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RESEARCH ARTICLE

Evaluation of different low-dose multidetector CT and cone beam CT protocols in maxillary sinus imaging: part I—an *in vitro* study

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Objectives: This *in vitro* study aimed to assess radiation dose and image quality of different low-dose multidetector CT (MDCT) and CBCT imaging protocols in comparison with the standard MDCT protocol for maxillary sinus imaging.
Methods: Effective dose (*E*) and image quality of 10 MDCT (changing effective milliampere second starting from 141.3 EmAs to 20 EmAs) and 3 CBCT protocols (changing milliampere second and voxel size) were assessed throughout scanning an anthropomorphic head and neck Alderson Rando phantom. *E* values were calculated using thermoluminescent dosemeters (TLDs) fixed at 6 sensitive organs (14 sites) on the Rando phantom. Image quality was assessed objectively (by calculating the standard deviation values of the radiographic density of water) and subjectively (by assessing the diagnostic image quality using a four-graded scale: 1 = very good, 2 = good, 3 = acceptable and 4 = unacceptable).
Results: Two MDCT protocols (120 kV/32 EmA and 120 kV/25 EmA) had lower radiation doses with statistically significant differences ($p < 0.001$) compared with that of the standard MDCT protocol (120 kV/141.3 EmA), and they preserved a good diagnostic image quality. One CBCT protocol (120 kV/20 mA) had a reasonable radiation dose and good image quality. There were no statistically significant differences between the above-mentioned lower dose MDCT and CBCT protocols ($p > 0.05$) with respect to the radiation dose and image quality.
Conclusions: The low-dose MDCT and CBCT protocols are viable methods for maxillary sinus examination as evaluated using the above-mentioned phantom that yield a good diagnostic image quality using *E* approximately 7 and 11 times lower than that of the standard MDCT, respectively. These findings were evaluated in the *in vivo* part of this project.
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Keywords: Effective dose; dose reduction; CBCT; MDCT; maxillary sinus

Introduction

The maxillary sinus is a part of the craniofacial region, which is one of the most complex areas in the human body. It is a frequent site for pathologies of odontogenic origin, owing to its close anatomical relationship with the teeth and periodontal tissues, and of non-odontogenic origin as inflammatory diseases as well as cystic and neoplastic lesions.[1,2] Because this region is complicated, is composed of overlapping structures and the potential

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Table 1 Settings of the 10 multidetector CT protocols

Protocol number	*mA*	*mAs*	*PF*	*EmAs*
I	130	97.5	0.69	141.3
II	130	97.5	0.93	104.8
III	70	52.5	0.69	76
IV	130	97.5	1.5	65
V	70	52.5	0.93	56.5
VI	50	37.5	0.93	40
VII	70	52.5	1.5	35
VIII	40	30	0.93	32
IX	50	37.5	1.5	25
X	40	30	1.5	20

EmAs, effective milliampere second; mA, milliampere; mAs, milliampere second; PF, pitch factor.
The fixed settings; 120 kV, 0.75-second per rotation time, 1×16 collimation, and 1 mm slice thickness.

of disease extension to vital organs is likely, assessment of its pathologies requires precise and careful selection of the diagnostic imaging modalities.[2]

CT is the standard for specific diagnosis of the maxillary sinus diseases and their extension in otolaryngology.[2] However, the associated high radiation dose that affects the radiosensitive organs within the scanning field represents its main disadvantage. This dose is still alarming, and hence it is essential to optimize it.[3–5]

It is essential to evaluate whether low-dose multidetector CT (MDCT) imaging protocols for the maxillary sinus can produce images with appropriate quality for diagnostic purposes. If so, this will greatly reduce the hazard of ionizing radiation to patients from maxillary sinus imaging. However, there is a wide variability between studies regarding selection of the parameters and the cut-off values of the applied protocols. Moreover, many of those studies considered bone window in their assessment and totally ignored the soft tissue window.[3,6–9]

Introducing CBCT to dentomaxillofacial applications has been evolutionary; it is generally considered as a low-dose alternative to MDCT scanners.[4,10] However, so far, few studies have been conducted on maxillary sinus diseases by CBCT and, moreover, addressed the image quality on account of the dose measurements.[11–13]

Before a decision is made whether to replace the standard MDCT protocol with the CBCT or with a low-dose MDCT protocol, many questions must be answered. First, which dose level of the suggested low-dose MDCT can be reached while preserving both osseous and soft tissue details? Second, at the low-dose level, how will be the image quality provided by either CBCT or the suggested low-dose MDCT in comparison with that of the standard MDCT? Third, does the higher dose typically used in the standard MDCT provide more information than CBCT or the suggested low-dose MDCT in a manner that might affect the diagnosis and surgical planning?

Table 2 Settings of the CBCT protocols

Protocol number	*RT*	*mAs*	*VS*
1	4	20	0.25
2	4	20	0.3
3	2	10	0.3

mAs, milliampere second; RT, rotation time in seconds; VS, voxel size.
Fixed settings: 120 kV and 5 mA.

So far, few *in vivo* studies have compared CBCT with MDCT in maxillary sinus diseases.[14,15] In general, *in vivo* studies do not allow making multiple comparisons between different exposure settings owing to radiation concerns. Kei et al[15] found that the image quality of CBCT scans in the assessment of opacification and osseous details of the maxillary sinus is generally inferior but adequate for screening purposes when compared with the standard MDCT protocol. On the contrary, Pekiner et al[14] indicated comparable image quality between MDCT and CBCT in the assessment of maxillary sinus diseases.

On the other hand, two studies have compared CBCT, low-dose MDCT and standard MDCT in maxillary sinus evaluation.[16,17] Bacher et al[17] investigated one low-dose MDCT scan in a phantom head; however, the exposure settings of that protocol were not detailed. Moreover, the study by Al Abduwani et al[16] evaluated chronic sinusitis retrospectively. It did not measure absorbed dose in a phantom head, and the exposure settings were not mentioned.

This study, therefore, aimed at assessing whether decreasing radiation dose may diminish the diagnostic image quality in maxillary sinus imaging by comparing different low-dose MDCT and CBCT imaging protocols with the standard MDCT protocol. Hence, comparisons within and between different protocols were conducted to ultimately choose the best protocols for clinical application.

