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CBCT Artifact Evaluation in a Single Device: Insights and Limitations

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ABSTRACT

Objective: To classify the types of artifacts in cone-beam computed tomography (CBCT) and to evaluate them according to age and gender.

Methods: CBCT images of 1500 patients (766 males and 734 females) aged 5-92 (mean age: 40.89 ± 18.82 years) were retrospectively evaluated and the patients were categorized into 4 age groups: under 20 years old, 20-39 ages, 40-59 and over 60 years old. The types of artifacts encountered in CBCT images were classified. The relationship between the artifact types with age and gender were investigated. Chi-square test was applied to analyze the relationships between variables and distribution of parameters.

Results: Of the cases, 284 (18.9%) were under the age of 20, 389 (25.9%) were between the ages of 20-39, 554 (36.9%) were between the ages of 40-59 and 273 (18.2%) were over the age of 60. Moire artifact was observed at the highest rate (100%), while motion artifact was determined at the lowest rate (19.5%), and no ring artifact was detected in the analyzed images. Metallic artifact, metallic artifact removal, streak artifact and presence of dark bands were found to be statistically significant in females ($p = .002$, $p = .001$, $p = .002$ and $p = .002$, respectively). There was no statistically significant correlation between cupping artifact, metallic artifact, metallic artifact removal, streak artifact, dark band and noise, and stitched artifact ($p > .05$).

Conclusion: Both device and patient-based artifacts in CBCT images should be known, as well as the ways to prevent them.

Keywords: Artifacts, metallic artifact, streak artifact, motion artifact, cone-beam computed tomography

1. INTRODUCTION

Cone-beam computed tomography (CBCT) has become one of the important diagnostic methods for dentists and researchers working in the rapidly changing field of digital dentistry with the innovations in computers and developments in scanning technology (1). Compared to medical computed tomography (CT) images used for similar purposes, the radiation dose required for CBCT is lower than for CT (2). Besides its many advantages, one of the main disadvantages of the CBCT system is the appearance of artifacts in reconstruction images due to various reasons. These artifacts cause image distortion and may lead to erroneous diagnosis or misdiagnoses (3, 4).

There are some studies on different artifact classifications in the literature (1, 5-10). Two studies were found that evaluated metallic and motion artifact according to age group (11, 12). Most of the previous work evaluates on algorithm and software developments to reduce and prevent metal and motion artifacts (5, 12-14). Efforts have been made to eliminate metal artifacts by applying this algorithm and software on images or phantom models of patients with materials such as dental implants, orthodontic materials, endodontic posts and metal-supported prostheses that cause metal artifacts (15-18). In studies regarding motion artifact, the effect on diagnostic accuracy was evaluated. In addition, the effect of patient anxiety on motion artifact was investigated (19, 20).

However, as far as we know, there is no study examining all types of artifacts according to age and gender. Therefore, the aim of this study is to classify the types of artifacts detected in CBCT images of patients, and to evaluate them retrospectively according to age and gender.

2. METHODS

Before commencing the study, the Clinical Research Ethics Committee of Gaziantep University granted ethical approval (Protocol No: 2020/403). The images used in this study were taken between 2017-2020 at the Department of Dentomaxillofacial Radiology, located in the Faculty of Dentistry at Gaziantep University, using the Planmeca

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Promax 3D (Helsinki, Oy, Finland) CBCT device. The images were retrieved from the tomography archive, asymptomatic patients who underwent CBCT exam for various indications were selected. Multiplanar images were obtained from 16×5, 16×9, 16×16 FOV (field of view) with 0.4 mm^3 voxel size and 1 mm slice thickness. Inclusion criteria for this study are CBCT scans acquired from patients aged 5-92 between 2017-2020. Exclusion criteria; include patients with syndromes or facial growth disorders, presence of distortion, magnification or foreign bodies in the study area on CBCT images, metabolic bone diseases, cysts, tumors, or fracture lines in the examination area, cysts affecting the maxillary sinuses, tumors, or trauma in the maxillofacial region, and odontogenic infections. CBCT images of 1500 patients (766 males and 734 females) aged 5-92 (mean age: 40.89 ± 18.82 years) were evaluated retrospectively. 1500 patients were classified into 4 age groups: under 20 years old, 20-39 ages, 40-59 ages and over 60 years old. More than one artifact can be found in the same CBCT scan.

