ACTA ODONTOLOGICA SCANDINAVICA
2023, VOL. 81, NO. 6, 449–455
https://doi.org/10.1080/00016357.2023.2170462

Taylor & Francis
Taylor & Francis Group

ORIGINAL ARTICLE

OPEN ACCESS Check for updates

Visibility of anatomical landmarks in the region of the mandibular third molar, a comparison between a low-dose and default protocol of CBCT

Josefine Cederhag[a], Durer Iskanderani[a,b], Per Alstergren[c,d], Xie-Qi Shi[a,e] and Kristina Hellén-Halme[a]

[a]Department of Oral and Maxillofacial Radiology, Malmö University, Malmö, Sweden; [b]Department of Oral & Maxillofacial Radiology, King Abdulaziz University, Jeddah, Saudi Arabia; [c]Department of Orofacial Pain and Jaw Function, Malmö University, Malmö, Sweden; [d]Specialized Pain Rehabilitation, Skåne University Hospital, Lund, Sweden; [e]Section of Oral and Maxillofacial Radiology, Department of Clinical Dentistry, University of Bergen, Bergen, Norway

ABSTRACT

Objective: Optimization of radiographic examinations is essential for radiation protection. The objective of the study was to investigate the clinical applicability of a low-dose CBCT protocol as compared to the default for pre-surgical evaluation of mandibular third molars.

Material & Methods: Forty-eight patients (62 teeth) referred for pre-surgical mandibular third molar investigation were recruited after justification for CBCT. Two CBCT scans of each site were made using a default protocol and a low-dose protocol (Veraviewepocs 3D F40, J Morita Corp, Kyoto, Japan). The low-dose protocol had the same tube potential (90 kV) and exposure time (9.4 s) as the default, but with reduced tube current, from 5 mA to 2 mA. Four observers evaluated the visibility of five relevant anatomical variables. Image quality was ranked on a 3-point scale as diagnostically acceptable, doubtful, or unacceptable. The Wilcoxon signed-rank test compared differences between the two protocols. The significance level was set at $p \leq .05$.

Results: No significant differences were found between the two protocols for any observer regarding the visibility of the relationship and proximity between the roots and the mandibular canal; root morphology; and possible root resorption of the second molar. The periodontal ligament differed significantly in visibility between the two protocols ($p \leq .05$).

Conclusions: This study indicates that a low-dose CBCT protocol with a 60% reduction of the tube current provides, in most cases, acceptable image quality for pre-surgical assessment of mandibular third molars. Optimization of CBCT protocols should be a priority according to recommended guidelines.

ARTICLE HISTORY
Received 26 August 2022
Revised 10 January 2023
Accepted 12 January 2023

KEYWORDS
Molar third; cone-beam computed tomography (CBCT); radiation

Introduction

Pre-surgical radiographic evaluation of mandibular third molars is a common procedure in dentistry. A 2D intraoral examination using parallax technique, panoramic radiographs, or a combination of these often suffice in delivering adequate diagnostic information [1]. Studies have shown that cone beam computed tomography (CBCT) uniquely defines the root morphology of the third molar and its relation to the mandibular canal in three dimensions [2–5]. However, CBCT delivers a higher radiation dose compared to 2D radiography [6]. Several studies have observed increased use of CBCT when imaging the mandibular third molar [7–10]. Guidelines by SEDENTEXCT [5] suggest that CBCT is indicated in cases of close proximity between the mandibular canal and roots when the relationship is not accurately depicted with 2D radiography alone, and if a decision of removal has been made [5]. Correspondingly, the European Academy of DentoMaxilloFacial Radiology (EADMFR) recently published recommendations regarding CBCT imaging of the mandibular third molar advocating that CBCT is indicated in selected patient cases when 2D radiography cannot answer the clinical question [11].

Most countries regulate radiation delivery to patients by law, consistent with the “as low as diagnostically acceptable” (ALADA) principle [12] which is a modification of “as low as reasonably achievable” (ALARA) [13]. Diagnostic purpose, therapeutic choice, and patient category should determine the required image quality, and thus dose [14,15].

Young adults are often subject to pre-surgical radiographic evaluations since a majority of mandibular third molar removals are made at 20–29 years of age [16,17] due to pericoronitis [17–19]. Younger patients are more sensitive to ionizing radiation because of the higher cell proliferation rate that occurs in growing individuals and young adults (20–29 years) [5,20], and because of the probable, longer post-exposure lifetime.