Methods and materials

A head phantom and thermoluminescent dosemeters

An anthropomorphic head and neck Alderson Rando phantom (The RANDO® Phantom; Alderson Research Laboratories Inc., Stanford, CT) was used. It consists of a human skull embedded in an isocyanic rubber

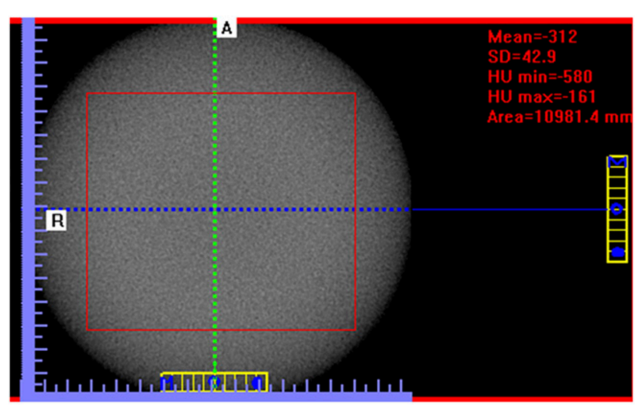

Figure 1 Measurement of image noise.

equivalent to the human soft tissues, in which the radiation absorption and spread match that of the human tissues. This phantom consists of 10 transverse sections of 2.5-cm thickness. Each section is perforated to accommodate thermoluminescent dosemeters (TLDs) (LiF : Mg–Ti (TLD-700) whose dimensions are 4.5-mm diameter and 0.9-mm thickness. These TDLs were used to record radiation doses at pre-selected locations in the head and neck region of the Rando phantom. Ten sensitive organs (14 sites) were chosen on the Rando phantom for placement of TLDs: the brain and eye (inner and outer canthi), 3 sites on the skin (nasion, cheek and midline of the neck), 4 sites representing the bone marrow (calvarium, cervical spine and the body and ramus of the mandible), 3 salivary glands, thyroid gland and remainder tissues (4 tissues were measured: lymph nodes, oral mucosa, muscles and extrathoracic airway, in which their sites were measured in the previous

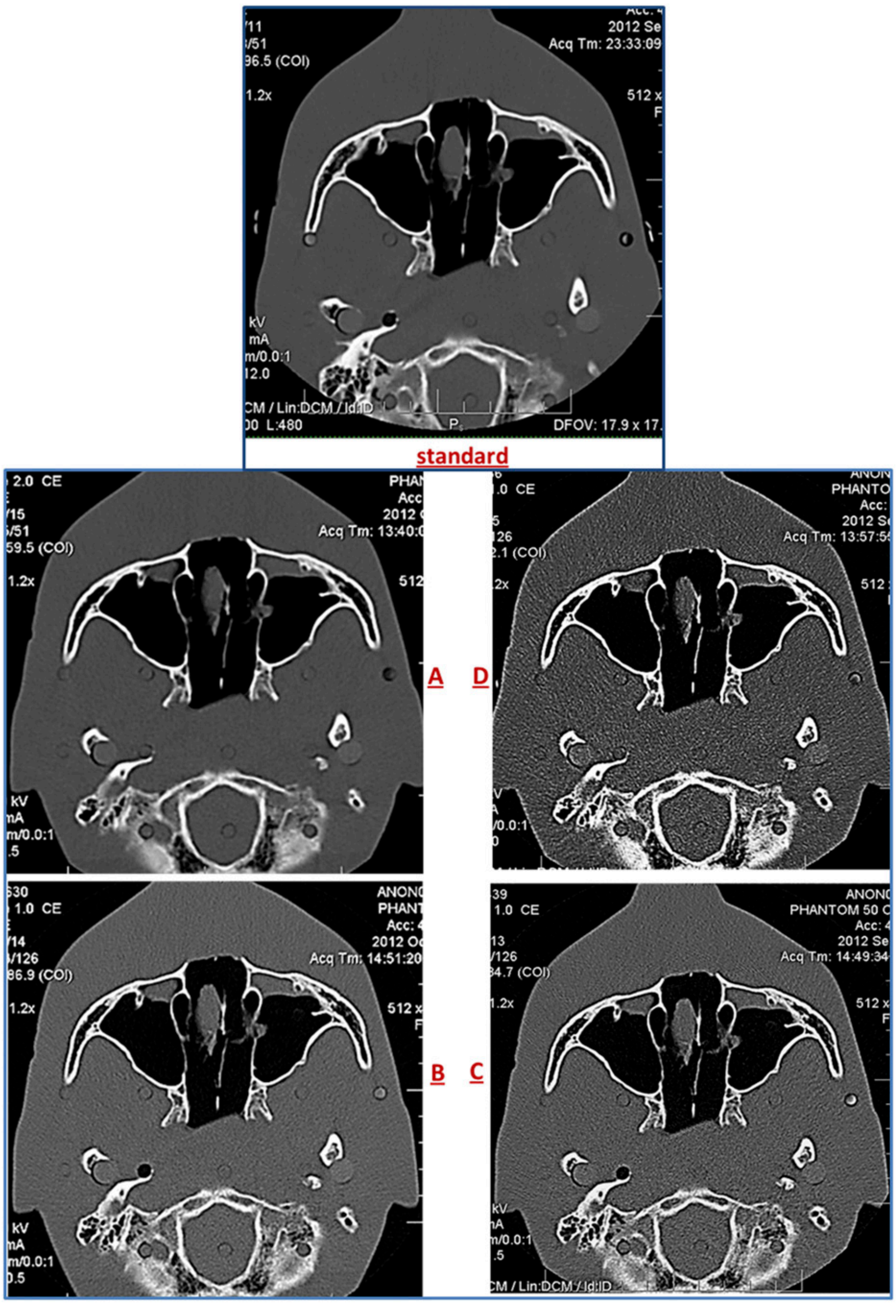

Figure 2 Axial sections of bone window (window level and width are 700 HU and 3000 HU, respectively) scanned at levels of maxillary sinus revealed the variations in image quality (image noise) of different multidetector CT (MDCT) protocols: (Standard) standard MDCT protocol (Standard), (A) Protocol VII, (B) Protocol VIII, (C) Protocol IX and (D) Protocol X.

sensitive organs). The sites of the remainder tissues measured in this study were seven sites on lymph nodes and muscles (3 salivary glands, ramus and body of the mandible, cervical spine and thyroid gland), five sites on the oral mucosa (3 salivary glands and the ramus and body of the mandible) and nine sites on the extrathoracic airway (2 orbit, 3 salivary glands, ramus and body of the mandible, cervical spine and thyroid gland). A total of 42 TLDs were placed in each scan, 3 chips per site. After that, the slices of the phantom were assembled and screwed well to be ready for scanning. The above steps were repeated twice for each protocol.

