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RESEARCH ARTICLE

Localization of the inferior alveolar canal using ultralow dose CT with iterative reconstruction techniques

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Objectives: To compare subjective and objective localization of the inferior alveolar canal (IAC) on multidetector CT (MDCT) images obtained by ultralow doses in combination with the reconstruction techniques of filtered backprojection (FBP), adaptive statistical iterative reconstruction (ASIR), or model-based iterative reconstruction (MBIR) as compared to standard dose MDCT and FBP.
Methods: Three cadavers were imaged with a reference standard dose MDCT examination (volume CT dose index: 29.4 mGy) reconstructed with FBP and 5 low dose protocols (LD1-5) (volumeCT dose index: 4.19, 2.64, 0.99, 0.53, 0.29 mGy) reconstructed with FBP, ASIR 50, ASIR 100, and MBIR. Linear measurements from the crest of the ridge to the roof of the IAC were recorded. The results from the test protocols were compared with those from the reference using Bland–Altman plots.
Results: Only three test protocols allowed the identification of the position of the IAC on all the sample sites: LD1/FBP and LD1/ASIR 100 and LD2/FBP. All three protocols allowed identification of the IAC with comparable results to the reference dose protocol; the 95% confidence interval limits for the measurement differences were ± 0.41 mm, but the differences were not statistically significant. The calculated effective dose for the LD2 protocol, for a scan length of 5 cm, was 27.7 μSv.
Conclusions: Using FBP, comparable IAC measurements were achieved with 91% reduction in dose compared with a standard exposure protocol. The use of ASIR and MBIR did not improve identification of the IAC in MDCT low dose images.
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Keywords: Anatomy; image-guided surgery; imaging; multidetector CT; radiation dosage; cross-sectional; three-dimensional

Introduction

Three-dimensional imaging using CT is recommended for evaluation of prospective dental implant sites.[1] However, the widespread use of CT has been cited as a reason for the increased collective dose of ionizing radiation to populations.[2] Although cone beam CT (CBCT) is increasingly replacing multidetector CT (MDCT) in implant diagnostics due to the reportedly lower radiation dose and cost, MDCT is still the only option available in some settings. Therefore, dose optimization of MDCT for the various diagnostic tasks involved in implant site imaging is necessary.[1,3,4] The importance of dose optimization has been emphasized

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by the National Council on Radiation Protection through their modification of the ALARA (as low as reasonably achievable)concept to ALADA, as low as diagnostically achievable, which stresses that imaging should utilize the lowest possible doses which produce diagnostic images.[3] It is also mandated as a legal requirement by some governmental bodies.[4]

One of the most important diagnostic tasks during the analysis of prospective implant sites is identification of the roof of the inferior alveolar canal (IAC). Previous studies have reported that, at MDCT dose reductions of up to a factor of 8, implant site measurements above the IAC recorded from low-dose MDCT images were comparable to those from standard-dose MDCT images, but that further dose reductions were not possible due to compromised image quality.[5,6] However, the advanced iterative reconstruction techniques (IRTs) of adaptive statistical iterative reconstruction (ASIR) and model-based iterative reconstruction (MBIR) have been shown to allow significant improvement in subjective image quality of high-resolution images of the craniofacial bone at ultralow doses of 76 and 91% dose reductions compared with filtered backprojection (FBP) reconstruction using the recommended volume CT dose index (CTDIvol) of sinusitis.[7] Furthermore, a 97.5% reduction in dose compared to a standard imaging protocol has shown no significant difference in ridge measurements of dental implant sites when FBP, ASIR, or MBIR were used, and other investigators have found that an IAC that is visible in standard dose/FBP CT images is also visible in ultralow dose CT using IRT.[8,9]

However, to our knowledge, there is no information in the published literature regarding the lower limit of MDCT dose reduction, in combination with ASIR or MBIR, which will allow objective measurements of the position of the IAC. The investigation of more aggressive dose reductions using such techniques has the potential to improve dose optimization for MDCT imaging of dental implant sites. Therefore, this study aimed to compare the following parameters recorded from MDCT images obtained by ultralow doses in combination with FBP, ASIR, or MBIR with those from a reference MDCT protocol using standard dose and FBP:

(1) Subjective visibility of the roof of the IAC, and
(2) Objective linear measurements of the position of the IAC.

