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Original Article

The incidence of artifacts in cone beam computed tomography images: A pilot study

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Abstract

Aim: Cone-beam computed tomography is an important diagnostic tool in dentistry. However, cone-beam computed tomography technology has various limitations such as image artifacts. The aim of this study was to evaluate the incidence of various artifacts or errors in the cone-beam computed tomography images and to investigate the correlation between artifacts and parameters such as age groups, gender, imaging areas and acquisition times.

Material and Methods: Five different types of artifacts were evaluated. Patient's age, gender, the reason for radiographic examination, the field of view (FOV), acquisition time, anatomical area and presence of artifacts were recorded. The Pearson Chi-Square and Fisher's Exact test were used for comparisons of the parameters.

Results: The images of 600 patients aged from 6 to 88 years (mean age ± standard deviation: 36.2 ±16.8) were examined. The beam hardening (dark band or streaks) were the most common artifacts (38.8%). An increase in the number of artifacts was observed with the increase in FOV and voxel size ($p<0.05$). The prevalence of motion artifacts was 0.7% and a statistically significance was found between motion artifact and age. ($p<0.05$). The cupping and aliasing artifacts were also correlated with the FOV.

Conclusion: The results of our study showed that artifacts are an important problem affecting image quality. Careful patient positioning and the optimum selection of scan parameters are the most important factors in preventing image artifact.

Keywords: Artifacts; cone-beam computed tomography; field of view, limitations; imaging; voxel.

INTRODUCTION

Cone-beam computed tomography (CBCT) is a commonly used imaging modality in the maxillofacial area with a lower radiation dose compared to conventional computed tomography (1,2). The dental applications such as implant planning, three-dimensional modeling, maxillofacial surgery, and orthodontic are a widely used imaging tool (3,4). CBCT produces high-resolution images of tissues and is a useful imaging method, especially for the evaluation of hard tissues. However, CBCT technology has various limitations such as lack of the accuracy of soft tissue and the presence of various types of imaging artifacts that cause images to deteriorate (5). Artifacts can seriously reduce the quality of the images, can sometimes make them unusable as diagnostic. The presence of irregularity in the gray plane in the reconstructed CBCT images contributes to the formation of artifacts (6). It should take into considering that the artifacts seen in cone beam imaging are generally related to the geometric process of the x-ray tube head and detector rotating around the object used to capture the base images from which 3D volumes are reconstructed (7). When dentists and surgeons have interpreted tomography images, they should be aware of these limitations and the errors and distortions affecting the image quality. These distortions may lead to a false or inadequate diagnosis.

In recent studies agreed that artifacts may be associated with the unit-related (scatter, aliasing, and unit-motion artifacts), and object-related or patient-related factors (2,8,9). One of the most common artifacts is the white and dark lines or light flares resulting from the dense structures in the image (7). Metallic restorations, brackets, and implants affect the quality of the image because they cause effects such as beam hardening and scatter (10). Beam hardening appears as two different artifacts on the reconstructed image with a cupping artifact and

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dark bands or streaks (11,12). The streak artifacts, in turn, appear as linear radiopacities emitted from a metallic material (5).

A motion artifact is another commonly observed artifact in CBCT images (7). This condition is observed as parallel lines in the direction of movement direction in images. It causes the image to blur in small movements and physical displacements in larger movements. It is also necessary to understand why artifacts emerge and how to prevent them to optimize image quality. The aim of this study was to evaluate the incidence of image artifacts and errors in cone-beam computed tomography images, retrospectively.

MATERIAL and METHODS

Ethical approval and permission to undertake the study were given by the Ethical Committee of Gazi University (2019-056). The CBCT images present in the archive of the Dentomaxillofacial Radiology department were evaluated, and patients' privacy was maintained. In our Radiology clinic, informed consent was routinely obtained from all patients before CBCT examinations. In this X-ray unit, patients stand during exposure. To prevent movement of the patient's head, two vertical support bars were balanced with adjustable head support and chin support. CBCT images belonging to 600 patients (357 females and 243 males) aged between 6-88 years old were examined. The CBCT images were obtained using a Promax 3D unit (Planmeca, Helsinki, Finland), operating at 90 kVp, 9-14 mA, with 0.1, 0.2 and 0.4 mm voxel size, and effective exposition time. The acquisition time is also adjusted by the device according to the image area (mean times; 12.0 sn, 12.6 sn or 13.7 sn). The field of view (FOV) was changed according to the imaging protocol chosen by the CBCT operator. All patients were immobilized using a headband to reduce retakes. According to the manufacturers' suggestions, the patient's head was balanced using two vertical support bars, head support, and chin support during the exposure time. All images were analyzed with software (Planmeca, Romexis viewer 2.6.2.R) on a 24-inch Nvidia Quadro FX 380 screen with 1280 x 1024 resolution in a quiet room with subdued ambient lighting. All images were evaluated in three orthogonal planes (sagittal, axial, coronal planes). The evaluation of the images was made by two Oral and Maxillofacial Radiology experts simultaneously. The final decision on the images was based on the consensus of both observers. Patient's age, gender, reasons for CBCT examination, the field of view (FOV), voxel, acquisition time, anatomical areas, and presence of artifacts were recorded. The patients' age was divided into four groups (6-15 years, 16-35 years, 36-55 years, and over 56-years). Artifacts were classified (8,12) and recorded as follows; Beam hardening (dark bands or streaks), cupping and aliasing artifact, metal artifact, motion artifact (Figure 1). The type of artifact relating to beam hardening appeared as dark bands or streaks in the adjacent areas to high-density structures. Cupping artifact was seen as a distortion of metallic structures as a result of differential absorption. Aliasing appeared as fine striations in the image. It was recorded as a motion artifact if images were seen double or un-sharpness of bony contours.