CONTACT Josefine Cederhag josefine.cederhag@mau.se Department of Oral and Maxillofacial Radiology, Faculty of Odontology, Malmö University, Malmö, SE-205 06, Sweden

When new radiographic devices are implemented in clinical use optimizing examination protocols concerning diagnostic image quality is mandatory and essential. Adjustments of tube current (mA), scan time (s), tube voltage (kV), field of view (FOV), voxel size (resolution), and rotation-scan mode can be used to fine-tune low-dose protocols [21–24]. Modification of tube current is a feasible approach to keep the energy spectrum and adapt the patient dose according to the diagnostic question at hand [25]. Several *in-vitro* studies have shown that the tube current can be dramatically reduced compared to the suggested settings from the manufacturer for various diagnostic tasks [26–29]. Neves et al. [28] reported that tube current could be reduced for visualizing mandibular third molars but recommended prospective clinical trials. Clinical verification is needed since the image quality can be overestimated due to the absence of patient-related artifacts such as motion-blur and metal artifacts, and difficulties in accurately simulating soft tissue using an in-vitro study design. In one of the few clinical studies published, Iskanderani et al. [30] showed that altering tube current for CBCT imaging of temporomandibular joint assessment reduced the patient dose by five times while retaining acceptable diagnostic image quality. Yeung et al. [31] identified the need for evaluation of low-dose protocols from a clinical perspective for mandibular third molars. Therefore, the objective of our study was to investigate the clinical applicability of a low-dose CBCT protocol as compared to the default for pre-surgical evaluation of mandibular third molars, with the intention to reduce patient dose to as low as diagnostically acceptable. We hypothesized that the structure visibility and subjective image quality would not significantly differ between the protocols.

Materials and methods

Study design

The study was conducted from August 2020 to May 2021 at the Department of Oral and Maxillofacial Radiology at Malmö University in Malmö, Sweden. All adult patients (≥20 years of age) referred from the Department of Oral & Maxillofacial Surgery and Oral Medicine, Malmö University, for pre-surgical mandibular third molar investigation. Indications for CBCT examination were made by a licensed radiologist and individually assessed for each patient based on anamnesis and 2D examination. The inclusion criteria were when a decision of removal had been made by oral surgeons and at least one of the conditions was met: (1) when 2D radiographic assessment could not answer the relationship between the mandibular third molar and the mandibular canal indicating close proximity; (2) if clinical and radiographic examination indicated suspicions of root resorption of the adjacent tooth; (3) suspicion of pronounced root bending or root dilaceration.

In total 52 patients were presented for participation of which four declined. The study included 62 third molars of 48 patients (27 females, 21 males) with a mean age of 32 years (range: 20–61 years). For 14 patients the referral included both third molars and thus, independent justifications were made for each side. Eligible participants were informed about the study, and those who agreed to participate were enrolled and signed informed-consent forms.

Ethical considerations

The study design was strictly following the guidelines of ICRP for research projects, which emphasize the potential benefit on the population level of such projects to save future radiation [32]. The Swedish Ethical Review Authority [33], together with Swedish Radiation Safety Authority [9] approved the present prospective clinical trial (Dnr: 2020-01246). The study is registered on ClinicalTrials.gov (FO2020-242).

CBCT examination

To obtain a reasonable proposal on the low-dose protocol concerning the mandibular third molar a pre-clinical pilot study was performed. A series of exposures on an anthropomorphic phantom with varying tube currents (1–5 mA) at settings of 90 kVp and 9.4 s was evaluated by three experienced radiologists. The lowest exposure with the acceptable image quality of the mandibular third molar was determined to be at 2 mA after consensus.

Two CBCT scans were acquired of each examination site: one scan using the default protocol (90 kV, 5 mA, 9.4 s) and one, the low-dose protocol (90 kV, 2 mA, 9.4 s). All exposures were made with a Veraviewepocs 3D F40 (J Morita Corp.; Kyoto, Japan) using a field of view (FOV) of 4.0 × 4.0 cm and a rotation mode of 180°, voxel size of 0.125 mm. The dose area product (DAP) values provided by the CBCT unit were 330 mGy cm^2 for the default protocol and 132 mGy cm^2 for the low-dose protocol.

Image evaluation

In all, 124 reconstructed CBCT volumes with a slice thickness and interval of 1 mm, according to clinical standards, were included in the study as DICOM files [34]. Examples of CBCT images for the two protocols are shown in Figure 1. i-Dixel imaging software supplied with the CBCT device (3DX Integrated Information System, 3DXD version 2.5.4.10213; J Morita Corp. Kyoto, Japan) was used to view the images on a display monitor (Barco; 6 MP, Kortrijk, Belgium) under standardized conditions (ambient light less than 50 lux [35,36]). Before analysis, the volumes were anonymized and randomly coded in Microsoft Excel (Office Professional Plus 2016; Microsoft Corporation, Redmond, WA, USA). Four observers were calibrated regarding the scoring system of the evaluation protocol. One junior, with one year of experience, and three senior oral and maxillofacial radiologists, each with more than ten years of experience in CBCT evaluation, performed all evaluations individually. All image evaluations were performed according to normal procedure, that is, the whole stack of images in three different planes was considered. The observers were allowed to use all available tools in the viewing program, such as zoom, gray level