Imaging systems and scanning parameters

MDCT (Activion™ 16; Toshiba-Medical system, Otowara, Japan) and CBCT Next Generation i-CAT® (Imaging Sciences International, Hatfield, PA) were used in this study to scan a 13 × 10-cm field of view (FOV) from the beginning of the maxilla to the middle of the forehead.

Ten MDCT protocols (Protocols I, II, III, IV, V, VI, VII, VIII, IX and X), based on different scanning parameters [milliampere second (mAs) and pitch factor (PF)], were applied. This procedure started with the standard MDCT protocol for the maxillary sinus (according to manufacturer) until the cut-off value of a non-diagnostic image quality was reached (Table 1). All protocols were performed with a tilted gantry that was parallel to the Frankfort plane of the phantom which had been already loaded with the TLDs. First, the scout image was taken to locate the scan area with 30 mA, 0.75 second per rotation and 120 kV. Then, the area of interest was scanned. The image matrix consisted of 512 × 512 pixels. High resolution was chosen for data acquisition and for image reconstruction. After that, the axial images were reconstructed to produce sagittal, coronal and three-dimensional (3D) images.

Regarding CBCT scanning, three protocols (Protocols 1, 2 and 3) were applied by changing mAs and voxel size (VS) until the best diagnostic image quality

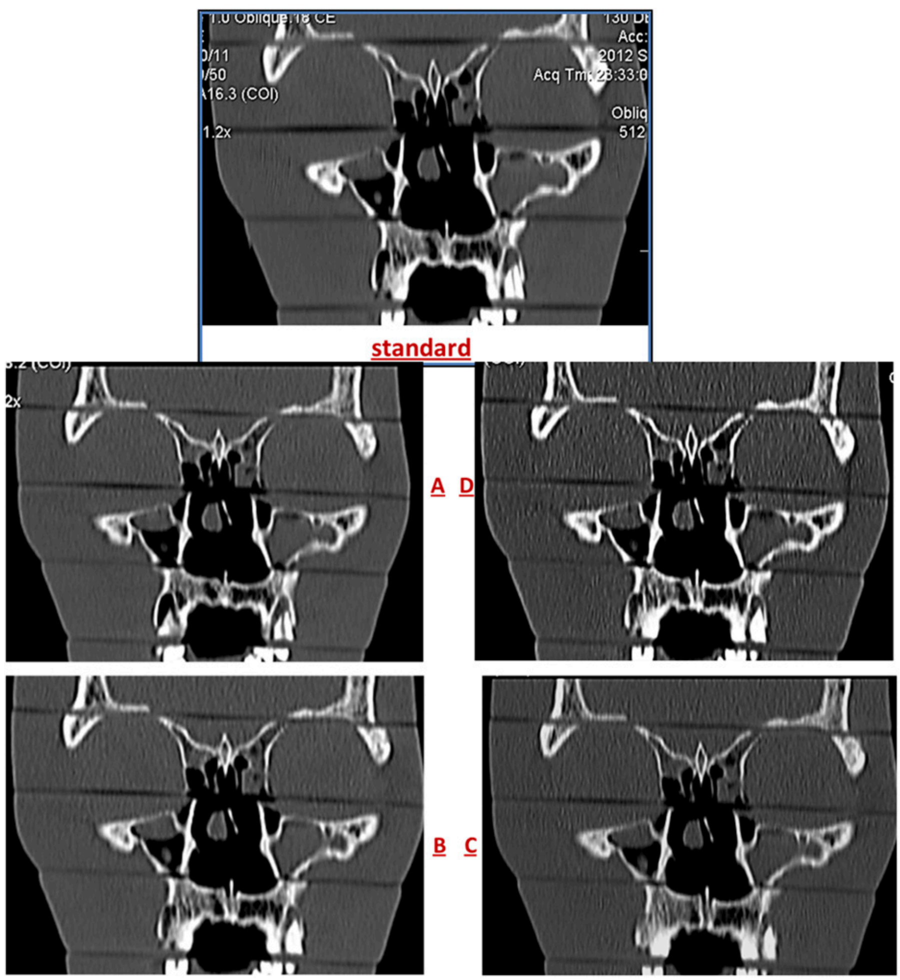

Figure 3 Coronal sections of bone window scanned at levels of maxillary sinus revealed the variations in image quality (image noise) of different MDCT protocols: standard multidetector CT (MDCT) protocol (Standard), (A) Protocol VII, (B) Protocol VIII, (C) Protocol IX and (D) Protocol X.

was obtained (Table 2). The phantom head, loaded with TLDs, was placed on the couch of the CBCT machine, centred by the laser beam, and its position was standardized by parallelizing its Frankfort plane to the floor to complete the scanning procedure. As the signal level of CBCT can be too low to be detected by TLDs, the phantom loaded with TLDs was exposed two times (two repetitive acquisitions) for each CBCT protocol to provide a reliable measurement of radiation by the dosemeters. Then, the obtained values were divided by 2 to get a mean value for each region. The scanning procedures for each MDCT and CBCT protocols were carried out two times in two different sessions in order to ensure reliability.

