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Improvement of image quality and dose reduction with SEMAR and AIDR 3D in paranasal sinus CT

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ABSTRACT

Aims: Computed tomography (CT) is a frequently used and useful technique although it causes radiation exposure. In some situations, metal artefacts can reduce the diagnostic value of imaging. Our study aims to investigate the CT parameters for paranasal sinus imaging with less artefact and lower radiation dose at diagnostic limits, by applying single energy metal artifact reduction+adaptive iterative dose reduction (SEMAR+AIDR 3D) techniques together.

Methods: A head-neck equivalent phantom was used to create a setup containing tissue-like densities and metal artefact at the paranasal sinus level. Then CT scans were performed with different tube voltage and current values when SEMAR+AIDR 3D techniques were off and on. Effective doses were calculated for each CT scan. Signal-to-noise ratio and contrast-to-noise ratio values were calculated for objective evaluation and image quality was assessed subjectively by two different observers blindly.

Results: After tecniques, significant improvments were observed both objective and subjective values ($p<0.05$ and $p<0.0001$ respectively). 16 low-dose scans were diagnostically adequate for both observers, SEMAR+AIDR 3D was present in 15 of the 16. The lowest effective dose (0.0145 mSv) was acquired with SEMAR+AIDR 3D at 100 kVp and 3 mAs parameters.

Conclusion: Image quality can be improved by using SEMAR+AIDR 3D in paranasal sinus CT, it is possible to obtain reasonable quality CT scans at head radiography effective dose values.

Keywords: AIDR 3D, CT, paranasal sinus imaging, radiation dose reduction, SEMAR

INTRODUCTION

Computed tomography (CT) is useful for detecting anatomy and pathology in the paranasal sinuses and surrounding tissues.[1,2] However, a limitation of paranasal CT images is the radiation dose received. Iterative reconstruction (IR), one of the applications developed to obtain images with lower radiation dose while preserving image quality, is offered by manufacturers in compatible devices to reduce radiation dose in CT. With IR, a comparison is made using the first image obtained on CT or a model, and the final image is reached through repeated reconstructions.[3] The aim is to obtain images with lower radiation dose but similar quality to standard shots, with acceptable noise and blur levels.[3] One of the IR applications is the AIDR 3D (adaptive iterative dose reduction) uses first images produced with filtered back projection (FBP), which is the standard reconstruction algorithm in CT, and reaches final images.[4]

In paranasal sinus CT scans, there can be limitations due to the presence of metallic surgical materials and other high-density foreign objects such as malposed dental implants in the imaged area which may cause artefacts and hinder evaluation.[5] This can affect the quality of the diagnosis, requiring repeat imaging and exposing the patient to more radiation. To address this issue, metal artefact reduction (MAR) applications have been developed to minimize artefacts caused by high-density objects such as metal in CT scans.[6] One of these applications is SEMAR (single energy metal artifact reduction), which aims to identify the position of high-density objects in the image and reduce the artefacts.

IR applications are commonly used in CT imaging today and they provide advantages in dose reduction, also they show a greater improvement in image quality when used together with MAR techniques in images with metal artefacts.[7] Studies have shown that using IR techniques in paranasal sinus CT scans can lead to a significant reduction in radiation dose.[8-10] However, it has not been evaluated how combining IR and MAR techniques can specifically reduce radiation in this region when metal artefacts are present. In such cases, we aimed to investigate how to acquire images with lower radiation doses while maintaining image quality in different scan parameters using SEMAR+AIDR 3D.

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METHODS

This study was approved by the Atatürk University Faculty of Medicine Clinical Researches Ethics Committee (Date: 30.09.2021, Decision No:30). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

The study was performed with an adult head-neck region equivalent phantom. (ATOM® 701-B, Computerized Imaging Reference System Inc Norfolk, VA/ABD). Different holes in the paranasal sinuses region were filled in soft tissue, fat, mucosa and metal density materials. In the study, a platinum-containing peripheral coil was used to create the metal density and artefact. To provide other tissue equivalent densities, chicken meat, oil and water were used, respectively. Before placement in the phantom, the materials were tested with our routine paranasal sinus CT protocol to verify the appropriateness of their density values. These materials were used in dimensions that matched the available compartment size of the phantom.

CT acquisitions were performed using a Multidetector CT scanner (Aquilion ONE, Canon Health Systems, Otawara/Japan). CT images were acquired using the following parameters: helical mode; four different tube voltages (80, 100, 120 and 135 kV); six different tube currents (3, 7, 14, 32, 64, and 129 mAs); 9 cm scan length, 1 mm slice thickness. Considering the parameter ranges frequently used in dose studies in the literature, the initial and final kVp and mAs values supported by the scanner were identified and utilized in this study. This approach was adopted to ensure comparability with clinical practice and to maintain consistency with previously published findings. Using the settings above a total of 48 CT scans were performed before and after SEMAR+AIDR 3D techniques.

