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ORIGINAL ARTICLE

Influence of cone-beam computed tomography milliamperage settings on image quality of the mandibular third molar region

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Abstract
Objective To assess the image quality of the mandibular third molar region using different milliamperage (mA) settings of cone-beam computed tomography.
Methods Twelve dry mandibles with impacted third molars were scanned with a Kodak 9000 unit (Kodak Dental Systems, Carestream Health, Rochester, NY, USA) using different mA settings (2, 4, 6.3, 8, 10, 12, and 15 mA). Two oral radiologists evaluated the images. They classified the tooth root, periodontal space, lamina dura, trabecular bone, mandibular canal, and overall image quality as excellent, good, poor, or inadequate for diagnosis. Statistical analyses were performed by one-way ANOVA with a post hoc Tukey test to investigate the influence of the mA settings in the image quality of the structures analyzed. The significance level was set at 5 %.
Results The 15 and 12 mA settings provided the highest mean values for all the evaluated criteria, with significant differences from the values for the other mA settings. The 10, 8, and 6.3 mA settings showed no significant differences in relation to tooth root and periodontal space. For the other evaluated criteria, no significant differences were observed for the 10 and 8 mA settings. The 4 and 2 mA settings gave the lowest mean values.
Conclusions The best low-dose protocol with good image quality was the 10 mA setting. Lower dose protocols with 8 and 6.3 mA settings can also be used for these purposes, but caution is necessary because of increased image noise.

Keywords Cone-beam computed tomography · Radiation · Mandible

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Introduction

Cone-beam computed tomography (CBCT) has spread into several areas of dentistry because of its clear, high-contrast, and three-dimensional images of dental structures. Increasingly, CBCT has been used instead of multidetector computed tomography (MDCT) given its lower exposure dose associated with adequate image quality [1, 2]. Other advantages of CBCT over MDCT are lower cost and fewer artifacts [3–5].

Nevertheless, the radiation exposure dose for CBCT is still higher than that for conventional radiographs. As the increasing concern about exposure to higher radiation doses is becoming public, the application of CBCT to some conditions is being reconsidered [6, 7]. Meanwhile, optimization of the exposure parameters is a way to reduce the radiation doses.

Image quality on CBCT (i.e., the visibility of anatomical structures) is determined by subjective visual interpretation. Excellent image quality means that sufficient diagnostic information is provided, thereby enabling treatment decisions with an acceptable degree of safety.

Multidetector computed tomography manufacturers normally indicate exposure protocols for achieving high image quality with little noise. However, such protocols usually demand higher exposure settings, which lead to higher radiation doses [8, 9]. Several studies have evaluated the influence of exposure settings on MDCT images [8–13], whereas few such data exist for CBCT [14–18]. Therefore, the aim of this study was to assess the image quality of the mandibular third molar region using different milliamperage (mA) settings of CBCT.

Materials and methods

This study was conducted under approval from the Ethical Research Committee of Piracicaba Dental School, State University of Campinas (CEP 034/2011). Twelve dry mandibles with impacted third molars (eight bilateral and four unilateral; total of 20 regions) were used. For inclusion in the study, the roots of the teeth had to be completely developed.

The mandibles were placed in a polystyrene box filled with water at 24 h prior to the CBCT examinations to displace air from the mandible and simulate soft-tissue attenuation. Images were acquired using a Kodak 9000 CBCT unit (Kodak Dental Systems, Carestream Health, Rochester, NY, USA) with the following exposure parameters: 60 kV; 10.8 s; 50 × 38-mm field of view (FOV); 0.2-mm voxel size. These settings were determined in a pilot study. The mA parameter settings examined ranged from the lowest to highest values provided by the device (2, 4, 6.3, 8, 10, 12, and 15 mA), as well as the kerma–area products (33.5, 66.9, 105, 134, 167, 201, and 251 μGy cm^2, respectively) provided by the CBCT unit. Thus, a total of 140 examinations were obtained for evaluation.

One of the authors (FSN) obtained cross-sectional slices of the scanned third molars using the Kodak Dental Imaging Software 3D module (KDIS-3D, v.2.4.14; Kodak Dental Systems, Carestream Health). The images were saved to allow standardization of the slices to be analyzed.