2.1. Image Analysis

The images were analyzed using Romexis software (Helsinki, Oy, Finland). Common types of artifact encountered in CBCT images were analyzed and classified (Figure 1) as follows:

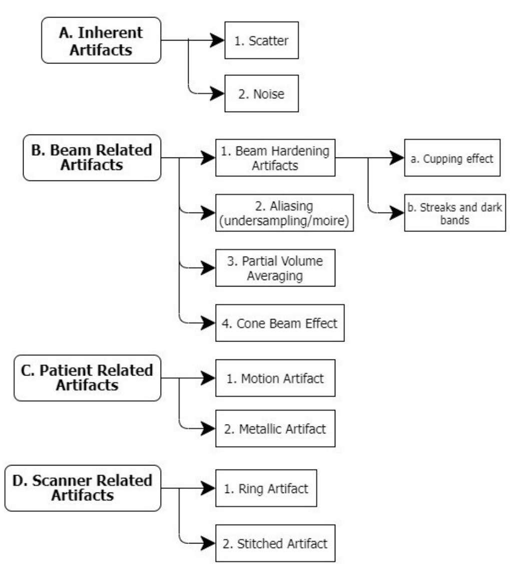

Figure 1. *Diagram showing the classification of artifacts considered.*

– Scatter is caused by X-ray photons being deflected from their original path as a result of interactions with matter. Since CBCT employs area detectors, scattered photons are captured, which contributes to an overall degradation of the image or "quantum noise" when compared to CT imaging (21). In projection images, noise can be identified by the presence of inconsistent gray values for attenuation, as well as larger standard deviations in areas where a constant attenuation is anticipated (1, 5, 8) (Figure 2).

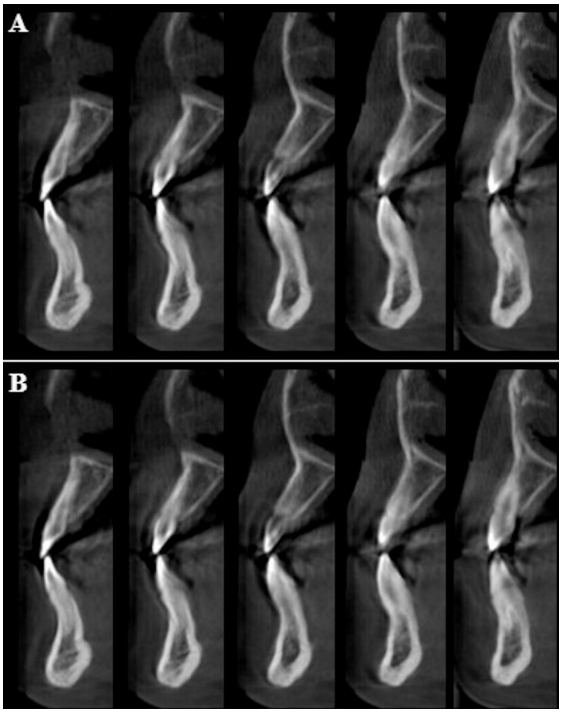

Figure 2. *It is known that the noise varies depending on the section thickness. Cross-sectional CBCT images show noise variation between images with slice thickness of 0.4 mm in A and slice thickness of 5.20 mm in B.*

-Low-energy rays emitted from the X-ray source are absorbed as they pass through objects, causing an increase in the remaining X-ray energy. Thus, beam hardening artifact occurs (22, 23). Beam hardening results in two phenomena: Cupping artifact is caused by the absorption of X-rays and results in the degradation of metallic structures (Figure 3A). It appears as dark streaks or bands between two dense objects and is more visible in axial planes and 3D reconstruction images (Figure 3B). The presence of this artifact can significantly reduce the quality of the image (23).