Image Analysis

Attenuations of CT images [expressed as the mean number of Hounsfield units (HU)] and their standard deviations (SD) were measured by placing at least 10 mm² region of interest (ROI) in similar locations for soft tissue, fat, mucosa, and air (**Figure 1**). Then using HU and SD values, Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated for objective evaluation. The formulas used to calculate SNR and CNR are as follows:

$$SNR = \frac{\text{average signal intensity of the selected area } (SI_{ROI})}{\text{signal standard deviation of the selected area } (SD_{ROI})} \quad [11]$$

$$CNR = \frac{\text{average signal intensity difference of selected areas } (\Delta(SI_{ROIa}, SI_{ROIb}))}{\sqrt{(\text{the sum of squares of signal standard deviations of selected areas})}\left(\sqrt{(SD_{ROIa})^2+(SD_{ROIb})^2}\right)} \quad [11]$$

Radiation Dose

For each CT scan, the effective dose (ED) was calculated using the equation:

ED = CTDIvol (CT scan data) x 9 cm (scan length) x ED/DLP conversion factor (0.0023 for the head region[12]).

Subjective Evaluation

Two radiologists evaluated the images independently and blindly, without knowledge of the image acquisition features and each other's scores. A scoring table (**Table 1**) was prepared using the European Guidelines on Quality Criteria for Computed Tomography[12] and images were assigned scores ranging from 1 to 5 based on their anatomical details, noise level, and artefacts. 5 point was the highest score for evaluations. The average scores given by the radiologists were calculated for each CT scan. Images receiving an average score of three or more from both observers were categorised as diagnostically sufficient (**Figure 2**).

Table 1. Subjective Evaluation Scoring Scale

Categories/ scores	Noise	Artefacts	Anatomic details
5	No or minimal	No or minimal artefacts	Clear, sharp edges
4	Mild	Less artefacts	Clear, but slight artefact
3	Moderate/ acceptable	Acceptable artefacts, diognosis is possible	Anatomic structures can be vizualized
2	Heavy	Considerable artefacts make diagnosis difficult	Anatomic structures can not be visualized clearly
1	Severe/ unacceptable	Not diagnostic	Unable to identify

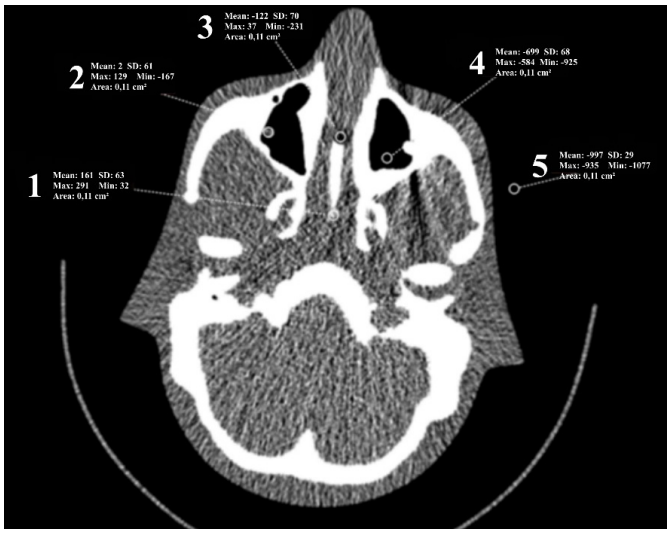

Figure 1. Example of measurements; soft tissue (1), mucosa (2), fat (3), paranasal air (4) and external air (5), respectively

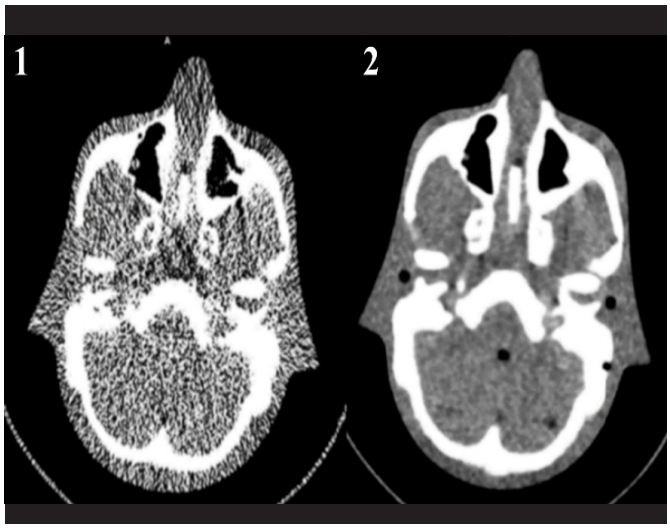

Figure 2. Left-sided (1) image had the worst subjective score (80 kVp/3 mAs/ without SEMAR+AIDR 3D). The right-sided (2) image had the lowest ED in the acceptable subjective scores (100 kVp/3 mAs/with SEMAR+AIDR 3D)