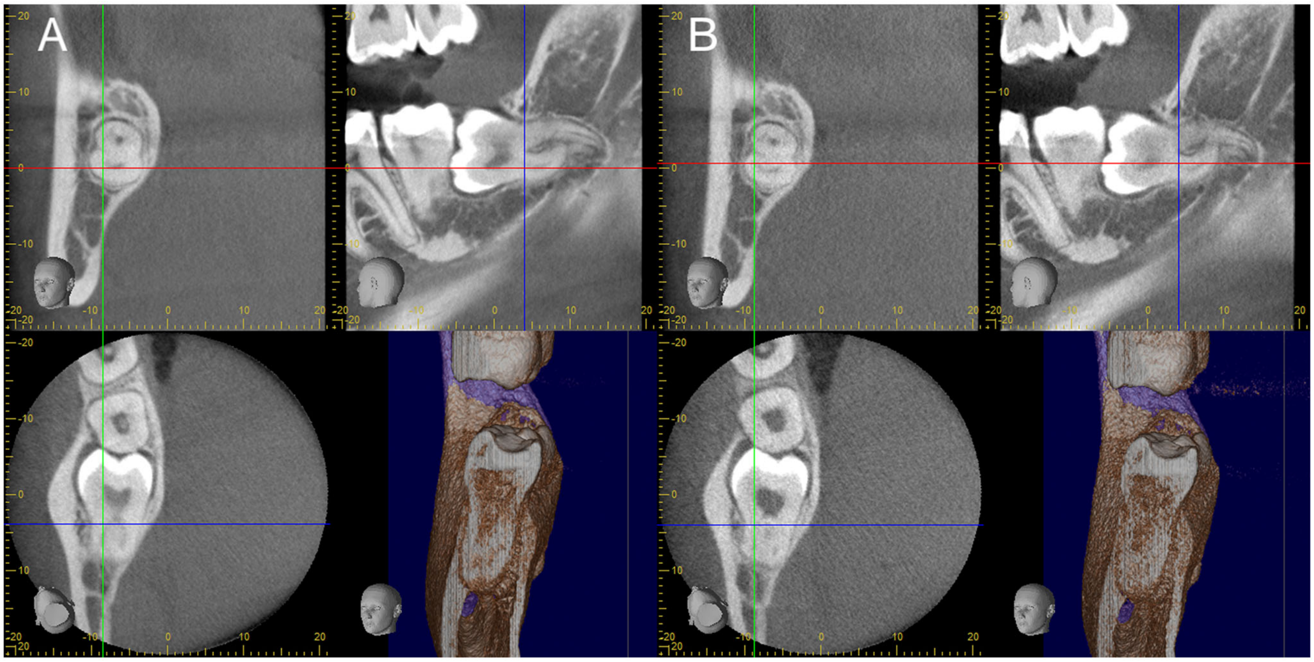

Figure 1. Example images of default protocol (A) and low-dose protocol (B) for the same mandibular third molar.

Table 1. Anatomical variables of the examination protocol.

Anatomical Variables	Categories
Relationship (MC and #8 mesial root)	Buccal[a] Lingual[b] Inferior[c] Inter-radicular if root appears bifid Not assessable
Proximity (Between MC and #8 mesial root)	More than 1 mm Direct contact, with continuity of MC Direct contact, with discontinuity of MC (deformed canal)
Periodontal ligament (All roots)	Visible periodontal ligament Partially visible periodontal ligament Periodontal ligament not visible
Root morphology (All roots) Excerpt from [37]	Convergent, straight root/s Divergent, claw-shaped, convergent with curved root/s in the direction and towards path of elevation Atypical, root dilaceration, root/s either curved in opposite direction or against path of elevation
Root resorption of 2nd molar (Extended at least to outer half of dentine)	Yes Uncertain No

MC: mandibular canal.
[a]MC located straight buccally in relation to the root.
[b]MC located straight lingually in relation to the root.
[c]MC located inferiorly, either straight below or in the lingual/buccal direction.

display, and adjustments of brightness and contrast. To determine intraobserver agreement twenty randomly selected cases were re-evaluated at least one month after the original evaluation.

An evaluation protocol was used to establish if the images, could visualize structures and relations relevant to a radiographic pre-surgical investigation. The variables were:

1. Relationship between the mandibular canal and the third molar's mesial root
2. Proximity between the mandibular canal and the third molar's mesial root
3. Periodontal ligament of the third molar
4. Root morphology of the third molar including all roots
5. Root resorption of the second molar.

