Original research

Contrast-to-noise ratios of different dental restorative materials: An in-vitro cone beam computed tomography study

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Purpose
In radiological views, strong beam hardening and streaking artifacts occur due to high-density structures and polyenergetic X-ray beams, and these lead to misdiagnosis. This study was performed in vitro to compare the contrast-to-noise ratio (CNR) of commonly used dental restorative materials by using Cone Beam Computed Tomography (CBCT) images with and without artifact reduction (AR) mode.

Materials and Methods
A total of 108 molar teeth were restored with nine different groups of restorative materials, with each group containing 12 teeth. Teeth were placed in a dry human mandible and scanned, one by one, via Planmeca 3D ProMax (Planmeca, Helsinki, Finland) with and without AR mode. Images were analyzed using ImageJ software (National Institutes of Health, Bethesda, MD) to calculate the CNR.

Results
CNR was calculated to be the highest in compomer (Glassiosite) images without AR mode (mean: 3.36) and with AR mode (mean: 3.61). CNR was calculated to be the lowest in amalgam (Tytin) images without AR mode (mean: 0.21) and with AR mode (mean: 0.23). A significant difference was found between materials in terms of CNR measurements ($p \leq 0.05$). CNR measurements were increased after the AR mode application ($p \leq 0.05$).

Conclusion
AR mode was effective in reducing artifacts arising from dental materials on CBCT images, so it is necessary to use AR mode for correct diagnoses.

Keywords: *Cone-Beam Computed Tomography; contrast-to-noise ratio; dental materials; artifacts; image quality*

Introduction

Cone Beam Computed Tomography (CBCT) has been used in dentistry for dental, maxillofacial, and various head and neck examinations (1). This technology supplies 3D images for regions of interest with high spatial resolution, geometric accuracy, and lower ionizing radiation doses than other tomographic devices (2, 3). Many parameters affect image quality; these include the field of view (FOV), X-ray beam quality and quantity, voxel sizeand rotation arc in CBCT images (4).

Imaging technology should obtain high-quality images with sufficient contrast-to-noise ratio (CNR) and soft-tissue differentiation while minimizing the required dose of radiation (5).

Since CNR is considered a standard factor in the evaluation of image quality, it has been measured in previous studies. Researchers have stated that the same material exhibits different CNR values with different exposure parameters (6, 7).

CBCT manufacturers are developing artifact reduction (AR) software to decrease the influence of beam hardening and streaking artifacts caused by high-density materials; this result in an increased CNR value (8, 9). Although these types of software programs eliminate streaks far from metallic objects, the details around metal-tissue interfaces, which might be the main regions of interest, still may not be visible to clinicians (10).

As a result of dental materials having been developed very rapidly, many studies have been planned to analyze their biological, physical, and mechanical characteristics, all of which can affect and predict their performance. Knowledge of the characteristic properties of dental materials is essential to support their correct application and to expect the long-term performance of these materials (11).

Materials containing metal have been reported to cause artifacts that inhibit the diagnostic quality of CBCT images by decreasing contrast, concealing structures, and consequently impairing estimates of the region of interest. In radiographic images, beam hardening and streaking effects occur due to high-density structures and polyenergetic X-ray beams; these lead to dark streaks that are known as image artifacts, resulting in misdiagnosis (12). The intensity of these artifacts increases in CBCT images as the percentage of radio-opacifying materials increases (13).

This study aimed to compare in-vitro the CNR of commonly used dental restorative materials by using CBCT images with and without AR mode.

Materials and Methods

Preparation of teeth

This in vitro study protocol was in accordance with the Declaration of Helsinki approved by the Local Ethical Committee of Fırat University (Review No. 15.06.17/02).

108 noncavitated human permanent molar teeth extracted for periodontal or orthodontic reasons independent from this study were used. The teeth had no cavitations, restorations, or hypoplastic pits as judged by the naked eye. Extracted teeth were cleaned and kept in distilled water for 24 hours at 37°C.