Methods and materials

Sample selection

Three cadavers were used in the study. The cadavers were selected based upon the fact that the roofs of their IACs were clear in MDCT images obtained with the reference protocol. The bodies were donated to the Division of Clinical and Functional Anatomy of the Innsbruck Medical University by people who had given their informed consent for their use for scientific and educational purposes prior to death.[10,11] All cadavers have been preserved using an arterial injection of a formaldehyde–phenol solution/an alcohol–glycerin solution and immersion in phenolic acid in water for 1–3 months.[12] The cadavers were selected based upon the fact that the roofs of their IACs were clear in MDCT images obtained with the reference protocol (Figure 1).

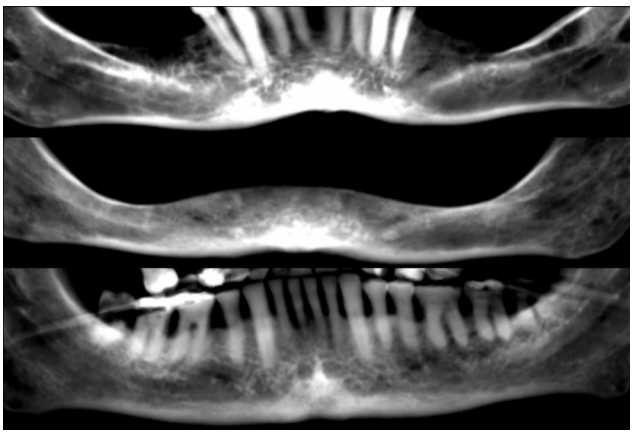


Figure 1 Reformatted panoramic sections of the mandibles used in the study obtained from the reference dose CT data sets. All the panoramic sections are 20 mm thick. Although the degree of cortication of the roof of the IACs is variable, the roof of the IAC is visible in all three mandibles bilaterally. IAC, inferioralveolar canal.

The inclusion criteria for the sample sites were areas of the mandibular bodies bounded by the external oblique ridge posteriorly and the mental foramen anteriorly. The exclusion criteria were:

(1) Areas with foreign objects.
(2) Areas with artificial defects.
(3) Areas where the roof of the IAC is not visible in the images obtained with the reference protocol (standard dose/FBP).
(4) Areas where the roof of the IAC is less than 2 mm away from the crest of the ridge.

A calculation of the sample size needed for the study referred to published data on MDCT linear measurement errors and found that a sample size of 30 was sufficient to detect a measurement difference of 0.35 mm with a power of 0.9.[13,14]

Imaging of the samples

Each of the cadavers was scanned with a 64-row CT scanner (Discovery CT750 HD, GE Healthcare, Vienna, Austria) using a standard dose and FBP (the reference protocol) and five test protocols, low dose protocols 1–5 (LD1–LD5). All six CT exposures were performed with the cadaver head in the same position within the gantry. Each of the LD protocols was reconstructed with FBP, ASIR 50, ASIR 100, and MBIR. As such, 21 MDCT data sets were obtained for each cadaver. Table 1 outlines the examination parameters of the various protocols used in the study, along with their

Table 1 List of MDCT exposure parameters and reconstruction techniques used in the reference and low dose protocols

									Effective dose (μSv)[a]	
Exposure protocol	*Reconstruction technique*	*Matrix*	*In-plane voxel size (mm)*	*kV*	*mA*	*Rotation time (sec)*	*Pitch*	*CTDIvol (mGy)*	*Scan length of 5 cm*	*Scan length of 10 cm*
Reference	FBP	512 × 512	0.391	120	100	1.0	0.53	29.4	308.7	617.4
LD1	FBP	512 × 512	0.391	100	35	0.5	0.53	4.19	44.0	88.0
	ASIR 50									
	ASIR 100									
	MBIR	1024 × 1024	0.195							
LD2	FBP	512 × 512	0.391	80	40	0.5	0.53	2.64	27.7	55.4
	ASIR 50									
	ASIR 100									
	MBIR	1024 × 1024	0.195							
LD3	FBP	512 × 512	0.391	80	15	0.5	0.53	0.99	10.4	20.8
	ASIR 50									
	ASIR 100									
	MBIR	1024 × 1024	0.195							
LD4	FBP	512 × 512	0.391	80	10	0.4	0.53	0.53	5.6	11.1
	ASIR 50									
	ASIR 100									
	MBIR	1024 × 1024	0.195							
LD5	FBP	512 × 512	0.391	80	10	0.4	0.97	0.29	3.0	6.1
	ASIR 50									
	ASIR 100									
	MBIR	1024 × 1024	0.195							