The categories of the variables are explained in detail in Table 1. Only one category for each variable could be chosen. Regarding variables number 1 and 2, the mesial root in relation to the mandibular canal was chosen to represent the interrelationship since in most cases it can be bifid compared to the distal root. Further, overall subjective image quality for the pre-surgical evaluation was ranked for each investigation on a three-point scale as diagnostically acceptable, doubtful, or unacceptable.

Statistical analysis

The power analysis indicated that a minimum of 60 third molars would be required to reach a power of 0.8 and a significance level of $p \leq .05$. Each variable of the evaluation protocol was compared pairwise (default vs low-dose protocol) for each observer. All calculations were made relative to the null hypothesis. The Wilcoxon signed-rank test was used to test for significant differences between the two protocols. Significance was set at $p \leq .05$. Intraobserver agreement was calculated using Cohen's weighted kappa and interobserver agreement, Fleiss' kappa according to the Landis & Koch scale [38]. Data were analyzed using the Statistical Package for the Social Sciences (IBM SPSS, version 28 for Windows, Armonk, NY: IBM Corp).

Results

No significant differences were found for pair-wise comparisons (default vs low-dose protocol) for any observer regarding the visibility of the relationship and proximity between the roots and the mandibular canal; root morphology; and possible root resorption of the second molar (Table 2). The three senior radiologists showed a significant difference ($p \leq .05$) between the protocols for the visibility of periodontal ligament in favor of the default protocol (Table 2). Two observers scored the overall subjective image quality for the low-dose protocol images more frequently as diagnostically doubtful compared to the default protocol images (Table 3), which resulted in significant differences shown in Table 2.

Table 4 present the κ values for intraobserver agreement for the different image variables. The highest values were obtained for proximity and root morphology (substantial to almost perfect). A majority of κ values for interobserver agreement (Table 5) ranged from fair to substantial agreement. Visibility of the periodontal ligament and overall subjective image quality had the lowest κ values (slight to fair). The conditional probability of subjective image quality for the diagnostically acceptable rank was good (Table 6). The data set can be obtained from the corresponding author.

Discussion

The present clinical study found that in most cases, a low-dose protocol incorporating a reduction of the tube current would produce images of mandibular third molars that delivered information equal to the default imaging protocol. The exception to this would be referral requests for a depiction of the periodontal ligament in finer detail, as in, for example, cases of suspected ankylosis; for this, a higher radiation protocol would most likely be needed. The experimental protocol delivered 60% less radiation according to provided DAP values compared with the default protocol. The unit used only provided 180° rotation mode, but other units regardless of manufacturers can be optimized by altering rotation mode as well as other exposure settings.

The method delivering the lowest possible patient dose is arguably two intraoral images taken with the parallax technique. For pre-surgical investigations, however, this modality used solely or as a complementary to panoramic radiographs seems to have become less popular with the rise of CBCT [7–10]. Clinician confidence in the sharp, detailed 2D information of intraoral images may have waned in favor of a corresponding 3D alternative, nevertheless, CBCT should only be considered in selected cases. The resultant increase in cumulative patient dose, however, has raised concerns, giving rise to demands for investigating low-dose protocol options in CBCT imaging of mandibular third molars [28,31]. Previous evidence on delivered doses is based on pre-clinical set-ups using cadavers, dry skulls, or head phantoms [28,29,31].

Although free and informed consent was given, the ethics of an additional scanning of each examination site may be debatable since each patient, for research purposes, received, per definition, unjustified radiation applied on an individual level. On a population level, the potential benefit was considered to exceed the potential individual harm. The study was conducted for research purposes to increase knowledge and hence, the ethical aspects must be viewed concerning its potential societal benefits [32]. Clinical investigation of a low-dose protocol can lead to a future net dose reduction for a big number of young patients and be justified for that cause. Furthermore, previous studies [39–42] using ethically approved designs have evaluated low-dose protocols for various clinical indications in medical CT.

A limitation of this study design is the potential difficulties in comparing and generalizing the results. The present study can only draw conclusions from one specific unit [21,43]. However, the results indicate that there is a need for emphasizing the work in optimizing exposure protocols used for any radiographic investigation. Another limitation was the propensity for subjectivity in observational studies. The number and selection of observers are critical for obtaining diversity and representativeness [44]. The number of observers in the present study corresponded to what is commonly used in similar studies [27,30,45].