Radiation dose measurement
First, the TLDs were calibrated and their sensitivity was determined using a RADO irradiator (Finland); they were exposed to a known quantity of radiation. After that, the TLDs were analyzed using an automatic hot gas reader, and the raw data were recorded. The sensitivity of the individual TLD chip was calculated and

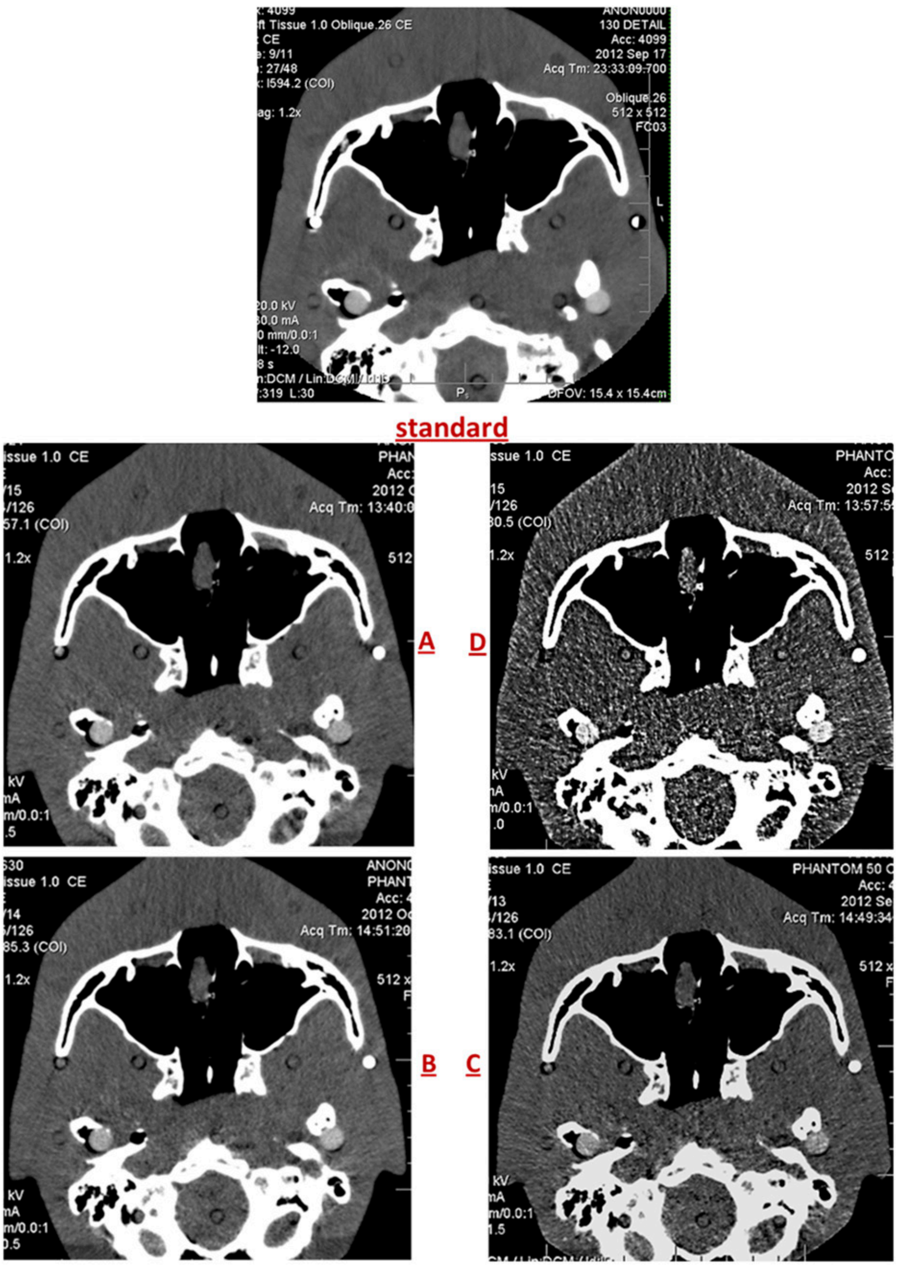

Figure 4 Axial sections of soft tissue window (window level and width are 40 HU and 400 HU, respectively) scanned at levels of maxillary sinus revealed the variations in image quality (image noise) of different multidetector CT (MDCT) protocols: standard MDCT protocol (Standard), (A) Protocol VII, (B) Protocol VIII, (C) Protocol IX and (D) Protocol X.

applied as a calibration factor to the subsequent exposure and reading of each TLD.

Reading of TLD dose values was accomplished by a TLD reader system (Alnor Dosacus TLD-reader; Finland) within a range of 24 h from exposure. Each of the three organ-/site-specific TLDs were installed in the Alnor slide, whose number was used as a code for that organ/site. These TLD slides were loaded in an Alnor cartridge and then read on the TLD reader; the obtained values were recorded. After reading, the calibration factor was applied for each TLD and the data were obtained in micrograys. Readings from each three organ-/site-specific TLDs per scan were averaged; the resultant organ- or tissue-absorbed dose was then the average of the averages of the two scans. The standard deviation (SD) of the readings from TLD-700 is ≤5%.

For measuring the effective dose (E), the equivalent dose (H_T) was calculated first. The values of the average tissue-absorbed dose were used to calculate the equivalent dose for a tissue or organ using the radiation-weighting factor (W_R) which, in case of X-ray radiation, is 1 and the measured absorbed dose (D_T) averaged over a particular tissue or organ (fraction irradiated of the organ) (Supplementary Table 1).[18–21] The following equation was used: $H_T = \Sigma\, W_R \times D_T$.[22]

Then, the E, expressed in μSv, was calculated using the following equation: $E = W_T \times H_T$, in which W_T represents the relative contribution of that organ or tissue to the overall risk (Supplementary Table 2).[22]

The whole-body risk is found by the summation of the weighted equivalent doses to all tissues or organs exposed.