ASIR, adaptive statistical iterative reconstruction; FBP, filtered back projection; LD, low dose protocol; MBIR, model-based iterative reconstruction.
[a]Effective doses calculated based on a *k*-factor of 0.0021 for adult head examinations and tissue weighting factors from the International Commission on Radiologic Protection document ICRP 103 (2007).

calculated effective doses [tissue weighting factors from the International Commission on Radiologic Protection document 103 (2007)].[15] All data sets were acquired with a slice thickness of 0.625 mm and a bone reconstruction kernel, except for MBIR, for which only a standard reconstruction kernel was available.

Preparation of sample images and identification of the inferior alveolar canal

Processing of the MDCT data sets, reformatting of sample sites, viewing the sample sites, and recording of study measurements were all performed as described in a previous study.[8] Because the reference and test MDCT examinations were performed with the cadaver head in the same position within the gantry, the default angulation and position of the standard sectional planes relative to the head were consistent in all the MDCT data sets of each cadaver. Therefore, using standardized shift and angulation of the orthogonal sectional planes, reformatted sample sites were obtained at standardized position and orientation in all the data sets for each cadaver. Table 2 demonstrates images of a sample site obtained by the reference and test protocols.

Two examiners who did not participate in reformatting of the images and were blinded to the examination protocols recorded the study measurements. Examiner 1 (WA) and Examiner 2 (Am A) were OMF Radiologists with 12 and 8 years' experience, respectively, in CT image processing and analysis. The examiners were permitted to interactively view the sample images and adjust contrast and density for maximum clarity of the roof of the IAC. Also, the examiners were permitted to scroll through the image sections and perform whatever image processing was necessary to determine the position of the IAC. However, prior to recording the objective measurement of the position of the IAC, the examiners reverted to the saved sample image.

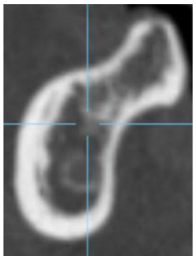
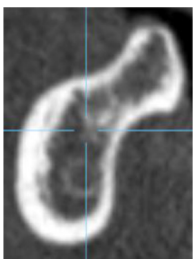
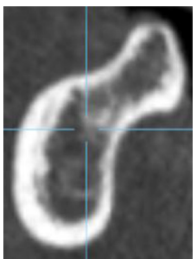
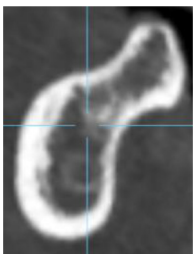
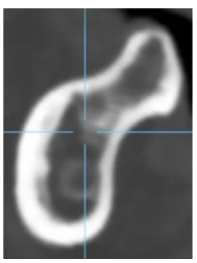
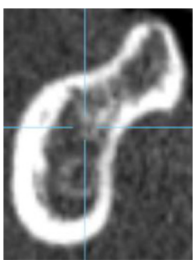
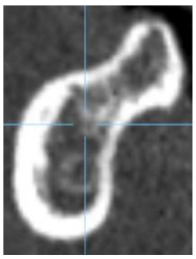
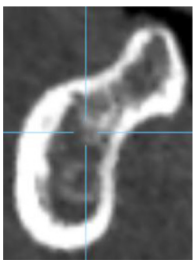
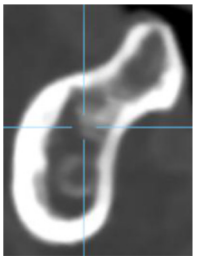
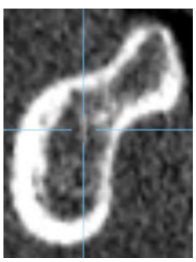
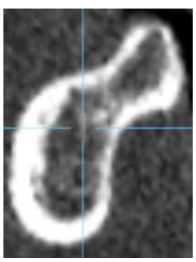
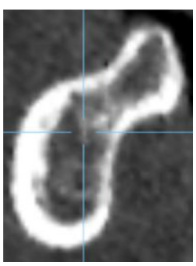
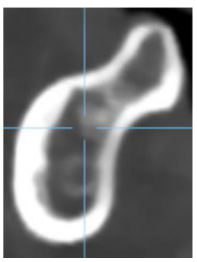
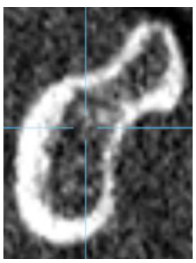
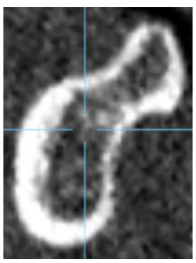
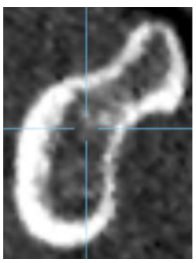
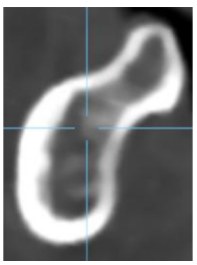
The first examiner recorded all the measurements once; the second examiner did not review the entire sample data set. For reliability testing, both examiners then independently recorded the measurements from 105 sites [5 sites randomly selected from each protocol using an online random numbers generator (http://stattrek.com/statistics/random-number-generator.aspx)].