Tube current and radiation dose have a linear relationship; for example, a reduction of 60% in current reduces the patient dose by 60%. A reduction in tube current reduces the number of photons reaching the detector and the signal-noise ratio, which results in noisier images. Hence, highly attenuating structures (e.g. bones), will appear noisier than less attenuating structures (e.g. soft tissues). Correspondingly, a study by Sur et al. [27] showed that the posterior region of the mandible is more susceptible to image quality degradation than other parts of the jaws due to its thick and dense bone structure. Noise appears as a grainy derangement in the radiographs. It restricts spatial resolution and affects contrast resolution and, hence, reduces low-contrast

Table 2. *p* Values for pairwise comparisons of default protocol versus low-dose protocol for image variables among observers.

	Observer			
Image variables	1	2	3	4
Relationship	.147	.180	.235	.847
Proximity	.346	.491	1.000	.489
Periodontal ligament	.405	.050*	.005*	.001*
Root morphology	.439	.052	.564	.683
Root resorption of 2nd molar	.776	.408	.914	.317
Subjective image quality	.012*	.317	.097	.008*

*Statistically significant difference ($p \leq .05$) Wilcoxon signed-rank test.

Table 3. Scores for subjective image quality for the default protocol and low-dose protocol among observers.

	Diagnostically acceptable (%)		Doubtful image quality (%)		Diagnostically unacceptable (%)	
	DP	LDP	DP	LDP	DP	LDP
Observer 1	95	77	3	23	2	0
Observer 2	98	95	2	5	0	0
Observer 3	97	86	2	13	2	2
Observer 4	94	77	7	23	0	0

DP default protocol (90 kV, 5 mA, 9.4 s), *LDP* low-dose protocol (90 kV, 2 mA, 9.4 s).

Table 4. Intraobserver agreements (Cohen's weighted kappa).

	Observer			
Image variables	1	2	3	4
Relationship	0.691	0.760	0.528	0.654
Proximity	0.867	0.832	0.718	0.933
Periodontal ligament	0.231	0.386	0.627	0.300
Root morphology	0.875	0.786	0.825	0.954
Root resorption of 2nd molar	0.351	0.583	0.686	0.273
Subjective image quality	-*	-*	1.000	1.000

*No variability in the ratings and κ values cannot be calculated.

Table 5. Interobserver agreements (Fleiss' kappa).

	Exposure protocol	
Image variables	DP	LDP
Relationship	0.625	0.596
Proximity	0.508	0.522
Periodontal ligament	0.281	0.220
Root morphology	0.483	0.393
Root resorption of 2nd molar	0.534	0.684
Subjective image quality	0.310	0.130

DP default protocol (90 kV, 5 mA, 9.4 s), *LDP* low-dose protocol (90 kV, 2 mA, 9.4 s).

Table 6. Conditional probability of subjective image quality for diagnostic purposes.

	Conditional probability	
Diagnostic image quality	DP	LDP
Acceptable	0.978	0.862
Doubtful	0.167	0.256
Unacceptable	0.333	0.000

DP default protocol (90 kV, 5 mA, 9.4 s), *LDP* low-dose protocol (90 kV, 2 mA, 9.4 s).

detectability. In the present study, the periodontal ligament, a subtle low-attenuation structure, was the only landmark observed to differ significantly in visibility on images taken with the low-dose protocol. Although suboptimal, this finding confirms previous results in the literature; small and low-attenuation structures require higher radiation doses to be adequately visualized [21,46]. The reconstructed images with 1 mm slice thickness were used even if the voxel sizes were smaller than this. In odontology, fine details less than 1 mm are usually not customary to establish. For three of the four observers, intraobserver agreement of the periodontal ligament was fair, which suggests that an individual observer generally has difficulties to repeatedly distinguishing and interpreting low-attenuation structures in low-dose images with the same result. This inconsistency may be due to the reduced contrast resolution of noisier images. Wang et al. [46] found that of eight anatomical landmarks, the periodontal ligament but also trabecular bone had the highest coefficient of variability among the observers. Hence, one could assume to see significant differences between the CBCT protocols regarding mandibular canal-related variables, since it is bounded by trabecular bone, although, this was not found. Their study, however, investigated visibility under varying combinations of both tube current and voltage settings in head phantoms [46]. Moreover, fair intraobserver agreement for two observers also applied to the variable of "root resorption of the second molar". The presence of root resorption may affect the treatment plan in specific cases where a decision on third molar removal can be dependent on the status of the second molar.

The present study found no significant differences between the default and experimental protocols regarding root morphology or the relationship and proximity between the third molar and mandibular canal. Likewise, the substantial to almost perfect intra- and interobserver agreement for all observers further confirms the reliability of identifying these landmarks. Comparative literature is limited; however, two non-clinical studies on CBCT imaging of the mandibular canal can be noted: Neves et al. [28] showed that the region providing best visibility of the canal was the dentulous mandibular region of third molars, and Zaki et al. [47], that the tube current necessary for adequate visibility of the canal was higher than otherwise needed in low-dose protocols. Both studies advocated the potential of using dose protocols tailored to the purpose of the investigation, since Zaki et al. [47], opined that some reduction in tube current was still possible. This is consistent with the suggestions of Pauwels et al. [21,43] that exposure protocols should be selected according to diagnostic requirements for the level of contrast and detail.