Assessment of image quality

Image noise, measured as the SD of the radiographic density of water, was used for objective assessment of image quality in MDCT and CBCT. A cylindrical water-filled Perspex phantom was scanned to measure the image noise of all MDCT and CBCT protocols. Measurement of image noise (measurement of the fluctuations of CT number) was performed using regions of interest (ROIs) on a scan of a uniform phantom without application of filter algorithms. A statistical ROI function (available on most CT and CBCT programs) allowed us to place a rectangular or oval ROI (110 cm^2 in CBCT and 150 cm^2 in MDCT) on the image within which the average of the CT numbers for the enclosed pixels (SD), three measurements in three sections for each protocol, was calculated (Figure 1). The SD indicates the magnitude of random fluctuations in the CT number that is related to noise; the larger the SD, the higher the image noise.[23]

Subjective assessment of image quality was performed for both imaging modalities by comparing different protocol images with the baseline image of the standard MDCT protocol (Protocol I). After scanning the phantom, the volume data sets of the Rando phantom

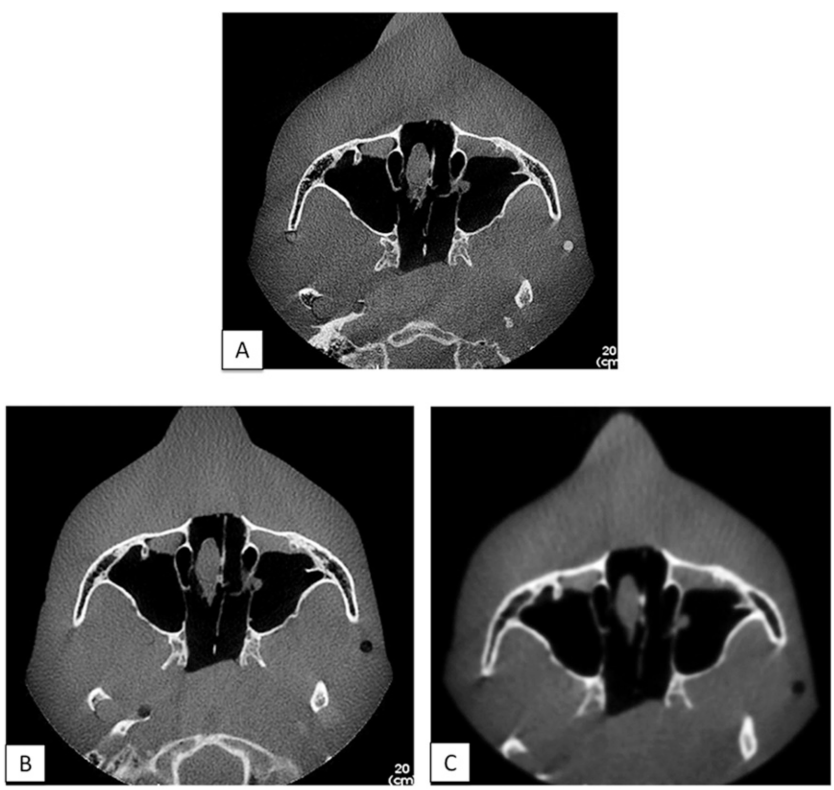

Figure 5 Axial sections of different CBCT protocols scanned at levels of the maxillary sinus reveal the variations in image quality: (A) Protocol 1, (B) Protocol 2 and (C) Protocol 3.

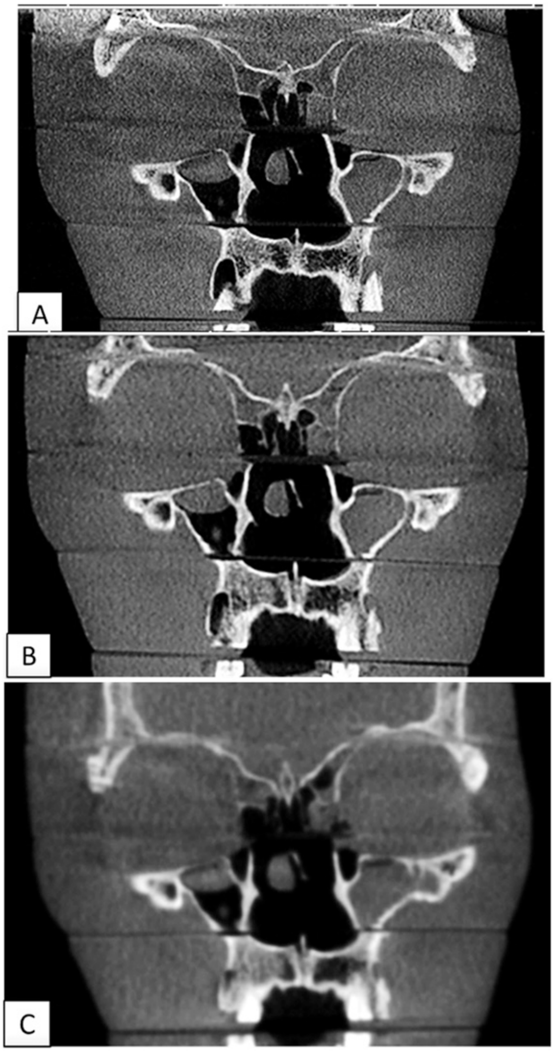

Figure 6 Coronal sections of different CBCT protocols scanned at levels of the maxillary sinus reveal the variations in image quality: (A) Protocol 1, (B) Protocol 2 and (C) Protocol 3.

of different MDCT and CBCT protocols were stored in a digital imaging and communications in medicine format and projected on a 3D workstation to evaluate image quality. These images were assessed blindly by two experienced oral and maxillofacial radiologists and one experienced general radiologist. The evaluation was performed for the overall diagnostic image quality (the sharpness and appearance of details in comparison with that in the standard protocol) and scored from 1 to 4: 1 = very good, 2 = good, 3 = acceptable and 4 = unacceptable. The image quality of MDCT was assessed for both the bone (window level and width are 700 HU and 3000 HU, respectively) and soft tissue (window level and width are 40 HU and 400 HU, respectively) windows to preserve the diagnostic image quality for both hard and soft tissues (Figures 2–6).

Statistical analysis: Numerical data were presented as means and SDs. Data were explored for normality using the Kolmogorov–Smirnov test. Dose and objective image noise variables revealed parametric distribution. Hence, a repeated measures ANOVA test followed by a Bonferroni's *post hoc* test for pairwise comparisons was used to compare these two variables between the different protocols. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with IBM® SPSS® Statistics for Windows v. 20 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL).