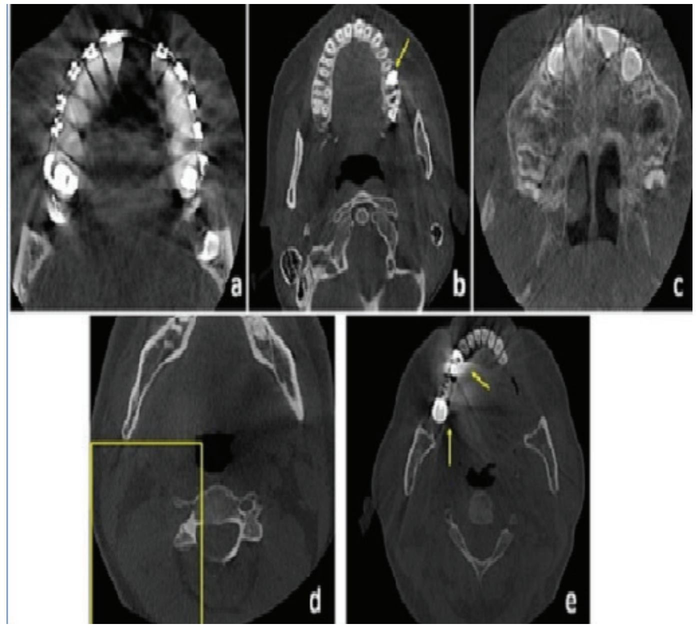

Figure 1. The appearance of the artifacts in axial sections; metal artifact (a), cupping artifact (b), motion artifact; un-sharpness of bony contours due to motion of 10-year-old male patient (c), aliasing artifact (d), beam hardening with dark bands and streaks (e).

Statistical Analysis

All statistical analysis was performed using IBM-SPSS (International Business Machines-Software Package for Social Sciences) Statistics, Version 23•0 (Armonk, New York). The statistical analysis was conducted with descriptive statistics. The significance level was set to 0.05. The analyses were conducted using Fisher's Exact, Pearson Chi-Square test, and Gama correlation coefficient.

RESULTS

In this study, CBCT images of 600 participants aged from 6 to 88 years (mean age: 36.2 years, St. deviation:16.8) were examined. 59.5% (nf=357) were female, 40.5% (nm=243) of the participants were male. The most common indications for CBCT scan were implant planning. The gender distribution and indications were given in Table 1.

In this study, five different types of artifacts were studied. Among all 600 images, 15 images were without artifact. At least one metal structure was observed in 429 images. The beam hardening (dark band or streaks) was the most common artifacts (38.8%). The motion artifact was only observed in ten CBCT images. The correlation between the existence of the artifact and gender was analyzed by Fisher's Exact test. According to the non-significant p-values ($p>\alpha=0.05$), for none of the artifacts, there were no significant relationships between the existence of artifacts and gender (Table 2).

Table 1. The most common indications for CBCT			
Indications	TOTAL, n (%)	Female, n (%)	Male, n (%)
Pre-operative implant planning	196 (32.7%)	120 (33.6%)	76 (31.3%)
Impacted teeth	67 (11.2%)	36 (10.1%)	31 (12.8%)
Lesions	245 (40.8%)	150 (42%)	95 (39.1%)
Others (Temporomandibular joint, paranasal sinus, trauma, etc)	92 (15.3 %)	51 (14.3%)	41 (16.8%)
TOTAL	600	357	243

Table 2. Correlation between gender and artifacts				
Artifacts	TOTAL, n (%)	Female, n (%)	Male, n (%)	p-values
Beam Hardening (dark bands or streaks)	585(38.8%)	345(38.3%)	240 (39.7%)	1.000
Cupping artifact	134(8.9%)	84(9.3%)	50(8.3%)	0.425
Aliasing artifact	348(23.1%)	213(23.6%)	135 (22.3%)	0.354
Motion artifact	10(0.7%)	3(0.3%)	7(1.2%)	0.099
Metal artifacts	429(28.5%)	256(28.4%)	173 (28.6%)	0.927
TOTAL	1506	901	605	0.654