-White streaks called metallic artifact are observed in relation to metallic structures such as prosthetic and amalgam restorations, orthodontic brackets and wires, implants, surgical plates or screws (1, 24) (Figure 3).

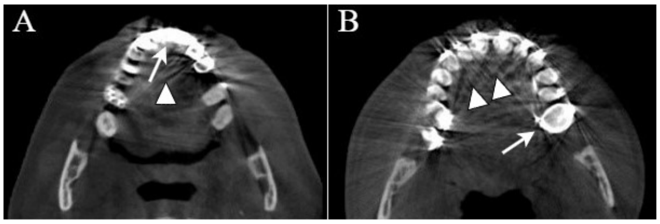

Figure 3. *Axial CBCT images (A and B): Cupping artifact (white arrows) and dark band (arrowheads) are shown.*

-Undersampling/aliasing artifacts, also known as the Moire pattern, can occur due to the undersampling of structures within the subject by the cone beam unit's detector, particularly when only a few basis projections are used for the reconstruction. Slightly wavy lines that diverge towards the periphery of the image are observed (1, 5) (Figure 4).

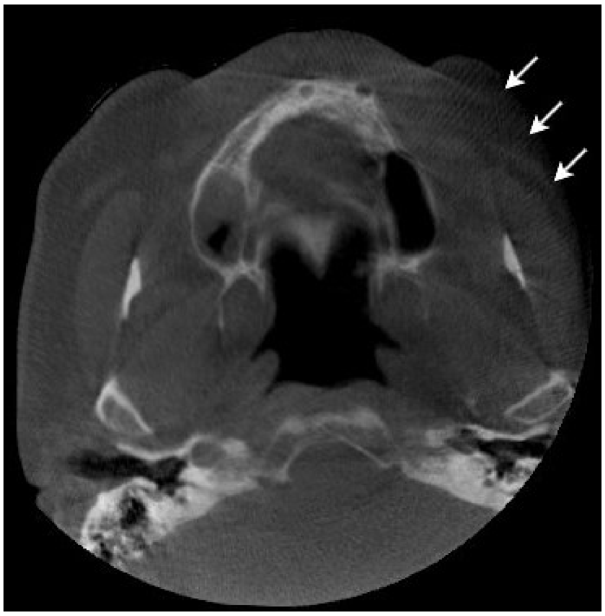

Figure 4. *Moire artifact (white arrows) is demonstrated in the axial CBCT image.*

-If the voxel size selected for a scan is larger than the size of the object being imaged, it can lead to partial volume averaging artifacts. Partial volume averaging artifacts are occured by regions with rapidly changing surfaces in the 'Z' direction, for example, in the temporal bone (1, 21).

– Cone-beam effect artifact occurs in the peripheral regions of the scan and is caused by the X-rays diverging in those areas. As a result of the cone beam effect, peripheral "V" artifact occurs, consisting of image distortion, lines, noise, and reduced contrast (1, 8, 21) (Figure 5).

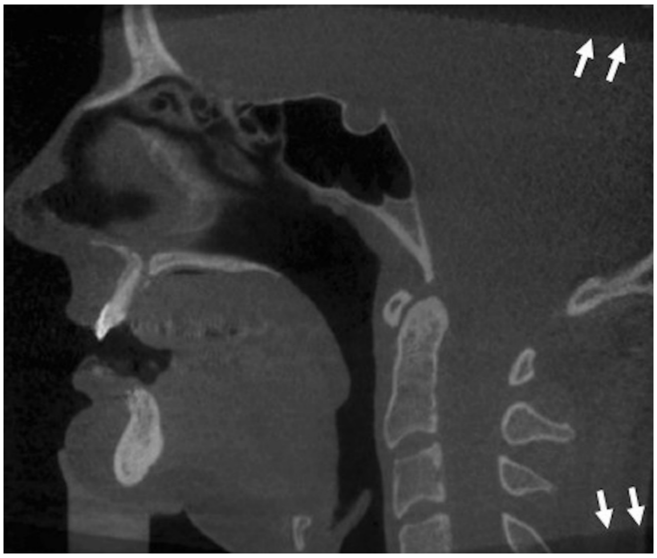

Figure 5. *Cone-beam effect (white arrows) is shown in the sagittal CBCT image.*

-Ring artifact is typically circular in shape and is caused by scanner detection defects or lack of calibration (21, 22).