Results

Regarding MDCT protocols, *E*, absorbed dose of the eye and assessment of image quality are presented for the 10 protocols as (Supplementary Tables 3 and 4). The results of the standard protocol (Protocol I), the cut-off value protocol (Protocol X) and the three protocols before the cut-off value (Protocols VII, VIII and IX) are presented in Tables 3 and 4. Protocol X revealed the lowest radiation dose, but it was associated with the highest score of image noise (non-diagnostic image). Protocols VIII and IX had lower radiation doses with statistically significant differences compared with that of standard MDCT protocol, and they preserved good diagnostic image quality. However, Protocol VII had a good image

Table 3 Means and standard deviation (SD) of effective doses (*E*) for different multidetector CT protocols in different organs and the absorbed dose of the eye

	Protocol I		*Protocol VII*		*Protocol VIII*		*Protocol IX*		*Protocol X*		
Organs	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	p-*value*
Brain	190.08^{a}	6.7	48.51^{b}	2.03	31.61^{c}	0.15	25.12^{c}	0.74	21.83^{c}	0.88	<0.001
Thyroid gland	119.96^{a}	4.96	36.9^{b}	0.36	24.76^{c}	0.48	23.12^{c}	0.24	21.36^{c}	0.24	<0.001
SG	248.6^{a}	4.47	50.92^{b}	1.34	39.70^{c}	1.08	35.19^{c}	1.39	29.51^{c}	0.49	<0.001
Skin	11.3^{a}	0.31	2.5^{b}	0.03	1.72^{c}	0.05	1.56^{c}	0.04	1.45^{c}	0.1	<0.001
Bone marrow	180.12^{a}	5.13	33.96^{b}	0.96	22.2^{c}	0.9	19.68^{c}	0.7	17.04^{c}	0.21	<0.001
Bone surface	69.64^{a}	1.98	13.13^{b}	0.37	8.60^{c}	0.35	7.61^{c}	0.27	6.59^{c}	0.08	<0.001
Remainder tissues	481.59^{a}	15.94	98.09^{b}	2.93	68.10^{bc}	1.61	60.89^{c}	2.20	51.81^{c}	1.07	<0.001
Total *E*	1301.2^{a}	39.54	283.99^{b}	8.02	196.7^{c}	4.62	173.17^{c}	5.58	149.61^{c}	3.07	<0.001
Eye	31394^{a}	1585	6352^{b}	269	4158^{b}	44	3686^{b}	117	2999^{b}	101	<0.001

SGs, Salivary glands.
Different letters in the same row are statistically significant different according to Bonferroni's test.

Table 4 Objective and subjective assessments of image quality of different multidetector CT protocols

Assessment		*Protocol I*	*Protocol VII*	*Protocol VIII*	*Protocol IX*	*Protocol X*	p-*value*
Objective, mean (SD)		30.8 (5.6)[a]	56.3 (7.2)[b]	63.4 (4.1)[b]	71.6 (6.2)[b]	84.6 (9.3)[c]	<0.001
Subjective	First observer	1	2	2	3	4	NC
	Second observer	1	2	2	3	4	
	Third observer	1	2	2	3	4	

NC, not calculated; SD, standard deviation.
Different letters in the same row are statistically significant different.

quality, but its radiation dose was statistically higher compared with that of Protocols VIII and IX. Thus, Protocols VIII and IX that had lower radiation doses and diagnostic image quality for both bone and soft tissue windows were chosen for further comparisons with the CBCT protocol (Figure 7).

Concerning CBCT protocols, Protocol 1 showed the highest radiation dose with the lowest image quality, while Protocol 3 had the lowest radiation dose with a lower image quality, compared with Protocol 2. As a result, Protocol 2, which had a reasonable radiation dose and good image quality, was chosen for the comparison with the two MDCT protocols (Protocols VIII and IX) (Tables 5 and 6) (Figure 8).

The *E* values of the selected low-dose MDCT and CBCT imaging protocols at the level of the TLD locations in the Rando phantom are presented in Table 7. Protocol I revealed the highest mean *E* with statistically significant differences compared with the other protocols. Protocol VIII showed statistically significant lower mean *E*, followed by Protocols IX and 2, respectively. There were no statistically significant differences between VIII, IX and 2 protocols.

With regard to the subjective assessment of the image quality of the selected low-dose MDCT and CBCT imaging protocols, Protocol IX showed lower score of image quality when compared with that of the other protocols, while Protocol I showed higher score. However, Protocols VIII and 2 had the same scores of image quality with agreement between all observers (Table 8).

Discussion

Clinical utility of CT examinations has increased recently, and the concern about radiation hazards from CT has increased accordingly. As a result, optimization of radiation dose has been given great attention by radiologists, technologists and physicists. In this context, various methods and strategies, based on modification of scanning parameters and application of recent technological innovations, have been assessed.[24]

However, radiation doses of MDCT and CBCT scanners are variable, and even from one scanner to other of the same system (consuming period and maintenance) making selection of scanning parameters and measurement of doses for each scanner essential.[3,10,19,25–27]

The MDCT radiation dose to which a patient is exposed is affected by many factors: scanner-related and patient-related factors. The most adjustable scanner-related factors are: mAs, PF, FOV and slice thickness.[23] In this study, the FOV was limited to the area of the paranasal sinus. The increased slice thickness leads to

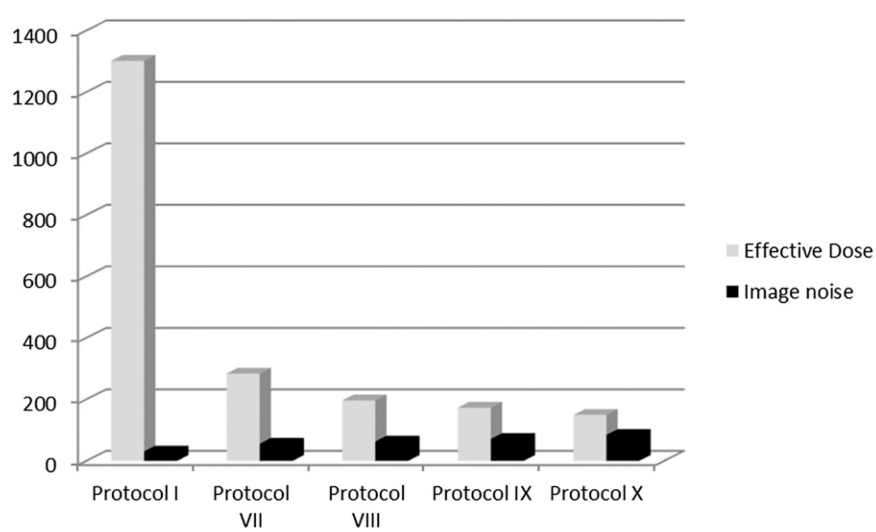

Figure 7 Effective dose against image noise in multidetector CT protocols.