Subjective measurement

The visibility of the roof of the IAC was subjectively evaluated using a 4-point scale:

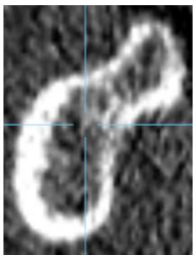
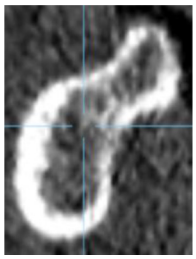
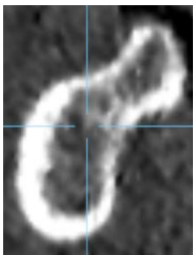
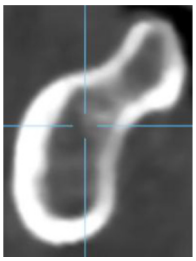
(1) Impossible to observe the roof of the IAC.
(2) Difficult to observe the roof of the IAC.
(3) Somewhat possible to observe the roof of the IAC.

Table 2 Images of one sample site obtained with the reference dose protocol and the various combinations of test protocols and reconstructions techniques

	Filtered backprojection	*ASIR 50*	*ASIR 100*	*MBIR*
Reference dose protocol				
LD1				
LD2				
LD3				
LD4				

(Continued)

Table 2 (Continued)

	Filtered backprojection	*ASIR 50*	*ASIR 100*	*MBIR*
LD5				

ASIR, adaptive statistical iterative reconstruction; LD, low dose protocol; MBIR, model-based iterative reconstruction.

(4) Definitely possible to observe the roof of the IAC.

Objective measurement

The position of the roof of the IAC was objectively measured as the distance between the crest of the ridge and the horizontal level of the inner surface of the roof of the IAC. Figure 2 demonstrates the position, orientation, and extent of the objective measurements. The linear measurements were recorded to the nearest 0.1 mm.

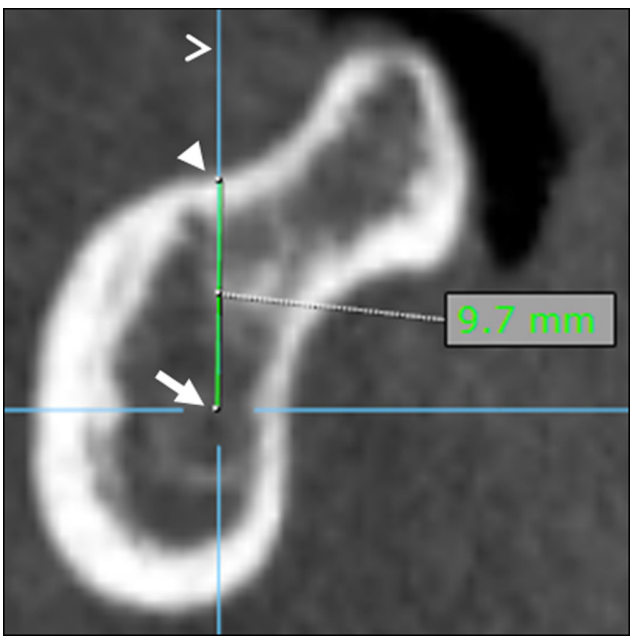


Figure 2 Sample site (transverse cross-sectional image of mandible) demonstrating the position and orientation and extent of the objective measurements. The measurement was recorded along the parasagittal reformatting line (open arrow head), and extended from the superior boundary of the ridge (arrow head) to inner surface of the roof of the IAC. If the parasagittal line did not pass through the roof of the IAC, the inferior extent of the measurement was determined by shifting the axial reformatting line until it contacted the inner surface of the roof of the IAC. The inferior extent of the measurement would then be determined as the point where the parasagittal line intersects with the axial line (arrow). IAC, inferior alveolar canal.