-Patient motion artifact can cause erroneous recording of data, along with a lack of image acuity or a double image of bone contours (1, 21) (Figure 6).

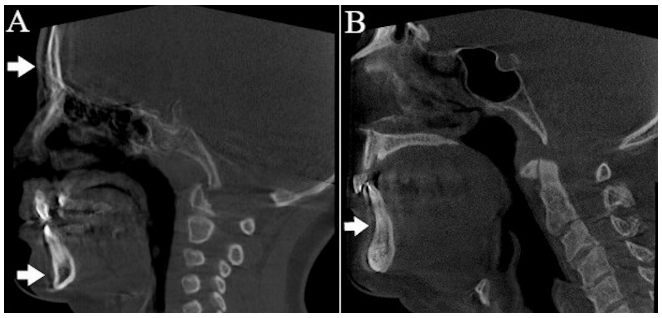

Figure 6. *Motion artifact is (white arrows) demonstrated in the sagittal CBCT images (A and B).*

-Stitched artifact formed during the reconstruction of the obtained data occurs in the 16×16 and 16×9 FOVs of the Planmeca Promax 3D device used in the present study (Figure 7).

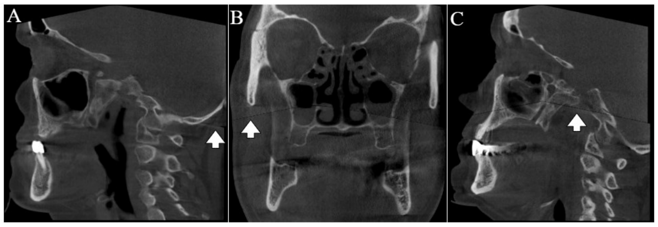

Figure 7. *Stitched artifact (white arrows) is indicated in the sagittal (A, C) and coronal (B) CBCT images.*

All evaluations were conducted by two dentomaxillofacial radiologists, one of whom was a four years experience specialist dentomaxillofacial radiologist (EMAO) and the other had nine years of experience dentomaxillofacial radiologist (EDY). In cases where there was disagreement between the observers, a consensus was reached through discussion. In order to ensure intra-examiner calibration and reliability of the evaluations, the same observers reviewed the images two weeks after the initial evaluation.

2.2. Statistical Analysis

The kappa statistics were utilized to determine inter-observer and intra-observer agreement. The relationships among categorical variables were analyzed using the Chi-square test. The data was analyzed using SPSS software version 22.0 (IBM Corp, Armonk, NY), and statistical significance was defined as $p < .05$.

3. RESULTS

The coefficient of intra-observer and inter-observer reliability for all assessments was determined to be excellent, with values of 0.93 and 0.88, respectively. The study analyzed a total of 1500 CBCT images, with 766 (51.1%) males and 744 (48.9%) females (with a mean age of 41.13 ± 18.55 and 40.64 ± 19.09, respectively) included in the analysis. Regarding the FOV of the exams evaluated, 45.1% were 16x16, 43.8% were 16x9 and 11.1% were 16x5. Cone beam effect 40.2%, moire artifact 100%, ring artifact 0% cupping artifact 40.5%, metallic artifact, streak artifact and dark band 67.6%, motion artifact 19.5%, stitched artifact 34.7% and noise at a rate of 76.6% were detected in the scans. In addition, metallic artifact removal rate was observed as 57.0%. The frequency of artifacts is shown in Table 1. The FOV with the most stitched artifact is 16×16 with 34.4%. It was detected 0.4% at 16×9 FOV and 0% at 16×5 FOV. A statistically significant correlation was observed between FOV and stitched artifact (p = .001).