Class I (occlusal) cavities (7 mm × 3 mm × 4 mm) were made with a carbide bur (#330, Mani; MANI Inc., Tokyo, Japan) for 108 molar teeth and randomly divided into nine groups each containing 12 teeth.

After cavity preparation, the groups were restored with 9 different restorative materials. These materials are summarized with their specifications in Table 1.

CBCT imaging

A dry human mandible covered with a pink wax layer to simulate soft tissues was used in the imaging procedures, and the restored teeth were placed in the same socket throughout the study. A hexagonal plexiglass box filled with

Table 1. *Restorative materials and their characteristics evaluated in the study*					
Material Name	**Manufacturer**	**Material type**	**Matrix type**	**Filler content**	**Filler ratio %**
Estelıte® Sıgma Quıck	Tokuyama Tokyo, Japan	Submicron filled composite resin	Bis-GMA, TEGDMA	Spherical silica-zirconia filler and silica-zirconia prepolymerized fillers	82
Estelıte® Flow Quıck	Tokuyama Tokyo, Japan	Low viscosity, medium flow, light cured, radiopaque composite resin	Bisphenol A polyethoxy Methacrylate (Bis-MPEPP), TEGDMA, UDMA	Silica- zirconia filler and silica-titanium filler	71
Filtek Bulk Fill	3M-Espe (St. Paul, Mn, USA)	Bulk-fill flowable composite	Bis-GMA, UDMA Bis-EMA	Procrylat resins	64.5
Surefil SDR	Dentsply Caulk, Universal	Bulk-fill composite	Modified UDMA TEGDMA, EBPDMA	Ba-Al-F-B-Si glass and St-Al-F-Si glass as fillers	68
Ionoseal	VOCO Gmbh, Cuxhaven, Germany	Resin-reinforced glass ionomer cement	Bis-GMA, HEMA, TEDMA	Fluoroaluminum silicate, champherechinon, amine	-
Tytin	Kerr Manufacturing Co., Romulus, MI, USA	Spherical high-copper amalgam alloy	-	Silver 59 %, Tin 28%, Copper %13, Hg 42.5 %	-
GCP Glass Fill	Gcp Dental Elmshorn Germany	New carbomised nano-particles	Modified Polysiloxanes	Fluoro-aluminosilicate Glass, Apatite, Polyacids	-
CAD/CAM Katana	KATANA® Noritake Dental Supply Japan	CAD/CAM inlay restorations	-	-	-
Glassiosite	VOCO Gmbh Cuxhaven, Germany	Compomer	BisGMA, di-UDMA,TEGDMA, BHT	Glass ceramics, silicates	77.5

Figure 1. *Dry human mandible positioned in a hexagonal plexiglass box with soft base plate wax covering the mandibular crest.*

water to mimic clinical conditions was used to position the machine. Colored markers were made to place the mandible into the same position after changing the teeth (Figure 1).

The mandible was radiographed with a Planmeca 3D Pro-Max (Planmeca, Helsinki, Finland). This device was operated with and without AR mode parameters at 76 kVp, 4.5 mA, 13.5 sn, 20 x 10.2 cm FOV, and 0.4 mm voxel size.

For each of the restorative materials, the mandible was scanned 24 times (12 times with the AR option and 12 times without the AR option) after changing the restored teeth (n = 12). A total of 216 scans were acquired for the nine different restorative materials.

All images were evaluated by one maxillofacial radiologist on two separate sessions with at least a one-week interval.