SEMAR+AIDR 3D: Single energy metal artifact reduction+adaptive iterative dose reduction, ED: Effective dose

Statistical Analysis

Data analyses were performed using SPSS (IBM, Armonk, NY, USA) software version 23. Both analytical (Kolmogorov-Smirnov/Shapiro-Wilk tests) and visual (histogram) methods were used to examine whether the data conformed to normal distribution. Descriptive statistics were presented as mean±standard deviation (mean±SD) for normally distributed variables, and median and interquartile range (IQR) for non-normally distributed variables. To determine the impact of SEMAR and AIDR 3D on the SNR and CNR values, a paired T test for normally distributed variables and the Wilcoxon test for non-normally distributed variables were used. For subjective scoring statistics, the Wilcoxon and McNemar tests were used. The presence and level of interobserver agreement were investigated using the Kappa test. p=0.05 was used to determine statistical significance.

RESULTS

SNR and CNR Values

After applying SEMAR and AIDR 3D, all SNR and CNR changes were statistically significant (p=0.034 for mucosa SNR, p<0.0001 for all other regions' SNR and CNR). The soft tissue showed the most significant improvement in SNR (mean±SD 2.36±1.78 when the SEMAR+AIDR 3D were off, 6.28±2.64 when they were on), while the paranasal air showed the most significant improvement in CNR (median value 2.429 when the SEMAR+AIDR 3D were off, 7.7487 when they were on).

Radiation Dose

There were 24 different EDs for a total of 48 scans performed before and after SEMAR+AIDR 3D. The range of ED in all scans was between 0.0083 mSv and 1.1861 mSv. Compared to the ED (0.3726 mSv) calculated for the same scan length in paranasal sinus CT routinely used in our institution, 38 of the 48 scans had lower radiation doses. Observers found adequate diagnostic quality in 16 out of the 38 low-dose scans. SEMAR+AIDR 3D was present in 15 of the 16 scans. The scan with the lowest ED (0.0145 mSv) found suitable for evaluation was performed with SEMAR+AIDR 3D at 100 kVp and 3 mAs parameters (Table 2).

Table 2. Parameters of images with adequate diagnostic quality and lower ED

kVp/mAs	SEMAR+AIDR 3D	ED (mSv)
80/32	+	0.0725
80/64	+	0.1449
80/129	+	0.2919
100/3	+	0.0145
100/7	+	0.0290
100/14	+	0.0600
100/32	+	0.1346
100/64*	-/+	0.2712
120/3	+	0.0228
120/7	+	0.0455
120/14	+	0.0932
120/32	+	0.2111
135/7	+	0.0600
135/14	+	0.1221
135/32	+	0.2795

*: Observers found the image diagnostically sufficient with/without SEMAR+AIDR 3D in these parameters, SEMAR+AIDR 3D: Single energy metal artifact reduction+adaptive iterative dose reduction, ED: Effective dose

Subjective Evaluation

After SEMAR+AIDR 3D, there was a significant improvement in the median subjective score from 2.5 to 3.67 (p<0.0001). Before SEMAR+AIDR 3D, observers rated only 6 of 24 CT scans as adequate, of which only one was low-dose. After SEMAR+AIDR 3D, 20 of 24 CT scans were found suitable, of which 15 were low-dose. Interobserver agreement for subjective scoring was good (p<0.0001, Kappa=0.61).

The dot plots showed a positive correlation between subjective and objective data for all region subgroups (Figure 3).