Table 1. *The frequency of artifacts.*

Variables	Present N (%)	Absent N (%)
Cone-beam effect	603 (40.2)	897 (59.8)
Moire artifact	1500 (100)	0 (0)
Ring artifact	0 (0)	1500 (100)
Cupping artifact	608 (40.5)	892 (59.5)
Metallic artifact	1014 (67.6)	486 (32.4)
Metallic Artifact Removal	855 (57.0)	645 (43.0)
Streak Artifact	1014 (67.6)	486 (32.4)
Dark Band	1014 (67.6)	486 (32.4)
Motion Artifact	293 (19.5)	1207 (80.5)
Stitched Artifact	520 (34.7)	980 (65.3)
Noise	1151 (76.7)	349 (23.3)

Upon examining the relationship between parameters and gender, a statistically significant association was observed between cupping artifact, metallic artifact, streak and dark band artifacts, motion artifact, stitched artifact, and metallic artifact removal with gender. It was observed that the presence of metallic artifact, metallic artifact removal, streak artifact, and dark bands was significantly higher in females (p = .002, p = .001, p = .002 and p = .002, respectively). Table 2 displays the distribution of artifacts according to gender.

When the images were grouped according to age, 284 (18.9%) of the cases were under 20 years old, 389 (25.9%) were between 20-39 ages, 554 (36.9%) were between 40-59 ages and 273 (18.2%) were over 60 years old. Under the age of 20, the most frequently observed artifact was noise, with a rate of 72.5%. For the 20-39 age group, the most common artifacts were metallic artifact, streak artifact, and dark band artifact, with a rate of 72.7%. The most common artifact in the 40-59 age group was noise with 80.7%. It is followed by metallic artifact, streak artifact and dark band with 78.5% and cupping artifact with 61.6%. Age groups and the artifact frequencies are shown in Table 3.

After examining the relationship between the artifacts, a significant correlation was found between the cone-beam effect and all other artifacts (p < .05), except for stitched artifact (p = .737), motion artifact (p = .089), and noise (p = .337). No statistically significant correlation was determined between cupping artifact, metallic artifact, metallic artifact removal, streak artifact, dark band and noise and stitched artifact (p = .258, p = .182, p = 861, p = .182, p = .182 and p = 896, respectively). The relationship of the artifacts with each other is shown in Table 4. The distribution of artifact types with FOVs is shown in Table 5.

Table 2. *Distribution of artifacts by gender.*

	Male		Female		
	Present N (%)	Absent N (%)	Present N (%)	Absent N (%)	P
Cone-beam effect	325 (21.7)	441 (29.4)	278 (18.5)	456 (30.4)	.072
Moire artifact	766 (51.1)	0 (0.0)	734 (48.9)	0 (0.0)	****
Ring artifact	0 (0.0)	766 (51.1)	0 (0.0)	734 (48.9)	****
Cupping artifact	290 (19.3)	476 (31.7)	318 (21.2)	416 (27.7)	.031*
Metallic artifact	490 (32.7)	276 (18.4)	524 (34.9)	210 (14.0)	.002*
Metallic Artifact Removal	390 (26.0)	376 (25.1)	465 (31.0)	269 (17.9)	.001*
Streak Artifact	490 (32.7)	276 (18.4)	524 (34.9)	210 (14.0)	.002*
Dark Band	490 (32.7)	276 (18.4)	524 (34.9)	210 (14.0)	.002*
Motion Artifact	166 (11.1)	600 (40.0)	127 (8.5)	607 (40.5)	.033*
Stitched Artifact	290 (19.3)	476 (31.7)	230 (15.3)	504 (33.6)	.008*
Noise	587 (39.1)	179 (11.9)	564 (37.6)	170 (11.3)	.924