CNR measurement

Volumes were exported using multislice DICOM format. Identical images were chosen at the same level from each restored tooth image, and measurements were made using ImageJ software (National Institutes of Health, Bethesda, MD). Two separate areas were selected for each image, and mean gray value and standard deviation were measured. The first area was selected on the wax located lingual to the dental restorative material; the second area, called the control area, was chosen where the artifact was minimal (Figure 2). The CNR was calculated using the following formula: (9)
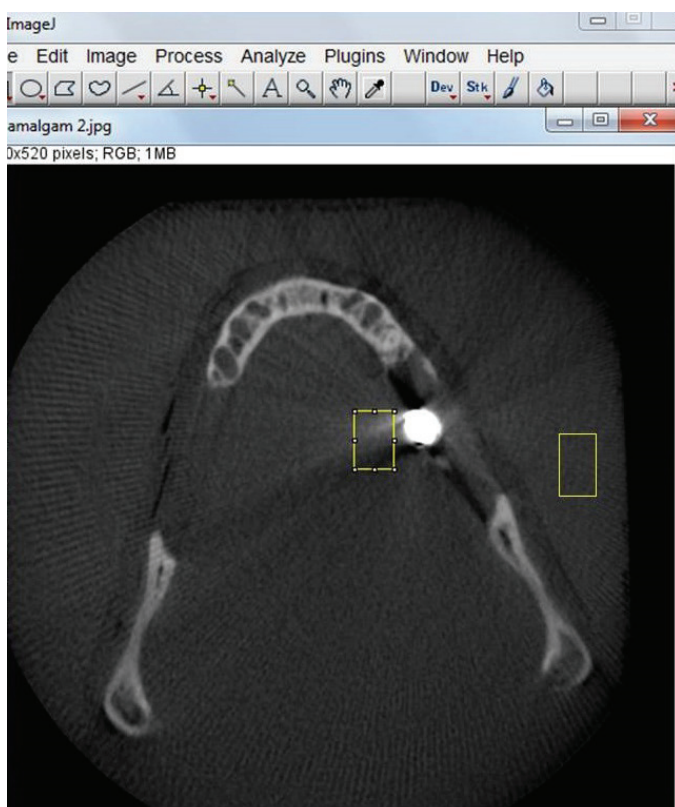

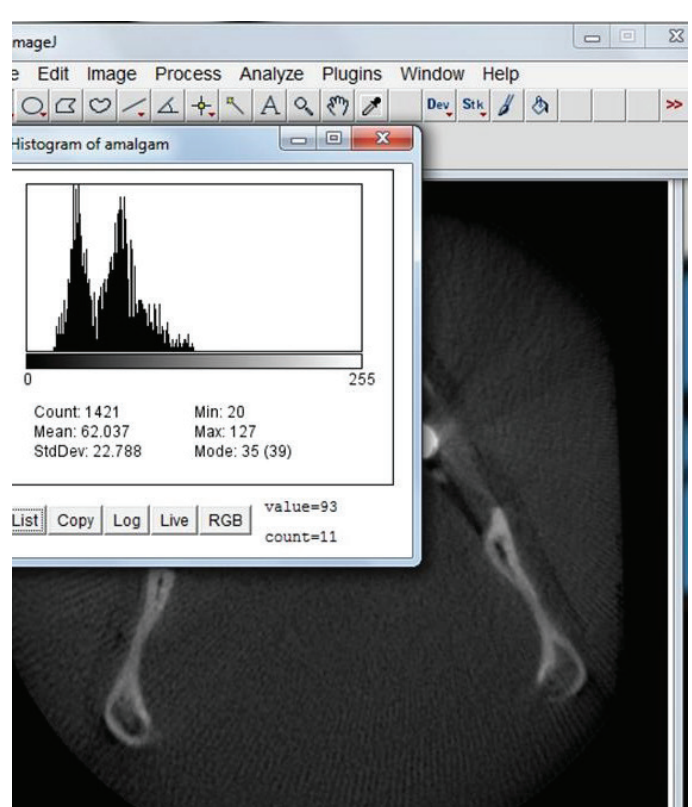**Figure 2.** *Areas of interest used for CNR calculation.*

Figure 3. *Histogram showing CNR values of restorative materials.*

Table 2. *Contrast-to-noise ratio (CNR) measurement values with and without AR mode for various restorative materials*