Manufacturers do provide pre-set default protocols tailored to patient category and indication. CBCT units allow users to modify the acquisition parameters. For instance, our clinic uses half rotation mode as standard which from start yields a reduced patient dose [48]. Accordingly, the ALADA principle emphasizes a focus on image quality that is "diagnostically acceptable" rather than "visually pleasing" [12]. Thus, applying the ALADA principle in daily practice reduces the health risk to patients and the overall radiation burden on the population.

A complicating factor in the determination of reliability is the definition of diagnostic acceptable image quality, which has a large component of subjectivity. The abilities of observers differ; hence, they consider and judge differently. In the present study, interobserver disagreement on the variable of "overall subjective image quality" occurred, illustrating this phenomenon: an interobserver agreement was markedly poor for the low-dose protocol and only fair for the default protocol. However, the conditional probability of the diagnostically acceptable rank for both protocols was the overwhelming majority, which means the observers' data were much skewed. Therefore, the interpretation of the observer agreement in terms of image quality shall be made with caution.

As a part of low-dose images having artefacts was ranked as diagnostical doubtful, a possible explanation for the discrepancy between the protocols may be the inclusion of patient-related artifacts a clinical study uniquely entails. Thus, in the noisier low-dose images, further artifact-induced degradation of image quality seems to have made them more susceptible to be interpreted as diagnostical doubtful.

Any user of CBCT has to optimize the exposure protocols of their specific unit. Both technical image quality and image quality needed for various clinical scenarios shall be evaluated. One way of doing this is to work with a medical physicist and establish an acceptable noise level in the images according to a specific diagnostic task. In the clinic, it is essential to carry out the interdisciplinary evaluation of the needed diagnostic information before treatment planning and thereby optimized the exposure settings that can be used in most investigations.

The present study has increased our knowledge of low-dose protocol use. However, questions remain, and future studies are recommended to establish higher evidential value. Although the periodontal ligament was found to be the critical drawback in low-dose imaging, this study offered valuable insights for its use in future practice, albeit with persistent justification criterion of the CBCT use. The current experimental protocol has been adopted into routine practice in our clinic.

Conclusion

This study indicates that a low-dose CBCT protocol with a 60% reduction of the tube current compared to a default protocol, provides, in most cases, acceptable image quality for pre-surgical assessment of mandibular third molars. Optimization of CBCT protocols should be a priority according to recommended guidelines.

Acknowledgments

The authors acknowledge Dr. Karin Näsström for her participation in image evaluation.

Clinical trial investigation

The study was registered on ClinicalTrials.gov (FO2020-242).

Ethical statement

All procedures were following the ethical standards of the responsible committee on human experimentation (national and institutional) and with the Helsinki Declaration. The study design was approved by the Swedish Ethical Review Authority (Dnr: 2020-01246).

Patient consent

Written informed consent was obtained from all patients for being included in the study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study has been financially supported by the Swedish Dental Society and the Swedish Society for Maxillofacial Radiology.

ORCID

Josefine Cederhag http://orcid.org/0000-0003-4611-3708

References

[1] Cederhag J, Lundegren N, Alstergren P, et al. Evaluation of panoramic radiographs in relation to the mandibular third molar and to incidental findings in an adult population. Eur J Dent. 2021;15(2):266–272.

[2] Suomalainen A, Venta I, Mattila M, et al. Reliability of CBCT and other radiographic methods in preoperative evaluation of lower third molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010;109(2):276–284.

[3] Guerrero ME, Botetano R, Beltran J, et al. Can preoperative imaging help to predict postoperative outcome after wisdom tooth removal? A randomized controlled trial using panoramic radiography versus cone-beam CT. Clin Oral Investig. 2014;18(1):335–342.

[4] Hauge Matzen L, Christensen J, Hintze H, et al. Diagnostic accuracy of panoramic radiography, stereo-scanography and cone beam CT for assessment of mandibular third molars before surgery. Acta Odontol Scand. 2013;71(6):1391–1398.

[5] European Commission [Internet]. Radiation protection N 172 cone beam CT for dental and maxillofacial radiology. Evidence-based guidelines. directorate-general for energy, directorate d—nuclear energy, unit d4—radiation protection. 2012;. [cited 2023 Jan 10]. Available from: http://www.sedentexct.eu/files/radiation_protection_172.pdf

[6] Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: newtom cone beam CT and orthophos plus DS panoramic unit. Dentomaxillofac Radiol. 2003;32(4):229–234.