*Chi-square test; *p < .05*

Table 3. *Distribution of age groups and frequency of artifacts.*

	Cone-beam effect		Cupping artifact		Metallic artifact		Metallic Artifact Removal		Streak Artifact		Dark Band		Motion Artifact		Stitched Artifact		Noise	
Age Groups	**Present N (%)**	**Absent N (%)**	**Present N (%)**	**Absent N (%)**	**Present N (%)**	**Absent N (%)**	**Present N (%)**	**Absent N (%)**	**Present N (%)**	**Absent N (%)**	**Present N (%)**	**Absent N (%)**	**Present N (%)**	**Absent N (%)**	**Present N (%)**	**Absent N (%)**	**Present N (%)**	**Absent N (%)**
< 20 age	93 (32.7)	191 (67.3)	6 (2.1)	278 (97.9)	105 (37.0)	179 (63.0)	132 (46.5)	152 (53.5)	105 (37.0)	179 (63.0)	105 (37.0)	179 (63.0)	100 (35.2)	184 (64.8)	60 (21.1)	224 (78.9)	206 (72.5)	78 (27.5)
20-39 age	144 (37.0)	245 (63.0)	99 (25.4)	290 (74.6)	281 (72.7)	108 (27.8)	243 (62.5)	146 (37.5)	281 (72.7)	108 (27.8)	281 (72.7)	108 (27.8)	46 (11.8)	343 (88.2)	127 (32.6)	262 (67.4)	277 (71.2)	112 (28.8)
40-59 age	253 (45.7)	301 (54.3)	341 (61.6)	213 (38.4)	435 (78.5)	119 (21.5)	339 (61.2)	215 (38.8)	435 (78.5)	119 (21.5)	435 (78.5)	119 (21.5)	66 (11.9)	488 (88.1)	210 (37.9)	344 (62.1)	447 (80.7)	107 (19.3)
60+ age	113 (41.4)	160 (58.6)	162 (59.3)	111 (40.7)	193 (70.7)	80 (29.3)	141 (51.6)	132 (48.4)	193 (70.7)	80 (29.3)	193 (70.7)	80 (29.3)	81 (29.7)	192 (70.3)	123 (45.1)	150 (54.9)	221 (81.0)	52 (19.0)

Table 4. *Correlations between artifacts.*

	Cone-beam effect	Cupping artifact	Metallic artifact	Metallic Artifact Removal	Streak Artifact	Dark Band	Motion Artifact	Stitched Artifact	Noise
	p	p	p	p	p	p	p	p	p
Cone-beam effect	******	.001*	.001*	.040*	.001*	.001*	.089	.737	.337
Cupping artifact	.001*	******	.001*	.001*	.001*	.001*	.001*	.258	.001*
Metallic artifact	.001*	.001*	******	.001*	.001*	.001*	.001*	.182	.001*
Metallic Artifact Removal	.040*	.001*	.001*	******	.001*	.001*	.001*	.861	.001*
Streak Artifact	.001*	.001*	.001*	.001*	******	.001*	.001*	.182	.001*
Dark Band	.001*	.001*	.001*	.001*	.001*	******	.001*	.182	.001*
Motion Artifact	.089	.001*	.001*	.001*	.001*	.001*	******	.001*	.001*
Stitched Artifact	.737	.258	.182	.861	.182	.182	.001*	******	.896
Noise	.337	.001*	.001*	.001*	.001*	.001*	.001*	.896	******

*Chi-square test; *p < .05*

Table 5. Distribution of artifact types with FOVs.

