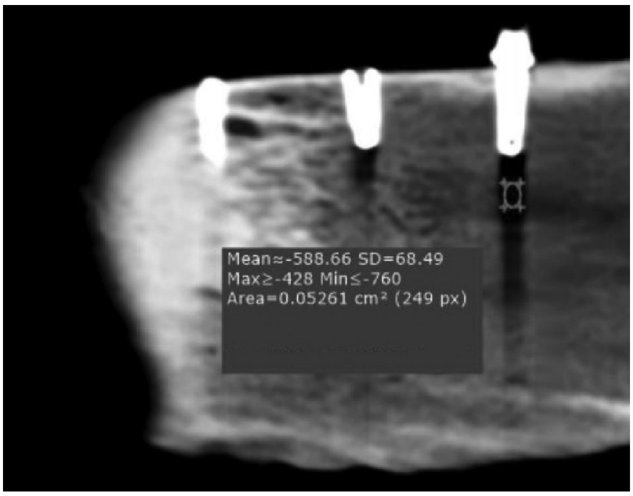

Figure 2. Artifact measurement on CT scan

Discussion

CT provides three-dimensional assessment of anatomic landmarks and direct measurement of bone density, expressed in HU[9]. Hounsfield units (HU) are standardized numbers deriving CT machine. HU values show the relative density of tissues according to a calibrated gray-level scale, based on some values. The values for air, water and bone density are -1000 HU, 0 HU, and +1000 HU, respectively[10].

Rao and Alfidi[11] reported that beam hardening artifact could increase CT numbers. In the present study, higher values were also interpreted as excessive artifact density. Beam hardening artifact negatively affect the image quality and some light lines reflected from the metal object or completely dark areas adjacent to the metal object could be seen. Artifacts around dental implants can affect the clinical decisions of the dentists[8,12,13].

Beam hardening occurs in polychromatic X-ray sources. As the X-ray passes through the body, low energy X-ray photons are more easily attenuated, and the remaining high energy photons cannot be attenuated easily. Therefore, beam transmission does not follow the simple exponential distortion observed with a monochromatic X-ray. This is a special problem with high atomic number materials such as bone, iodine, or metal. Compared to materials with low atomic number such as water, materials with high atomic number have increased attenuation at low energies[4].

Scanning at a higher kVp results in a harder X-ray beam, and therefore beam hardening artifacts occur less. Additionally, metallic object is more “transparent” to higher energy photons, which reduces the likelihood of blocking all photons, thereby reducing scattering artifacts. However, the cause of the tradeoff is less tissue contrast at high kVp[4].

Among exposure parameters, kVp appears to be the most important factor affecting metallic artifacts produced by dental implants[14]. In this study, higher kVp was associated with smaller artifacts, which is in accordance with the results of previous studies[15-17].

The size of the metallic artifact depends on the energy of the photons coming into the object and the detection of the beam that can pass through the object[18]. Demirturk Kocasarac *et al*.[19] reported that Grade 5 dental implants have a slight advantage to cause less severe artifacts. Similarly, in this study, artifact in Grade 4 implants was greater than that in Grade 5 implants. In our opinion, the fact that the grade 5 implant causes a lower artifact can be attributed to the lower amount of x-rays passing through the object since it is harder than the grade 4 implant. Additionally, titanium is a transition metal and element that have the atomic number of 22[20]. Grade 4 titanium is unalloyed. However, Grade 5 titanium includes aluminum and vanadium[6], which have atomic numbers of 13 and 23, respectively[21,22]. So, we think that having a low atomic number of titanium Grade 5 may be the reason for the low artifact density it produces.

Draenert *et al*.[23] reported that CBCT shows strong beam hardening artifact whereas the multi dedector CT provides a good image quality. However, Demirturk Kocasarac *et al.*[19] reported that greater artifact production was observed on CT images than Cone beam CT images, but both modalities exhibited the fewest artifacts from Grade 4 and 5 titanium implants. So, in this study, we preferred using CT to evaluate the artifacts produced by dental implants.

There are some advantages and limitations of this study. To the best of our knowledge, except the study of Demirturk Kocasarac *et al.*[19], the absence of any other CT study in the literature comparing the artifact density produced by Grade 4 and 5 dental implants may be a sign that this subject is needed and this can be said as an advantage. However, the lack of literature has caused difficulties in the writing of the discussion part of this article. Draenert *et al.*[23] reported that the accurate reason for the severe beam hardening artifact cannot be given and suggested that further investigations could include CT scans at 90 kVp. This can be an advantage that the present study was carried out using values close to 90 kVp. Despite the power analysis result, the fact that the study could not be performed with a higher number of implants is a limitation. Another limitation is that even though the size of ROI is standardized, the HU values depend on the observer. To solve this problem, the same observer performed two observations at two-week intervals and the HU values measured of these observations were averaged.

Conclusions

Wrong diagnoses lead to wrong treatment. Especially late diagnosis of a malignant lesion can be very important for the life of the patient. High-quality and artifact-free radiological images are needed for an accurate diagnosis and early treatment. We think that this study will benefit the literature. However, further studies with higher number of samples and different parameters are required.

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Correspondence

Gozde Serindere
Department of Dentomaxillofacial Radiology
Hatay Mustafa Kemal University, Faculty of Dentistry, Turkey
e-mail:gozdeserindere@mku.edu.tr