Two oral radiologists with more than 3 years of experience in CBCT were calibrated for the study. Under dim light conditions, they individually assessed the cross-sectional images using the KDIS-3D software in a random order. They were allowed to adjust the brightness and contrast if necessary, but could not use task-specific filters or the “zoom” tool. Half of the images were individually re-evaluated after 30 days to examine the reliability statistics.

The oral radiologists evaluated the image quality of the tooth root, periodontal space, lamina dura, trabecular bone, and mandibular canal, without previous knowledge of the mA settings used (Fig. 1). The overall image quality (i.e., the noise level in the image) was also subjectively assessed. A four-point scale, similar to that used by Sur et al. [15], was applied to each anatomical structure. The image quality was considered to be excellent (4), good (3), poor (2), or inadequate for diagnosis (1).

Data were analyzed using SAS software 9.1 (SAS Institute, Cary, NC, USA). Weighted kappa statistics were calculated for the intraobserver and interobserver agreements (<0.40, poor agreement; 0.40–0.59, moderate agreement; 0.60–0.74, good agreement; 0.75–1.00, excellent agreement). One-way ANOVA with a post hoc Tukey test was applied to investigate the influence of the mA settings on the image quality of the structures analyzed. The significance level was set at 5 %.

Results

The intraobserver and interobserver agreements were good with respect to all the evaluated criteria (Table 1).

Table 2 shows comparisons of the mean values attributed to the tooth root, periodontal space, lamina dura, trabecular bone, mandibular canal, and overall image quality. The 15 and 12 mA settings provided the highest mean values for all the evaluated criteria, with significant differences from the values for the other mA settings. The 10, 8, and 6.3 mA settings showed no significant differences in relation to tooth root and periodontal space. For the other evaluated criteria, no significant differences were observed for the 10 and 8 mA settings. The 4 and 2 mA settings gave the lowest mean values.

In summary, the image quality for all the evaluated criteria (root, periodontal space, lamina dura, trabecular bone, mandibular canal, and overall image quality) rose concomitantly with the increase in mA.

Discussion

The mA, kV, FOV, and acquisition at 180° (half-scan mode) or 360° (full-scan mode) can be modified depending on the CBCT unit. Although these settings can reduce the radiation exposure dose, degradation of the image quality is a side effect. Therefore, they should be considered in light of the diagnostic question being asked [19]. The mA setting and exposure time specifically control the amount of electrons in the electric current used to produce X-ray photons. In general, increasing both of these parameters increases the number of photons produced and the overall image quality. Consequently, the mA setting and exposure time are linearly related to the dose, such that a reduction of 50 % in the mA or exposure time reduces the dose by about half [20]. For this study, we set the exposure time (10.5 s) and fixed the kV (60 kV), with significant reductions in the kerma–area product values related only to the mA settings.