Table 5 Means and standard deviation (SD) of effective doses (E) for different CBCT protocols in different organs and the absorbed dose of the eye

	Protocol 1		*Protocol 2*		*Protocol 3*		
Organs	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	p-*value*
Brain	22.38[a]	0.55	19.06[b]	0.83	9.725[c]	0.35	<0.005
Thyroid gland	21.2[a]	0.16	10.9[b]	0.54	8.56[c]	0.12	<0.001
SG	23.05[a]	0.46	22.4[a]	0.69	12.2[b]	0.11	<0.001
Skin	0.995[a]	0.027	0.9[a]	0.03	0.48[b]	0.005	<0.005
Bone marrow	17.64[a]	1.2	13.15[b]	0.56	6.6[c]	0.05	<0.002
Bone surface	6.82[a]	0.46	5.09[b]	0.22	2.55[c]	0.02	<0.002
Remainder tissue	38.35[a]	1.07	37.61[a]	1.43	25.09[b]	0.60	<0.002
Total E	130.435[a]	3.93	109.11[b]	4.3	65.21[c]	1.26	<0.007
Eye	2736[a]	66	2185[b]	118	1186[c]	16	<0.006

SG, salivary gland.
Different letters in the same row are statistically significant different according to Bonferroni's test.

radiation dose reduction, but at the same time it affects the reconstructed images, which in turn affects the diagnostic image quality.[22,23,28] Therefore, slice thickness was fixed in this study in all protocols to provide acceptable image quality, to avoid increased radiation dose and to decease variability between protocols. The mAs and PF were manipulated in this study until the lowest possible radiation dose with acceptable diagnostic image quality was reached. This was accomplished by reducing the mAs and increasing the PF, as reported in studies conducted by Tack et al[9] and Mulkens et al.[8]

Factors affecting dose and image quality in CBCT systems are: mAs, VS and FOV. The FOV was limited to the area of interest as it was for MDCT. On the other hand, mAs and VS were manipulated in the present study until the best image quality with an appropriate dose was reached. Similar to that in MDCT, mAs is an important factor affecting dose and image quality.[29–31] The only difference is that the photons in some CBCT systems, such as i-CAT and Scanora 3D systems, are not emerging from the device along the scanning period, and a pulsed time was used to determine mAs.[32]

Ten MDCT protocols were tried until the cut-off value of 20 EmAs was reached at which the image quality of the bone and soft tissue windows was taken into consideration. This cut-off value is inconsistent with the cut-off value of Hojreh et al.[6] Marmolya et al[33] found that as little as 23 mAs provided sufficient diagnostic quality when only sinusitis was of concern. Sohaib et al[34] revealed that only 50 mA was sufficient for assessment of bone structures. Brem et al[35] recorded a higher cut-off value than the present study, which may be related to their method that relied on computer simulations.

The cut-off value in the present study is contradicted by that of Tack et al,[9] Mulkens et al[8] and Abul-kasim et al,[3] who found lower cut-off values ranged from 10 EmAs to 17 EmAs. However, these studies assessed only sinusitis, found some difficulties in assessment of some anatomical landmarks and focused only on the image quality of bone window, in contrast to our study which tried to preserve the image quality of both bone and soft tissue windows. Moreover, Mulkens et al[8] included only children in their study. Hofmann et al[10] compared the image quality of the low-dose MDCT (17.5 EmAs) and CBCT protocols and concluded that the image quality in the MDCT devices had been judged to be significantly worse when their radiation doses were reduced to a level equal to or lower than the CBCT devices.

The E of the standard MDCT protocol in this study was comparable with the E recorded by Bacher et al[17] (1400 μSv), but it was higher than that reported by Abul-kasim et al[3] (371 μSv), Al Abduwani et al[16] (480 μSv) and Tack et al[9] (700 μSv for males and 760 μSv for females). This can be attributed to the differences in the scanning parameters used by Abul-kasim et al,[3] where they used 70 mA rather than the 100 mA used in the present study. The study of Tack et al[9] was an *in vivo* study in which the absorbed dose was not measured for all sensitive organs that were used for E calculation. Al Abduwani et al,[16] however, did not mention their parameters and accordingly the differences could not be

Table 6 Objective and subjective assessments of image quality of different CBCT protocols

Assessment		*Protocol 1*	*Protocol 2*	*Protocol 3*	p-*value*
Objective, mean (SD)		86.3 (6.5)[a]	45.5 (5.6)[b]	62.9 (7.2)[c]	0.001
Subjective	First observer	3	2	3	NC
	Second observer	4	2	3	
	Third observer	3	2	3	

NC, not calculated; SD, standard deviation.
Different letters reflect different means.

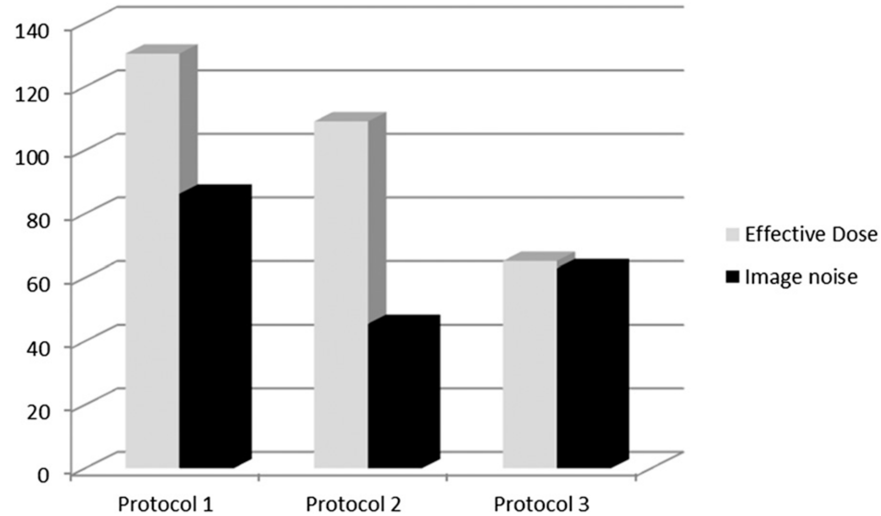

Figure 8 Effective dose against image noise in CBCT protocols.