Materials	N	Without AR Module				P*	With AR Module				P*
		Mean	SD	Median	Range (min-max)		Mean	SD	Median	Range (min-max)	
Gcp Glass Fill		0.49[a]	0.07	0.51	0.30-0.57		0.52[a]	0.08	0.55	0.31-0.61	
Ionoseal		0.58[a]	0.12	0.57	0.42-0.92		0.62[a]	0.13	0.59	0.49-0.98	
Estelite Sigma Quick		1.29[b]	0.17	1.25	1.13-1.65		1.44[b]	0.20	1.37	1.25-1.84	
Cad-Cam/Katana		0.25[a]	0.50	0.25	0.19-0.37		0.29[a]	0.07	0.27	0.21-0.49	
Tytin	12	0.21[a]	0.03	0.22	0.14-0.27	**0.001**	0.23[a]	0.03	0.24	0.16-0.29	**0.001**
Estelite Flow Quick		2.30[c]	0.25	2.20	1.92-2.69		2.47[c]	0.23	2.42	2.11-2.84	
Filtek Bulk Fill		3.04[d]	0.39	2.97	2.40-3.69		3.20[d]	0.43	3.10	2.51-2.89	
Glassiosite		3.36[d]	0.12	3.36	3.14-3.64		3.61[d]	0.15	3.59	3.28-3.90	
Surefil SDR		2.41[c]	0.44	2.46	1.24-2.85		2.57[c]	0.47	2.64	1.32-3.10	

*P-values refer to statistically significant differences between groups (p < 0.05). SD: Standard Deviation

$$\mathrm{CNR} = \frac{|Mean_{wax} - Mean_{control}|}{\sqrt{SD_{wax}^2 + SD_{control}^2}}$$

Where mean is the mean gray value and SD is the standard deviation gray value in the same region of interest as seen in Figure 3.

Statistical analysis

A non-parametric test (Kruskal-Wallis Test) was used due to unequal variances across groups, and another non-parametric test (the Mann-Whitney U test) was performed for comparisons between groups. The SPSS 10.0© software (SPSS Inc., IBM Company Headquarters, Chicago, IL) was used for analyzing data. The significance level value was set at 0.05.

Results

The compomer (Glassiosite) exhibited the highest CNR (mean: 3.36), and amalgam (Tytin) exhibited the lowest CNR (mean: 0.21), showed statistically significant difference without AR mode (p ≤ 0.05, Table 2).

The compomer (Glassiosite) exhibited the highest CNR (mean: 3.61), and amalgam (Tytin) exhibited the lowest CNR (mean: 0.23), showed statistically significant difference with AR mode (p ≤ 0.05, Table 2).

When we compared CNR using the AR module, significant differences were found between groups (p ≤ 0.05). The AR application enhanced the CNR values of all the tested materials.

Discussion

Contrast resolution, which is identified as the capability to discriminate between different contrast levels in an acquired image, is a substantial aspect of image quality in CBCT scans (14). The CNR is a factor associated with image quality rather than image noise. It is one factor among many other factors that depend on an acceptable level of lesion-to-background contrast (15, 16).

In the present study, AR mode indicated positive effects on CBCT images of dental restorative materials with a significant increase of CNR results. Applying the AR algorithm to CBCT scans prolongs the reconstruction time; therefore, when high-density materials are in the FOV, applying the AR algorithm is indicated to increase the image quality (6).

Bechara *et al.* (17) showed that the CNR is increased if the AR algorithm is used, but metal artifacts cause a decrease in the CNR. Previous studies report that artifacts and low CNR, particularly in the presence of gutta percha and canal sealers, lead to misdiagnoses of root fractures and voids and also lead to false-positive diagnoses (9).

In studies conducted with a Planmeca ProMax CBCT system, Kamburoğlu *et al.* (18) estimated no difference in the examination of peri-implant and periodontal defects among CBCT scans with and without the AR mode. Bechara *et al.* (12) found the highest accuracy of detecting root fractures in endodontically treated teeth without the AR mode.

It has been stated that using AR modes may be helpful if there is no need for high contrast and spatial resolution. This was stated as a result of a study that proved that the accuracy of root fracture detection in endodontically treated teeth was reduced after using the AR modes in two different CBCT devices (9).