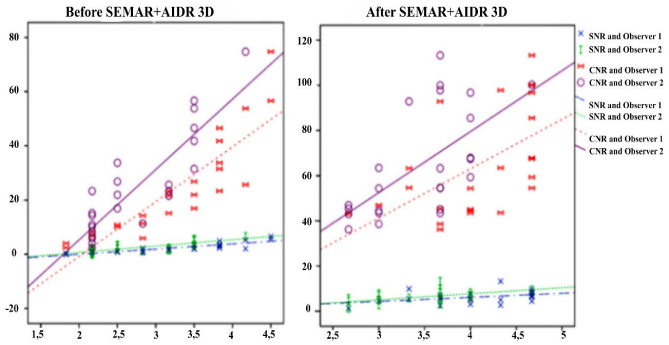

Figure 3. Correlation graph for soft tissue subgroup data

DISCUSSION

When evaluating the three areas examined in the current study (image noise, subjective image quality, and radiation dose reduction), images with the same acquisition parameters and dose values showed better diagnostic performance after applying SEMAR+AIDR 3D. Although 19 of the 24 acquisition presets had lower doses than our institutional dose, after the techniques there were significant improvements in all SNR and CNR values and subjective scores, in line with the aim of dose and artefact reduction. It is desirable to reduce both artefacts and radiation dose in imaging, but this may result in the loss of the high-acuity images to which the eye is accustomed and a decrease in diagnostic quality. Parallelly, even after applying SEMAR+AIDR 3D, 4 of 19 low-dose scans still weren't diagnostic sufficiency for observers. X-Ray exposure due to CT causes damage to DNA with direct and indirect effects and causes an increase in the risk of some cancers.[13,14] According to AAPM's report, the dose value of dental radiography is <0.1 mSv, while the dose value of CT for the head area is 1-2 mSv.[15] The ED for the adult head radiograph ranges between 0.107 and 0.022 mSv.[16] Even though a CT scan contains at least 10-20 times more radiation dose compared to radiography, it is diagnostically superior to radiographs.[17,18] In our study, when SEMAR+AIDR 3D was applied, diagnostic adequacy could be achieved in low-dose paranasal CT scans. The lowest ED we found was within the dose range specified for standard radiographs (0.0145 mSv). Thus, we achieved to combine the diagnostic superiority of CT with the low doses of radiographs, as the ALARA (as low as reasonably achievable) principle.

Studies conducted with IR techniques attempt to provide diagnostic image quality while reducing ED. Some studies in adult cadavers or real patients have shown that ED can be reduced to 0.08-0.11 mSv for the paranasal sinus region with various IR applications,[8-10] and some more recent studies on the pediatric population have shown that dose reduction with IR applications can reach 0.008-0.05 mSv[19,20] The ED

we obtained (0.0145 mSv) was lower compared to the results of adult studies. Our study shares similarities with others in terms of anatomical localization and the use of IR, but differs in that it was conducted using a phantom, includes metal artefacts, and employs the IR technique supported by the MAR technique. It is stated that the use of MAR and IR together is superior to their use alone in terms of image quality.[7] One study has shown that in addition to reducing metal artefacts, image quality can be preserved in low-dose CT using the combination of iMAR+ADMIRE.[21] Similar to this, in our study, SEMAR+AIDR 3D was used in 15 of the 16 low-dose scans that the observers found sufficient. There wasn't only AIDR 3D group in our study, but the dose value we reached was lower compared to containing only IR studies. SEMAR, which we used additional here, was likely to contribute. Another IR study with SAFIRE in this region found that while the low radiation dose was sufficient in real patients, the same dose was insufficient in the phantom.[22] Considering studies together, the scanning parameters we achieved in the phantom and found lower ED can also be sufficient in real patient studies. It is not yet clear whether our protocol is sufficient for real-patient CT scans, but we hope that our results may guide real patients undergoing CT scans. In the next step, it will be appropriate to validate our findings in an actual patient study. We predict that similar results can be obtained in other devices but some studies suggest that not all manufacturers' techniques are equally effective.[23]

Limitations

The most important one is there were no real patients. We were able to perform many different scans using phantom without worrying about radiation exposure, but we may not be aware of the obstacles in real scanning. So, it is needed to investigate the parameters we found in our study on real patients. Another limitation is that we examined the techniques we used from only one manufacturer (Canon). Therefore, it may not be possible to talk about a clear result at this point.

CONCLUSION

Developments in CT show that image quality will improve with much lower radiation exposure than known. In paranasal sinus CT, it is possible to perform images with sufficient quality at lower radiation doses with SEMAR+AIDR 3D techniques. Thus, detecting pathologies that may be overlooked due to artefacts will be easier. Imaging scenarios for real patients can be constructed using the data from our study.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of the Atatürk University Faculty of Medicine Clinical Researches Ethics Committee (Date: 30.09.2021, Decision No:30).

Informed Consent

As no biological material from humans or animals was used in the study, informed consent was not required.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

Data Sharing Statement

The data that support the findings of this study are available on request from the corresponding author.

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