[7] Deleu M, Dagassan D, Berg I, et al. Establishment of national diagnostic reference levels in dental cone beam computed tomography in Switzerland. Dentomaxillofac Radiol. 2020;49(6):20190468.

[8] Carter JB, Stone JD, Clark RS, et al. Applications of cone-beam computed tomography in oral and maxillofacial surgery. an overview of published indications and clinical usage in united states academic centers and oral and maxillofacial surgery practices. J Oral Maxillofac Surg. 2016;74(4):668–679.

[9] Swedish Radiation Safety Authority [Internet]. Stockholm: SSM; [cited 2023. Jan 10]. Available from: https://www.stralsakerhetsmyndigheten.se/en/.

[10] Strindberg JE, Hol C, Torgersen G, et al. Comparison of swedish and norwegian use of Cone-Beam computed tomography: a questionnaire study. J Oral Maxillofac Res. 2015;6(4):e2.

[11] Matzen LH, Berkhout E. Cone beam imaging of the mandibular third molar: a position paper prepared by the European Academy of Dentomaxillo Facial Radiology (EADMFR). Dentomaxillofac Radiol. 2019;48(5):20190039.

[12] National Council on Radiation Protection and Measurements [Internet]. NCRP: achievements of the past 50 years and addressing the needs of the future. Fiftieth annual meeting program. Bethesda: NCRP; 2014. [cited 2023 Jan 10]. Available from https://ncrponline.org/wp-content/uploads/2018/08/Annual/pp50.pdf.

[13] ICRP [Internet]. The 2007 recommendations of the international commission on radiological Protection. ICRP publication 103 2007; [cited 2023 Jan 10]. Available from: http://www.icrp.org/publication.asp?id=ICRP%20Publication%20103.

[14] Jaju PP, Jaju SP. Cone-beam computed tomography: time to move from ALARA to ALADA. Imaging Sci Dent. 2015;45(4):263–265.

[15] Oenning AC, Jacobs R, Salmon B, et al. ALADAIP, beyond ALARA and towards personalized optimization for paediatric cone-beam CT. Int J Paediatr Dent. 2021;31(5):676–678.

[16] Kautto A, Vehkalahti MM, Venta I. Age of patient at the extraction of the third molar. Int J Oral Maxillofac Surg. 2018;47(7):947–951.

[17] McArdle LW, Andiappan M, Khan I, et al. Diseases associated with mandibular third molar teeth. Br Dent J. 2018;224(6):434–440.

[18] Patel S, Mansuri S, Shaikh F, et al. Impacted mandibular third molars: a retrospective study of 1198 cases to assess indications for surgical removal, and correlation with age, sex and type of impaction-A single institutional experience. J Maxillofac Oral Surg. 2017;16(1):79–84.

[19] Knutsson K, Brehmer B, Lysell L, et al. Pathoses associated with mandibular third molars subjected to removal. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1996;82(1):10–17.

[20] Wondergem J. Radiation biology. In: Dance D, Christofides S, Maidment A, McLean I, Ng K. Diagnostic radiology physics: A handbook for teachers and students. Vienna (Austria): International Atomic Energy Agency; 2014. p. 512.

[21] Pauwels R, Seynaeve L, Henriques JC, et al. Optimization of dental CBCT exposures through mAs reduction. Dentomaxillofac Radiol. 2015;44(9):20150108.

[22] Hidalgo Rivas JA, Horner K, Thiruvenkatachari B, et al. Development of a low-dose protocol for cone beam CT examinations of the anterior maxilla in children. Br J Radiol. 2015; 88(1054):20150559.

[23] Liljeholm R, Kadesjo N, Benchimol D, et al. Cone-beam computed tomography with ultra-low dose protocols for pre-implant radiographic assessment: an in vitro study. Eur J Oral Implantol. 2017; 10(3):351–359.

[24] Waltrick KB, Nunes de Abreu Junior MJ, Correa M, et al. Accuracy of linear measurements and visibility of the mandibular canal of cone-beam computed tomography images with different voxel sizes: an in vitro study. J Periodontol. 2013;84(1):68–77.

[25] Kadesjo N, Benchimol D, Falahat B, et al. Evaluation of the effective dose of cone beam CT and multislice CT for temporomandibular joint examinations at optimized exposure levels. Dentomaxillofac Radiol. 2015;44(8):20150041.

[26] Pauwels R, Silkosessak O, Jacobs R, et al. A pragmatic approach to determine the optimal kVp in cone beam CT: balancing contrast-to-noise ratio and radiation dose. Dentomaxillofac Radiol. 2014;43(5):20140059.