Demirtürk *et al.* (9) investigated the CNR of multiple exposure parameters for different types of retrograde filling materials in CBCT scans with and without AR mode and stated that although there was no statistically significant difference between Biodentine, SuperEBA, MTA, and amalgam, the highest CNR was seen in Biodentine. Also, they reported that AR mode reduced the effect of the beam hardening and streaking artifacts caused by filling materials, resulting in a significant increase in the CNR seen with all four root-end filling materials (9).

Querioz *et al.* (6) studied the efficacy of AR mode in different dental materials and observed a significant reduction of artifact expression in tested materials except for gutta-percha, which may be explained by its having a low number of atoms. Parsa et al. (19) investigated if the AR tool can increase the gray value levels in CBCT images which were obtained

after implant placement and reported that the software did not correct the voxel gray values caused by the metal artifact around the implant in dry human mandibles.

Pauwels *et al.* (20) stated that CNR values are dependent on specific machines due to variations in hardware and software. This study was designed with a single CBCT with single exposure settings. Therefore, these results cannot be compared with those obtained from other CBCT units. Future studies will focus on other CBCT units and several exposure settings.

We recommend that CBCT imaging of patients with high-density dental materials be obtained using AR mode. In this way, the diagnostic quality is protected with an increase in CNR values. In examinations of CBCT images obtained for various reasons, it should be borne in mind that pathological conditions, such as caries, fracture, resorption, and other conditions, can be overlooked near restorations with lower CNR values, so it is better to support the diagnosis with an additional imaging modality (15).

Conclusions

Within the limitations of this study, we conclude that the CNR is affected by different restorative materials in CBCT scans. High-density materials exhibited lower results, and the application of the AR algorithm enhanced the CNR values. AR can be used on CBCT images of objects containing high-density restorative materials due to its efficacy in enhancing image quality.

Türkçe Öz: *Farklı dental restoratif materyallerin kontrast noise oranı: bir in- vitro konik ışınlı bilgisayarlı tomografi çalışması. Amaç: Radyografik görüntülerde, kuvvetli ışın sertleşmesi ve saçılma artefaktları yüksek dansiteli yapılardan ve polienerjik X ışını demetinden kaynaklanır ve yanlış tanıya neden olur. Bu çalışma yaygın kullanılan dental restoratif materyallerin in vitro olarak Konik Işınlı Bilgisayarlı Tomografi (KIBT) görüntülerinde artefakt azaltma (AA) modu kullanılarak ve kullanılmadan kontrast noise oranını (KNO) kıyaslamak için yapıldı. Materyal ve Metod: Her biri 12 dişten oluşan toplamda 108 molar diş dokuz farklı grup restoratif materyalle restore edildi. Dişlerin her biri kuru insan mandibulasına yerleştirilerek AA modu kullanılarak ve kullanılmadan Planmeca 3D ProMax(Planmeca, Helsinki, Finland) ile tarandı. Görüntüler ImageJ (National Institutes of Health, Bethesda) programı kullanılarak analiz edilip KNO hesaplandı. Bulgular: KNO, AA modu kullanılmadan (ortalama: 3,36) ve AA modu kullanılarak (ortalama:3,61) en yüksek kompomer (Glassiosite) görüntülerinde; AA modu kullanılmadan (ortalama: 0,21) ve AA modu kullanılarak (ortalama:0,23) en düşük amalgam (Tytin) görüntülerinde hesaplandı (p≤0.05). KNO ölçümleri AA modu kullanıldığında artış gösterdi. (p≤0.05). Sonuç: AA modu KIBT görüntülerinde dental materyallerden kaynaklanan artefaktları azaltmada etkilidir ve AA modunu kullanmak doğru tanı için gereklidir. Anahtar Kelimeler: Konik ışınlı bilgisayarlı tomografi; kontrast noise oranı; dental materyal; artefakt; imaj kalitesi*

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