Statistical analysis

The first examiners' complete readings were used to compare the results between the reference and test protocols. The subjective evaluation scores for all the samples were added up for each protocol, and descriptive statistics were used to compare the scores from the reference and test protocols. For analysis of the objective linear measurements, the comparability of the measurements recorded from each test protocol with those from the reference protocol were assessed by a Bland–Altman plot and regression analysis for each test protocol.

The 105 linear measurements recorded by both examiners were compared with the corresponding first readings by the first examiner for evaluation of the intra- and interexaminer reliability of the linear measurements. The measurements were analysed by correlation testing (intraclass correlation coefficient). Statistical significance for the regression analysis and correlation testing was set at a p-value of 0.05.

Results

Based upon the inclusion and exclusion criteria and reformatting protocol for obtaining the sample sites, 30 transverse cross-sectional images were obtained from the three cadavers. Since each cadaver had been examined with 1 reference and 20 test protocols, a total of 630 images were included in the study.

For each image, only 1 subjective visibility score was obtained, for a total of 630 subjective visibility scores. Table 3 demonstrates the sum of the scores of the subjective visibility of the roof of the IAC for each test protocol. The subjective visibility of the roof of the IAC was found to be minimally affected by reduction of radiation doses to LD1 and LD2. However, at lower doses, the visibility generally became less with decreasing doses. Although ASIR 100 demonstrated a markedly higher visibility score compared to the other techniques at LD3, no overall pattern of improved visibility was found with any specific reconstruction technique compared to the others.

Table 3 Sum of the scores of the subjective visibility of the roof of the inferior alveolar canal in images of the various protocols (n = 30 for all protocols)

	FBP	*ASIR 50*	*ASIR 100*	*MBIR*
Reference dose	107	–	–	–
LD1	111	105	99	102
LD2	96	108	115	99
LD3	90	83	103	86
LD4	68	73	84	80
LD5	84	85	74	80

ASIR, adaptive statistical iterative reconstruction; FBP, filtered back projection; LD, low dose protocol; MBIR, model-based iterative reconstruction.

For the objective linear measurements, most of the test protocols had one or more sites where the examiner was not confident in identification of the roof of the IAC, and did not record a measurement. Table 4 demonstrates the number of samples in each test protocol in which a linear measurement could not be recorded. The only test protocols in which the roof of the IAC was visible in all the sample sites were LD1/FBP and ASIR100 and LD2/FBP. For these three protocols, Bland–Altman plots (Supplementary Material 1) with linear regression showed no systematic variation between the linear measurements obtained with these protocols and the reference, with the 95% confidence interval limits for the measurement differences being within ± 0.41 mm, but not statistically significant (Table 4).

For the intra- and interexaminer reliability of the linear measurements, the intraclass correlation values were 0.977 and 0.953, respectively. However, examiners 1 and 2 were unable to obtain linear measurements from 15 and 33 sites, respectively. The more experienced examiner was able to identify the roof of the IAC at more sites compared to the other examiner. The high reliability scores do not take into account the numerous sites at which measurements could not be recorded.

Discussion

The present study investigated the effect of ultralow MDCT doses and ASIR and MBIR on subjective and objective measures of localization of the IAC. The results of the present study indicate that, for imaging of the IAC, a 91% dose reduction is possible with FBP and 86% reduction with ASIR 100, compared to a standard imaging protocol. With these three protocols, measurement of the position of the roof of the IAC was possible in all the samples, and the results were comparable to those from the reference. The IRTs of ASIR and MBIR

Table 4 Differences between the linear measurements obtained by the reference protocol (reference dose/FBP) and the various test protocols