	FOVs					
	16x5		16x9		16x16	
	Present N (%)	Absent N (%)	Present N (%)	Absent N (%)	Present N (%)	Absent N (%)
Cone-beam effect	0 (0.0)	166 (11.1)	291 (19.4)	367 (24.5)	312 (20.8)	364 (24.3)
Moire artifact	166 (11.1)	0 (0.0)	658 (43.9)	(0.0)	676 (45.1)	0 (0.0)
Ring artifact	0 (0.0)	166 (11.1)	0 (0.0)	658 (43.9)	1 (0.1)	675 (45.0)
Cupping artifact	32 (2.1)	134 (8.9)	285 (19.0)	373 (24.9)	291 (19.4)	385 (25.7)
Metallic artifact	76 (5.1)	90 (6.0)	480 (32.0)	178 (11.9)	459 (30.6)	217 (14.5)
Metallic Artifact Removal	72 (4.8)	94 (6.3)	383 (25.5)	275 (18.3)	400 (26.7)	276 (18.4)
Streak Artifact	75 (5.0)	91 (6.1)	480 (32.0)	178 (11.9)	459 (30.6)	217 (14.5)
Dark Band	75 (5.0)	91 (6.1)	480 (32.0)	178 (11.9)	459 (30.6)	217 (14.5)
Motion Artifact	44 (2.9)	122 (8.1)	107 (7.1)	551 (36.8)	142 (9.5)	534 (35.6)
Stitched Artifact	0 (0.0)	166 (11.1)	4 (0.3)	654 (43.6)	516 (34.4)	160 (10.7)
Noise	123 (8.2)	43 (2.9)	524 (34.9)	134 (8.9)	504 (33.6)	172 (11.5)

4. DISCUSSION

Artifacts present in medical images can significantly reduce the visibility of important details, and as a result, negatively impact the accuracy of diagnoses. When the quality of images is not sufficient for accurate reporting, re-imaging is often necessary. However, rescanning the patient with CBCT leads to an additional exposure to radiation, which does not comply with the ALARA (as low as reasonably achievable) principle.

Accurate recognition of artifacts is very important for clinically correct diagnosis and successful surgery. As far as we know, artifact studies in the literature are on algorithms to prevent artifacts (5, 12, 13, 25). There are different studies on the classification of artifacts in the literature (1, 6, 9, 10). Except for the study conducted by Nardi et al. (11) and Donaldson et al. (12), no study similar to the current study was found. Nardi et al. (11) only analyzed metal and motion artifact by age group. Donaldson et al. (12) only examined motion artifact according to age group.

In the study of Bhoosreddy et al. (1), artifacts were classified under the main headings of beam-related, patient-related, image noise, and poor soft tissue contrast. Subtypes of beam-related artifacts include beam hardening artifact, cone-shaped beam-related faults, scatter, exponential edge gradient effect, photon deprivation, and metallic artifact. The subtitles of patient-related are unsharpness, double image, scanner-related artifacts and foreign bodies. In the study of Jaju et al. (6), artifacts were classified into four categories: physics-based, patient-based, scanner-based, and motion artifact. Physics-based artifacts are caused by the physical processes that take place during the acquisition of CBCT data. Physics-based artifacts subgroup: noise, beam hardening, filtration, antiscatter grids, calibration, software corrections, partial volume artifacts. Patient-based artifacts arise due to factors related to the patient's form or function. Metallic artifact is in the subgroup of patient-based artifact. Scanner-based artifacts are resulted from by imperfections in the function of the scanner itself. Ring artefact is in the subgroup of scanner-based artifacts. In the research of Nagarajappa et al. (7), artifacts were categorized as x-ray beam artifacts, patient-related artifacts, scanner-related artifacts, and image noise main groups. In the present study, artifacts were classified according to their causes. Unlike other studies, the inherent artifact group was created in the classification and scatter and noise were included in this group. The beam-related artifact group comprises beam hardening artifacts, aliasing, partial volume averaging, cone-beam effect.