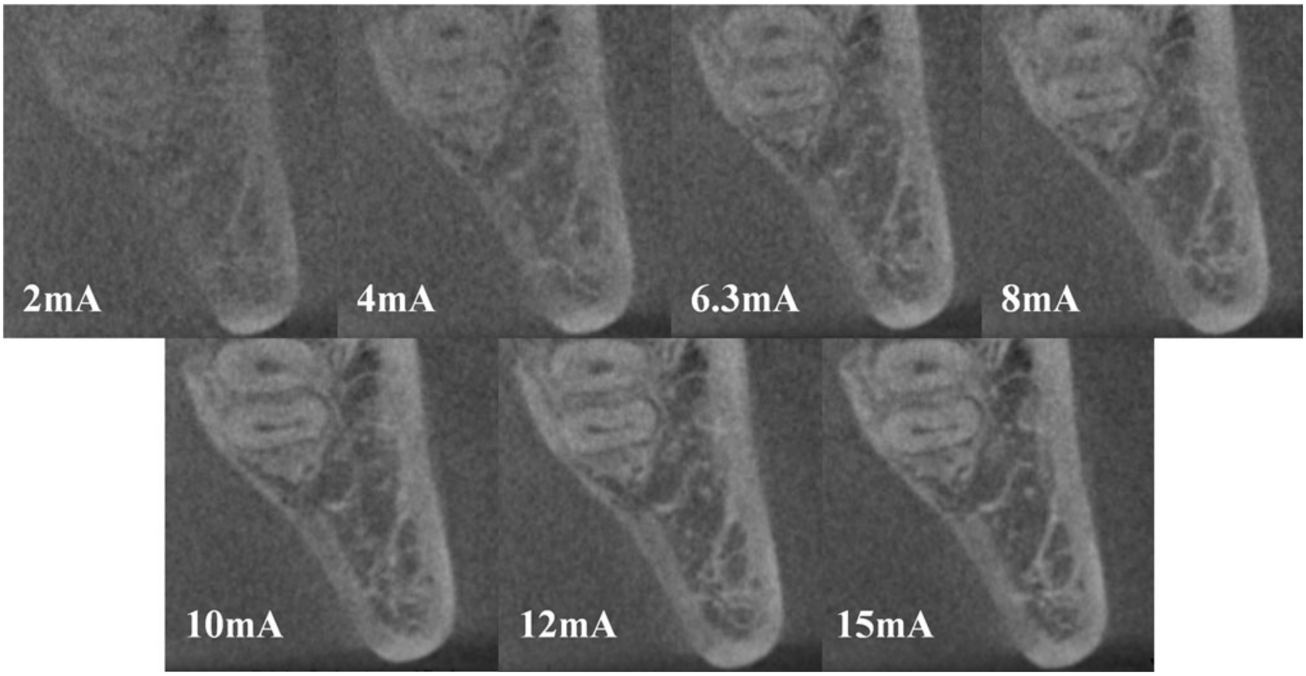

Fig. 1 Cross-sectional slices of the mandibular third molar region under different mA settings

Table 1 Intraobserver and interobserver agreements

Image variables	Obs 1 vs. Obs 1	Obs 2 vs. Obs 2	Obs 1 vs. Obs 2
Tooth root	0.79	0.72	0.66
Periodontal space	0.65	0.62	0.61
Lamina dura	0.70	0.69	0.65
Trabecular bone	0.67	0.72	0.63
Mandibular canal	0.64	0.63	0.60
Overall image quality	0.67	0.73	0.63

Obs observer

A significant dose reduction can be achieved by cautiously considering individual characteristics, as well as each case's requirements [15]. The justification practice means balancing the individual's or society's benefit with the inherent risk of radiation exposure (risk/benefit ratio). For optimization, the need to keep the dose levels "as low as reasonably achievable" (ALARA) is understood. This principle includes taking X-ray examinations according to the patient's needs, which are determined by clinical examination, and use of the appropriate radiographic technique [21].

The ALARA principles regarding dose optimization have been especially recommended by the International Commission on Radiological Protection (ICRP) [6] and, more recently, by the SEDENTEXCT project [7]. The ICRP [6] and the SEDENTEXCT project [7] both state that high-quality images are not essential for all diagnostic tasks, and that the quality level depends on the diagnostic task. An excessive dose reduction may adversely affect the image quality and decrease lesion detection. Likewise, the visibility of lesions in high-quality images acquired at the expense of high doses is not necessarily better than that

Table 2 Mean (standard deviation) values of the image variables under different mA settings

mA	Tooth root	Periodontal space	Lamina dura	Trabecular bone	Mandibular canal	Overall image quality
2	1.31 (0.20)^{d}	1.04 (0.04)^{c}	1.01 (0.32)^{e}	1.01 (0.03)^{e}	1.19 (0.21)^{e}	1.01 (0.03)^{e}
4	2.21 (0.29)^{c}	1.64 (0.22)^{c}	1.37 (0.19)^{de}	1.83 (0.35)^{d}	2.18 (0.16)^{d}	1.78 (0.26)^{d}
6.3	2.85 (0.33)^{b}	2.37 (0.35)^{b}	1.96 (0.41)^{cd}	2.35 (0.37)^{cd}	2.68 (0.45)^{cd}	2.38 (0.29)^{c}
8	2.98 (0.36)^{b}	2.78 (0.54)^{ab}	2.29 (0.48)^{bc}	2.81 (0.29)^{bc}	2.99 (0.37)^{bc}	2.69 (0.29)^{bc}
10	3.33 (0.28)^{ab}	3.02 (0.50)^{ab}	2.79 (0.44)^{ab}	3.22 (0.31)^{ab}	3.10 (0.35)^{abc}	3.10 (0.26)^{ab}
12	3.53 (0.19)^{a}	3.25 (0.34)^{a}	3.03 (0.34)^{a}	3.30 (0.21)^{ab}	3.45 (0.36)^{ab}	3.30 (0.32)^{a}
15	3.59 (0.35)^{a}	3.39 (048)^{a}	3.12 (0.46)^{a}	3.60 (0.38)^{a}	3.63 (0.22)^{a}	3.60 (0.41)^{a}