* significant at α=0.05

The patients' age was divided into four groups; 6-15, 16-35, 36-55, and over 56-years. The correlation between the existence of the artifact and age is analyzed by the Pearson Chi-Square test. The motion artifact, the 6-15 age group has a larger proportion compared to over 16 years. A statistically significant difference was found between age groups and the presence of motion artifact (p<0.05). For metal artifact, two age groups; 6-15 and 16-35 differs from the older age groups. The existence proportion of metal artifact increases as age increases (Table 3).

Table 3. The correlations between age groups and artifacts					
Artifacts	Age groups				p-values
	6-15 age	16-35 age	36-55 age	56+ age	
Beam Hardening (dark bands or streaks)	34	288	159	104	0.795
Cupping artifact	6	59	41	28	0.240
Aliasing artifact	12	169	91	76	0.000*
Motion artifact	4	2	2	2	0.024*
Metal artifact	23	195	126	85	0.001*

* significant at α=0.05

The correlation between the existence of the artifacts and FOV is analyzed by the Pearson Chi-Square test and the Gamma correlation coefficient. The existence of the aliasing artifact is highly and positively correlated with the FOV (r=0.974, p=0.000). Moreover, the cupping artifact is also correlated with the FOV (r=0.179, p=0.030). In total, the correlation between the existence of the artifacts and the FOV is statistically significant (r=0.283, p=0.000). The aliasing artifact is highly and positively correlated with voxel (r=0.994, p=0.000). In total, the correlation between the existence of the artifacts and voxel sizes is statistically significant (r=0.298, p=0.000) (Table 4).

Table 5 shows the correlation between acquisition times and artifacts. According to the non-significant p-values (p>α=0.05), for the beam hardening, streaking, cupping and metal artifacts, the acquisition time does not an affect. However, for aliasing artifact, three different acquisition times statistically differ from each other (p=0.000<α=0.05) and the aliasing artifact is highly and positively correlated with acquisition time (r=0.951, p=0.000). Moreover, the motion artifact was the common highest observed when the acquisition time was 12.2 sec.

Table 4. The correlations between FOVs, voxel sizes and artifacts									
Artifacts	FOV				p- values	Voxel sizes			p- values
	4 cm	8 cm	10 cm	20 cm		0.1 mm	0.2 mm	0.4 mm	
Beam Hardening (dark bands or streaks)	3	177	71	334	0.674	2	244	339	0.969
Cupping artifact	1	27	24	82	0.030*	1	51	82	0.422
Aliasing artifact	0	14	2	332	0.000*	0	15	333	0.000*
Motion artifact	0	7	0	3	0.074	0	5	5	0.620
Metal artifact	3	127	55	244	0.448	2	179	248	0.846
TOTAL	7	352	152	995	0.000*	5	494	1007	0.000*

* significant at α=0.05

Table 5. The correlation between acquisition times and artifacts

Artifacts	Acquisition Times (mean)			P-values
	12.0 sn	12.6 sn	13.7 sn	
Beam Hardening (dark bands or streaks)	229	24	332	0.369
Cupping artifact	48	4	82	0.408
Aliasing artifacts	8	4	336	0.000*
Motion artifact	5	2	3	0.022*
Metal artifact	168	16	245	0.670
TOTAL	458	74	1328	0.000*

* significant at α=0.05

DISCUSSION

CBCT is an important imaging technique in dentistry with diagnostic accuracy. Therefore, it is important to fully understand the limitations or drawbacks of CBCT imaging to achieve the full benefit of this technique. The aim of this study was to evaluate the artifacts in the CBCT images and to investigate the correlation with age, gender and imaging parameters. Our results showed that 15 CBCT images were only without artifact. The beam hardening artifact was the most commonly observed artifact (38.8%).

Basic image quality characteristics can be defined using four basic parameters: spatial resolution, contrast, noise and artifacts (3,13). The artifact is any distortion or error that is not related to the subject (tissue/organs) examined the image. Artifacts can be classified according to their reasons (14). In the literature, the most frequently mentioned artifacts are; beam hardening, streak, and motion artifacts (5). There are several in vitro or phantom studies in the literature regarding the evaluation of artifacts. According to our knowledge, there is only one study in the literature and evaluate both image parameters such as FOV, acquisition time, age, anatomic areas and artifacts as in vivo (15).