In the study conducted by Donaldson et al. (12), 200 CBCT images were examined and repetitive CBCT images were evaluated for motion artifact formation for under 16 and over 65 years old. 0.5% of the images required repeating the exam because of double bone contours and motion artifact that prevented the diagnosis. In the study performed by Nardi et al. (11), 416 CBCT images were examined, the analyzed images were divided into groups as 6-10 years old, 11-18 years old, 19-60 years old and over 60 years old, and the metal artifact percentages were examined in these age groups. Metallic artifact was found to be 12.2% in the 6-10 age group, 14.7% in the 11-18 age group, 41.4% in the 19-60 age group, and 27.2% over the age of 60. Motion artefact was detected as 10.8% in the 6-10 age group, 14.2% in the 11-18 age group, 42.4% in the 19-60 age group, and 32.6% over the age of 60. In this study, metallic artifact, streak artifackt and dark band were observed as 37.0% in the under-20 age, 72.7% in the 20-39 age group, 78.5% in the 40-59 age group, and 70.7% in over 60 age group, and mostly in females. The difference between the study of Nardi et al. (11) and this study may be due to the difference in the number of images examined, different classification of age groups and different ethnic origins. In the present study, it is thought that the reason for the high number of metal artifacts in the 40-59 age group is the increase in the need for prosthetic restoration in this age group. In addition, the reason for the metallic, line and dark bands are more in the group under 20 years of age compared to the other groups may be the increase in the need for orthodontic treatment in this age group. The difference in motion artifact between the study of Nardi et al. (11) and this study may be the use of devices with different technical characteristics (e.g. patient position during acquisition (sitting or standing), head stabilization features of each equipment, and scanning time of both equipments, factors affecting image quality; spatial resolution, contrast, density, sharpness, tube current, tube voltage, FOV, number of projections, detector type, etc.), the creation of different age groups, increased dental anxiety and claustrophobia under the age of 20.

A smaller FOV also means a shorter scan time. The shorter scan time allows the amount of artifacts to decrease by increasing the detector frame rate, reducing patient motion, and reducing the number of projections (26). In the present study, we observed an increase in almost all artifact types with increasing FOV. The results of our study support the information in the literature.

As a result of the cone-beam effect seen in the peripheral parts of the scanning area and caused by the separation of X-rays in these areas, the image distortion, lines, and peripheral noise occur. The present investigation showed the cone-beam effect was observed at a rate of 40.2% and there was a statistically significant relationship between other artifacts except noise, stitched and motion artifacts ($p < .05$). In this study, a result compatible with the general information in the literature was found (1, 8, 10), but sufficient comparison could not be made because there were no similar studies. For more comprehensive results, it is recommended to increase the studies on this subject.

Ring artifact caused by insufficient calibration was never encountered in the current study. To evaluate this comprehensively, it is suggested to conduct comparative studies with different brand devices.

No study was found in the literature regarding the stitched artifact that occurred during the reconstruction of the obtained data. It is suggested to develop software and algorithms to prevent this by examining different brands of devices.

Moire artifact, which was observed at a rate of 100% in this study, could not be compared with the literature since there was no similar study.

The limitation of this study is the use of a single brand device and the evaluation of artifacts only in the "Planmeca Promax 3D" brand device. In future studies, it is recommended to produce devices to minimize artifacts in terms of technology, according to the results obtained by using different branded devices and making comparisons. In addition, multicenter studies by increasing the number of samples and age groups are important in terms of guiding technological developments.

5. CONCLUSION

CBCT images have artifacts that can arise from both the patient and the device. These artifacts should be well known so that the physician does not misdiagnose and avoid re-imaging. The formation of some artifacts can be prevented by taking the necessary precautions (such as informing the patient before the shooting and fixing the head, removing metal-containing objects and performing periodic maintenance of devices: preventive technical maintenance of equipment, control of all physical and irradiation parameters and software). With the developing technology, these artifacts can be prevented. The devices should be calibrated on time and care should be taken to ensure that the software required for reconstruction is up-to-date.

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Peer-review: *Externally peer-reviewed.*
Author Contributions:
Research idea: EDY, EMAO
Design of the study: EDY, EMAO
Acquisition of data for the study: EDY, EMAO
Analysis of data for the study: EDY, EMAO
Interpretation of data for the study: EDY, EMAO
Drafting the manuscript: EDY, EMAO
Revising it critically for important intellectual content: EDY, EMAO
Final approval of the version to be published: EDY, EMAO

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