	Number of samples (out of 30) from which linear measurement could be obtained	*Mean difference (mm)*	*Sig. (one-sample T-test)*	*Standard deviation of the differences (mm)*	*95% confidence interval limits (mm)*		*Sig. (linear regression)*
					Upper limit	*Lower limit*	
LD1/FBP	30 (100 %)	0.05	0.781	0.98	0.41	−0.31	0.176
LD1/ASIR50	27 (90 %)	−0.04	0.771	0.65	0.22	−0.30	0.094
LD1/ASIR100	30 (100 %)	0.10	0.349	0.56	0.30	−0.11	0.743
LD1/MBIR	28 (93.3 %)	0.01	0.953	0.63	0.25	−0.24	0.960
LD2/FBP	30 (100 %)	0.05	0.664	0.67	0.30	−0.20	0.626
LD2/ASIR50	27 (90 %)	−0.07	0.478	0.48	0.12	−0.26	0.887
LD2/ASIR100	28 (93.3 %)	−0.02	0.880	0.62	0.22	−0.26	0.832
LD2/MBIR	29 (96.7 %)	−0.10	0.367	0.57	0.12	−0.31	0.489
LD3/FBP	28 (93.3 %)	0.41	0.029a	0.94	0.78	0.05	--
LD3/ASIR50	23 (76.7 %)	0.23	0.387	1.28	0.79	−0.32	0.640
LD3/ASIR100	26 (86.7 %)	−0.15	0.262	0.65	0.12	−0.41	0.358
LD3/MBIR	28 (93.3 %)	−0.10	0.433	0.69	0.16	−0.37	0.773
LD4/FBP	19 (63.3 %)	−0.28	0.230	0.98	0.19	−0.75	0.420
LD4/ASIR50	26 (86.7 %)	−0.28	0.079	0.79	0.04	−0.60	0.694
LD4/ASIR100	26 (86.7 %)	−0.37	0.002[a]	0.55	−0.14	−0.59	[b]
LD4/MBIR	24 (80 %)	−0.36	0.014[a]	0.66	−0.08	−0.64	[b]
LD5/FBP	26 (86.7 %)	0.19	0.485	1.35	0.74	−0.36	0.552
LD5/ASIR50	28 (93.3 %)	0.16	0.420	1.06	0.58	−0.25	0.264
LD5/ASIR100	29 (96.7 %)	0.29	0.136	1.00	0.67	−0.10	0.494
LD5/MBIR	22 (73.3 %)	0.43	0.161	1.39	1.05	−0.19	0.832

ASIR, adaptive statistical iterative reconstruction; FBP, filtered back projection; LD, low dose protocol; MBIR, model-based iterative reconstruction.
[a]Statistically significant difference.
[b]Bland–Altman Plot and linear regression not performed due to a significant difference detected in the one-sample *t*-test.

did not allow the same dose reduction as FBP. The lowest dose to permit acceptable identification of the IAC in the present study was LD2. The effective dose imparted by this protocol for a scan length of both 5 and 10 cm is lower than many of those reported in a meta-analysis of CBCT effective doses, even for some small field of view CBCT examinations.[16]

The lowest dose achievable in the present study was considerably lower than those reported by previous studies which investigated accuracy of MDCT low dose protocols for recording measurements at the IAC. For Rustemeyer et al[5] found the lowest effective dose to allow accurate ridge measurements at the IAC to be 400 μSv (for a scan length including only the mandible), which is approximately 14 times larger than the effective dose calculated for a scan length of 5 cm in the present study is.[5] The considerably larger effective dose calculated for the previous study is, despite the fact that the effective dose in the previous study was calculated with the ICRP 60 (1990) tissue weighted factors, which tend to underestimate the effective dose of examinations in the jaw regions compared to estimates using the ICRP 103 (2007) tissue-weighted factors, which were used in the present study.[15] Another study, by Suomalainen et al,[6] reported that the lowest dose that did not significantly affect MDCT measurement error of ridge dimensions at the IAC was a CTDIvol of 5.6 mGy, which is more than double the dose achieved in the present study.[6] Lower doses were achieved in the present study, despite acquiring the MDCT images with considerably thinner slice thickness and pitch value, because the mAs was lower than that used by the previous studies. Maintaining a low pitch value in the present study allowed faithful reproduction of the anatomy with no loss of information through interpolation, which occurs at unacceptably high pitch factors.[17] This is supported by the finding of Suomalainen et al[6] who investigated the effect of different exposure parameters on measurement accuracy and found that the pitch factor was negatively associated with the number of successful measurements.