[27] Sur J, Seki K, Koizumi H, et al. Effects of tube current on cone-beam computerized tomography image quality for presurgical implant planning in vitro. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010;110(3):e29-33–e33.

[28] Neves FS, Freitas DQ, Campos PS, et al. Evaluation of cone-beam computed tomography in the diagnosis of vertical root fractures: the influence of imaging modes and root canal materials. J Endod. 2014;40(10):1530–1536.

[29] Lagos de Melo LP, Oenning ACC, Nadaes MR, et al. Influence of acquisition parameters on the evaluation of mandibular third molars through cone beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol. 2017;124(2):183–190.

[30] Iskanderani D, Nilsson M, Alstergren P, et al. Evaluation of a low-dose protocol for cone beam computed tomography of the temporomandibular joint. Dentomaxillofac Radiol. 2020;49(6): 20190495.

[31] Yeung AWK, Jacobs R, Bornstein MM. Novel low-dose protocols using cone beam computed tomography in dental medicine: a review focusing on indications, limitations, and future possibilities. Clin Oral Investig. 2019;23(6):2573–2581.

[32] ICRP [Internet]. Radiological protection in biomedical research. ICRP publication 62; 1992. 22(3):1–28 [cited 2023 Jan 10]. Available from: https://www.icrp.org/publication.asp?id=ICRP%20Publication%2062.

[33] Swedish Ethical Review Authority [Internet]. Uppsala; [cited 2023. Jan 10]. Available from: https://www.stralsakerhetsmyndigheten.se/en/.

[34] DICOM Digital Imaging and Communication in medicine [Internet]. DICOM Grayscale Standard Display Function 2011; [cited 2023 Jan 10]. Available from: https://dicom.nema.org/medical/dicom/current/output/pdf/part14.pdf.

[35] Hellen-Halme K, Petersson A, Warfvinge G, et al. Effect of ambient light and monitor brightness and contrast settings on the detection of approximal caries in digital radiographs: an in vitro study. Dentomaxillofac Radiol. 2008;37(7):380–384.

[36] American Association of Physicists in Medicine (AAPM) [Internet]. Task Group 18. Assessment of Display Performance for Medical Imaging Systems 2006. [updated 2018 July 23; cited 2023 Jan 10]. Available from: https://deckard.duhs.duke.edu/∼samei/samei_tg18/.

[37] Gbotolorun OM, Arotiba GT, Ladeinde AL. Assessment of factors associated with surgical difficulty in impacted mandibular third molar extraction. J Oral Maxillofac Surg. 2007;65(10):1977–1983.

[38] Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–174.

[39] Meyer E, Labani A, Schaeffer M, et al. Wide-volume versus helical acquisition in unenhanced chest CT: prospective intra-patient comparison of diagnostic accuracy and radiation dose in an ultra-low-dose setting. Eur Radiol. 2019;29(12):6858–6866.

[40] Pan S, Su JJ, Syed J, et al. Reduced dose computed tomography: the effects of voltage reduction on density measurements of urolithiasis. J Endourol. 2019;33(8):682–686.

[41] Phexell E, Akesson A, Soderberg M, et al. Intra- and inter-rater reliability in a comparative study of cross-sectional and spiral computed tomography pelvimetry methods. Acta Radiol Open. 2019;8(6):2058460119855187.

[42] Ludes C, Labani A, Severac F, et al. Ultra-low-dose unenhanced chest CT: prospective comparison of high kV/low mA versus low kV/high mA protocols. Diagn Interv Imaging. 2019;100(2):85–93.

[43] Pauwels R, Beinsberger J, Stamatakis H, et al. Comparison of spatial and contrast resolution for cone-beam computed tomography scanners. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012; 114(1):127–135.

[44] Obuchowski NA, Zepp RC. Simple steps for improving multiple-reader studies in radiology. AJR Am J Roentgenol. 1996;166(3): 517–521.

[45] Beumer LJ, van der Meij EH, Kamstra JI, et al. Interobserver and intraobserver variability in the radiological assessment of sialolithiasis using cone beam computed tomography. Med Oral Patol Oral Cir Bucal. 2022;27(1):e94–e98.

[46] Wang MF, Xie X, Li G, et al. Relationship between CNR and visibility of anatomical structures of cone-beam computed tomography images under different exposure parameters. Dentomaxillofac Radiol. 2020;49(5):20190336.

[47] Zaki IM, Hamed WM, Ashmawy MS. Effect of CBCT dose reduction on the mandibular canal visibility: ex vivo comparative study. Oral Radiol. 2021;37(2):282–289.

[48] Lofthag-Hansen S, Thilander-Klang A, Gröndahl K. Evaluation of subjective image quality in relation to diagnostic task for cone beam computed tomography with different fields of view. Eur J Radiol. 2011;80(2):483–488.