Mean values with different superscript letters differ significantly at $P < 0.05$

in low-dose images. Thus, it is necessary to have an understanding of the image acquisition and reconstruction processes to maintain adequate image quality associated with low doses.

Previous studies have shown that lower exposure parameters on MDCT can result in images of maxillofacial structures that are comparable to those obtained with higher parameters [8, 10, 11, 13]. Rustemeyer et al. [12] evaluated MDCT images obtained with fixed kV and varied mA (50 and 165 mA). They found no significant differences in the visibility of the mandibular structures. According to these authors, the low-dose protocol in MDCT is the same as that for CBCT. However, they did not specify the model of the unit being used. Using the Kodak 9000 unit, we observed that lower mA settings produced lower image quality of the mandibular structures, with significant differences.

Any mA reduction should be undertaken with caution, because it can result in increased image noise, which may adversely affect the diagnosis. In this study, it was evident that the mA setting linearly influenced the image quality for all the structures analyzed. Furthermore, image noise (analyzed in overall image quality) was inversely proportional to the mA setting. The use of 4 and 2 mA may be unacceptable for preoperative assessment of mandibular third molars because of the dark boundary in the images caused by noise.

Ekestubbe et al. [8] observed that the mandibular canal was better identified in low-dose MDCT images compared with high-dose MDCT images. They justified that an increase of noise in the low-dose images enhanced the contours of the superior and inferior cortical regions of the mandibular canal. In contrast, our results demonstrated that the mandibular canal was better visualized using higher mA settings. We believe that this finding may be explained by the different process of image acquisition and the mA variation scale of CBCT.

Structures located in the posterior region produce higher image degradation than those in the anterior region. This can be explained by the greater volume of the structures in the posterior region, especially in the mandible, because of its denser composition than the maxilla [15]. The present study only evaluated the posterior region of the mandible, which is another producer of image noise associated with reduction of the mA.

In our study, reducing the mA negatively influenced image quality for all the criteria analyzed. It is important to consider the relationship between the mA setting and the image quality when imaging before third molar extractions. The image quality found with the 10 mA setting was very similar to those obtained with the 15 and 12 mA settings, which provided good images for preoperative planning of third molar extractions. Likewise, the images with the 8 and 6.3 mA settings appeared usable for the same purpose, despite some deterioration in the image quality being observed. However, we discourage use of the 4 and 2 mA settings for preoperative planning because of the poor image quality. On the other hand, the literature has demonstrated that mA reductions have little influence on the image quality of CBCT examinations for preoperative implant planning [14–18]. However, it is important to consider the different clinical purposes of such studies, as well as the particularities of the CBCT units used.

Since the study was carried out with dry mandibles, the absence of soft tissues may have influenced our findings. Therefore, a clinical trial would be necessary to corroborate these results. However, this is a difficult methodological model to apply, given the current ethical principles for medical research involving human subjects provided in the Declaration of Helsinki. According to Sandborg et al. [22], water is a good material for soft-tissue simulation in in vitro studies. However, the water surrounding the human dry mandibles used in our study may not have completely mimicked real clinical situations because of the absence of the vertebrae, tongue, and surrounding musculature. In vivo examinations are also influenced by beam-hardening artifacts (caused by metallic materials) and reductions in spatial resolution owing to micromovements of the jaw, which were not simulated in our study. Finally, our results are limited by the subjective ability of the observers to classify the image quality.

In conclusion, the best low-dose protocol with good image quality was obtained with the 10 mA setting. Lower dose protocols with the 8 and 6.3 mA settings could also be used for diagnosis, but caution is necessary because of increased image noise. Furthermore, we observed that mA reduction negatively affected the image quality of the mandibular third molar region, thereby increasing the image noise.

Conflict of interest There are no financial or other relations that could lead to a conflict of interest.

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