The effective dose achieved in the present study (for a 5 cm height examination) was also markedly lower than those imparted by most CBCT devices reported in a meta-analysis and dosimetry study of effective doses of dental CBCT devices.[16] For, Ludlow et al[16] reported that for a 5 cm high examination, the range of effective doses imparted by the standard or default protocols of the CBCT devices was 5–262 μSv. The effective dose achieved in the present study (for a 5 cm height examination) is less than that imparted by 67% of the CBCT standard examination protocols reported in the study by Ludlow et al.[16]

The doses achieved by the present study for identification of the IAC, however, are not as low as those achieved in a previous study using ultralow dose protocols combined with FBP and ASIR and MBIR for measurement of implant site ridge dimensions. In the previous study, Al-Ekrish et al obtained ridge measurements comparable to those from a standard dose protocol by reducing the dose to a CTDIvol of 0.53 mGy, which is 20% of the dose achieved in the present study.[8] The more modest dose reduction achievable in the present study, compared to the study by Al-Ekrish et al[8] , is due to the fact that the diagnostic tasks investigated were different. For in order to adequately demonstrate the thin roof of the IAC, which may sometimes be hypocalcified, images must have less noise and higher spatial resolution than that required for identification of the outer boundaries of the bone, which is a very high contrast task.

The present study's finding of MBIR offering no advantage over FBP is in apparent contrast with the results of a previous phantom study, which found improved contrast resolution of MDCT images at ultralow doses with the use of MBIR, when compared with FBP.[18] The lack of an advantage to MBIR seen in the present study may be due to the fact that, although MBIR images were less noisy than other techniques at low doses, the oversmoothening of the images and the standard kernel used with MBIR leads to lower spatial resolution compared to images produced with bone kernels, thus compromising the visibility of the thin roof of the IAC.[18] Bone kernels were used for FBP and ASIR images in the present study because bone kernels have been shown to provide higher spatial resolution than standard kernels[18] and produce images with more accurate jaw measurements than standard kernels.[19] A standard kernel was used for MBIR because bone kernel is not available for use with MBIR.

In the present study, the examiners were permitted to interactively view the images and process the images in any way, including adjustment of window width and level (WW/WL), to improve visibility of the IAC. For, the variable density and trabecular patterns of the bone, and the variable thickness of the roof of the IAC amongst different mandibles preclude selection of standardized viewing parameters which could provide optimum visibility for all sample sites. The examiners were also permitted to use triangulation and interpolation to record the position of the IAC, even when they could not detect the IAC on the sample image. Standardization of WW/WL was not attempted because of the variability in the object contrast of the roof of the IAC of different cadavers, and even within the same cadaver at different sites. This variability precluded selection of a uniform WW/WL for optimum visibility of all samples in the study. The interactive image manipulation by the examiners, which may have varied with each sample site, may explain the lack of a pattern between the dose and the subjective visibility and/or number of objective measurements recorded. It may also explain the variable number of samples in which an objective measurement could not be recorded by the different examiners in the reliability study.

An important limitation of the present study is that the test measurements were not compared to a true gold-standard of physical measurements recorded directly from the cadavers. Since measurements obtained from the reference protocol are not true gold-standard measurements, and they are known to be associated with a certain degree of error,[13] the appropriate statistical tests to use in the present study only analysed comparability of the results to a clinical reference, and not absolute errors.[20] As such, further studies are recommended using cadavers and to analyse the absolute errors of the measurements of the ridge above the IAC recorded from ultralow dose MDCT images compared to a gold-standard recorded directly from the sectioned cadaveric mandibles. Also, future studies might improve the clinical applicability of the results by including panoramic radiographs of the sample mandibles in order to relate the visibility of the IAC on panoramic radiographs with the amount of MDCT dose reductions possible. For, it would be useful to be able to view the IAC on the panoramic radiograph then decide what is the lowest MDCT dose that may be used to produce sectional images in which the IAC would be clear. Relating the low dose protocol to the panoramic appearance may guide in development of general guidelines for MDCT imaging, as well as patient specific guidelines.

Conclusion

Using FBP, comparable IAC measurements were achieved with 91% reduction in dose compared with a standard exposure protocol. The use of ASIR and MBIR did not improve imaging of the IAC. Further studies are recommended to determine the absolute measurement errors of the various protocols and to relate the dose reductions possible with appearance of the IAC on panoramic radiographs.

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