explained. On the other hand, the E values of the low-dose MDCT protocols in this study are in agreement with a study conducted by Bacher et al[17] (200 μSv) and higher than that reported in Mulkens et al[8] and Abul-kasim et al[3] studies. This difference can be ascribed to the differences in the method of measurements. Statistically significant differences were found between the E of standard MDCT protocol and low-dose MDCT protocols, which is in consistent with the finding of Abul-kasim et al.[3]

Protocol selection was based on E value and image quality assessment. It is documented that the dose reduction causes increase in the image noise, which automatically affects the image quality. The diagnostic image quality in the present study was still preserved in MDCT Protocols VIII and IX, although there was a dose reduction by seven times. These findings are comparable with that of Cohnen et al[29] who concluded that the dose of CT could be reduced eight times with maintenance of the diagnostic image quality. Hence, the lowest possible radiation dose that still preserves the diagnostic image quality could be obtained with Protocol VIII followed by Protocol IX. On the other hand, the Rando phantom used in this study was an adult phantom in which the acceptable image quality of Protocol IX could have been improved if it was applied in children, who need lower radiation dose than adults.

The E of different CBCT protocols in the present study ranged from 65 μSv to 130 μSv. Few studies so far have measured E of CBCT of the paranasal sinuses. Bacher et al[17] reported an E comparable with that of Protocol 3 in this study (65 μSv). Al Abduwani et al,[16] however, reported higher E (270 μSv) than ours; this might be attributed to the differences in the machines and method of E measurements, in addition to the fact that they did not mention their protocol parameters.

CBCT protocols for the maxillary sinus examination in this study revealed a good diagnostic image quality, which is in agreement with another study performed with the Rando phantom for paranasal sinus examinations (Bacher et al[17]). Protocol 2 was selected because it yielded the best diagnostic image quality. Protocol 1 used a smaller VS than Protocol 2, delivered the highest radiation dose and was associated with the worst image quality. This can be attributed to the fact that a smaller VS was associated with increased image noise.[32,36]

Table 7 Means and standard deviation (SD) of effective doses (E) for the standard multidetector CT (MDCT), selected low-dose MDCT and CBCT protocols in different organs

	Protocol I		*Protocol VIII*		*Protocol IX*		*Protocol 2*		
Organs	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	p-*value*
Brain	190.08[a]	6.72	31.61[b]	0.15	25.12[b]	0.74	19.06[b]	0.83	<0.001
Thyroid gland	119.96[a]	4.96	24.76[b]	0.48	23.12[b]	0.24	10.9[b]	0.54	<0.001
SG	248.6[a]	4.47	39.70[b]	1.08	35.19[b]	1.39	22.4[c]	0.69	<0.001
Skin	11.3[a]	0.31	1.72[b]	0.05	1.56[b]	0.04	0.9[b]	0.03	<0.001
Bone marrow	180.12[a]	5.13	22.2[b]	0.9	19.68[b]	0.7	13.15[b]	0.56	<0.001
Bone surface	69.64[a]	1.98	8.60[b]	0.35	7.61[b]	0.27	5.09[b]	0.22	<0.001
Remainder tissues	481.59[a]	15.94	68.10[b]	1.61	60.89[b]	2.20	37.6[b]	1.43	<0.001
Total E	1301.2[a]	39.54	196.7[b]	4.62	173.17[b]	5.58	109.11[b]	4.3	<0.001

SG, salivary gland.
Different letters in the same row are statistically significant different according to Bonferroni's test.

Table 8 Subjective assessments of image quality of the standard multidetector CT (MDCT) and selected low-dose MDCT and CBCT protocols

Assessment	*Protocol I*	*Protocol VIII*	*Protocol IX*	*Protocol 2*
First observer	1	2	3	2
Second observer	1	2	3	2
Third observer	1	2	3	2

In Kei et al study,[15] the settings which they used for the MDCT scan were close to our Protocol VIII (effective milliampere second in their study was 29.3 EmAs *vs* 32 EmAs for our Protocol VIII). However, the eye lens dose in their study was lower than that mentioned in our study, and the image quality of MDCT was better than that of CBCT as per their results. This difference may be attributed to the smaller FOV in their study in comparison with the present *in vitro* one. In addition, their CBCT device has lower tube voltage than the CBCT device in our study, which may have contributed to the degradation of the image quality in their study in comparison with MDCT.

When the selected low-dose MDCT and CBCT protocols were compared, CBCT resulted in an image quality comparable with that of low-dose MDCT protocol with 40% dose reduction, but without statistically significant differences. However, it should not be overlooked here that CBCT cannot produce images with soft tissue window as in MDCT. Our findings are consistent with Yu et al[37] who stated that with a matched radiation dose, the CBCT system for sinus examinations had a comparable image quality (spatial resolution and image noise) relative to MDCT scanner. Moreover, Al Abduwani et al[16] concluded that CBCT has image quality and radiation dose comparable with that of low-dose MDCT, and they are good alternative to standard MDCT protocol. However, this result is contradicted by the result of Bacher et al,[17] who reported an image quality of CBCT scanner for sinus examination comparable with that of low-dose MDCT scanner, but with a 85% radiation dose reduction. This difference could not be explained because they did not mention the scanning parameters used in their methodology.

Conclusions

The low-dose MDCT and CBCT protocols are viable methods for maxillary sinus examination as evaluated using the above-mentioned phantom that yielded a good diagnostic image quality using an E approximately 7 and 11 times lower than that of the standard MDCT, respectively. These findings were evaluated in the *in vivo* part of this project.

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