Beam hardening and scattering radiation can cause gray-level irregularity in CT images (6). The beam hardening artifacts appear as dark bands or streaks in the adjacent areas to high-density structures (such as titanium implants, amalgam filling, and plaques). Streaks, in turn, appear as linear radiopacities emitted from a metallic material (5). High-density objects such as amalgam, crown prosthesis, titanium implant in the X-ray path cause beam hardening, which are the most prominent artifacts (8). Chindasombatjaroen et al (16) compared the streak artifacts produced by dental metals concerning metal types and imaging parameters in a CBCT and multi-detector computed tomography (MDCT) scanner. The result of their study showed that the metallic artifacts produced by most dental metals in CBCT were quantitatively smaller than those produced in MDCT under identical conditions (16). Although the increase in kVp resulted in a decrease in artifacts, an increase in tube electric current showed no effect on artifacts (16). It is recommended to reduce the FOV, and to change the position of the patient's head or separate dental arches to avoid beam hardening in the clinic (17). Benic et al (18) showed that regardless of the implant position, adjacent of the titanium implant always seen the artifact in vitro study. Nardi et al (15) reported that metal artifacts showed a statistically significant association with FOV and acquisition times. However, in our study, the association between both metal artifacts and FOV or acquisition times was no statistically significant (p>0.05).

In CBCT, the conical-shaped X-ray beam increases the amount of X-ray scattering that is captured by a flat image sensor. It also supports image artifacts with insufficient grayscale sensitivity and the use of lower exposure settings (8,19). Hunter and Mc-David (6) suggested that scatter radiation may provide a potential source of contributing to the grey level non-uniformity encountered throughout the FOV in CBCT. The acquisition parameters, detector type, technical factors, and reconstruction algorithms are important parameters evaluating image quality (20). The CBCT unit should have different voxel and FOV options to be used in different indications and to optimize the radiation dose of the patient (21). Pauwels et al (13) showed that large FOV performed better, because of the local tomography effect for small FOVs. To reduce the effect of artifacts, two possibilities are shown: increasing the FOV size and increasing the mAs. However, to use of larger FOVs leads to an increase in dose, while reducing artifacts, which is not applicable in practice (13,22). The voxel size is related to spatial resolution, small voxel sizes provide higher quality images than images obtained with larger voxels (23). In our study, the voxel dimensions were 0.2 mm for 4, 8 and 10 cm the FOV diameters and 0.4 mm for 20 cm the FOV diameters. An increase in the number of artifacts was observed with the increase in FOV and voxel size (p<0.05).

Beam hardening and scattering also produce a common artifact known as cupping artifact, especially more prevalent in the center of a uniform cylindrical object (6). In our series, cupping artifact showed in 8.9% of cases. It was also determined that there was a correlation between the FOV and cupping artifact.

The size of the detector elements and the divergence structure of the cone-beam are factors causing aliasing artifacts. This is observed as line patterns (moire patterns) in peripheral areas of reconstructed CBCT images (8). Our results showed that the aliasing artifact is highly and positively correlated with voxel and FOV (p<0.05). We observed that the rate of aliasing artifacts increased especially in the large FOV and voxel value (in 0.4 mm voxel).

A motion artifact is a general problem in radiology. This problem causes to reduce the image quality with patient movement in CBCT imaging. Several studies on motion artifacts have been published (15,24,25). One of the main reasons for patient motion artifacts is thought to belong screening time (15-40 seconds) (2). Patient anxiety, being of a very young age or old age and fear may be suggested as reasons for patient movement (15,24-26). The patient's position in the CBCT scanning (supine, sitting or standing) and the fixing status of the head may affect the patient's movement (27). Also, motion artifacts can be more visible for images with small voxel dimensions (8). In previous studies, prevalence of motion artifact in CBCT images was about 2-41.5% (2,15,24). Yıldızer Keriş (24) reported that excessive patient anxiety did not affect the artifact of motion during the CBCT examination and movement artifact was associated with age. Donaldson et al (25) reported that 95.5% of the first scans showed no signs of motion artifact and 99.5% is acceptable and have diagnostic accuracy. Besides, the results of their study showed that motion artifacts were most observed the patients under 16 years and over 65 years (25). In our study, the motion artifact was only observed in ten (0.7%) images and a statistical significance was found between motion artifact and age. ($p<0.05$). The motion artifacts were more observed under 16-year-old patients. The short acquisition times and the good fixation of the head during scanning were caused that observed less motion artifact. According to the results of this study, FOV, acquisition time and imaging areas are also not related to motion artifact and consistent with other CBCT studies (15,24). We would like to emphasize that all data is obtained in a Planmeca CBCT unit. It cannot generalize our results to other CBCT scanners. Other limitations of this study include the data from a single dentistry hospital.

CONCLUSION

In daily clinical practice, it is necessary to know its advantages and limitations to use CBCT imaging technology effectively. The results of our study showed that artifacts are an important problem affecting image quality. Beam hardening was observed as the most prominent artifact. Careful patient positioning and the optimum selection of scan parameters are the most important factors in preventing image artifact.

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