TECHNICAL REPORT

Small field of view cone beam CT temporomandibular joint imaging dosimetry

T D Lukat, J C M Wong and E W N Lam*

Discipline of Oral and Maxillofacial Radiology, Faculty of Dentistry, University of Toronto, ON, Canada

Objectives: Cone beam CT (CBCT) is generally accepted as the imaging modality of choice for visualisation of the osseous structures of the temporomandibular joint (TMJ). The purpose of this study was to compare the radiation dose of a protocol for CBCT TMJ imaging using a large field of view Hitachi CB MercuRay™ unit (Hitachi Medical Systems, Tokyo, Japan) with an alternative approach that utilizes two CBCT acquisitions of the right and left TMJs using the Kodak 9000® 3D system (Carestream, Rochester, NY).

Methods: 25 optically stimulated luminescence dosimeters were placed in various locations of an anthropomorphic RANDO® Man phantom (Alderson Research Laboratories, Stanford, CT). Dosimetric measurements were performed for each technique, and effective doses were calculated using the 2007 International Commission on Radiological Protection tissue weighting factor recommendations for all protocols.

Results: The radiation effective dose for the CB MercuRay technique was $223.6 \pm 1.1 \mu\text{Sv}$ compared with $9.7 \pm 0.1 \mu\text{Sv}$ (child), $13.5 \pm 0.9 \mu\text{Sv}$ (adolescent/small adult) and $20.5 \pm 1.3 \mu\text{Sv}$ (adult) for the bilateral Kodak acquisitions.

Conclusions: Acquisitions of individual right and left TMJ volumes using the Kodak 9000 3D CBCT imaging system resulted in a more than ten-fold reduction in the effective dose compared with the larger single field acquisition with the Hitachi CB MercuRay. This decrease is made even more significant when lower tube potential and tube current settings are used.

Dentomaxillofacial Radiology (2013) 42, 20130082. doi: 10.1259/dmfr.20130082

Cite this article as: Lukat TD, Wong JCM, Lam EWN. Small field of view cone beam CT temporomandibular joint imaging dosimetry. *Dentomaxillofac Radiol* 2013; 42: 20130082.

Keywords: temporomandibular joint; cone beam computed tomography; radiation dosimetry

Introduction

Diagnostic imaging of the temporomandibular joint (TMJ) has evolved significantly since its inception, and today CT is generally accepted as the imaging modality of choice for visualization of the osseous structures of the TMJ.¹⁻⁴ While CT imaging provides superior views of the hard tissue components of the joint to two-dimensional planar, panoramic and conventional tomographic techniques, one major drawback is its failure to adequately image the soft-tissue structures including the articular disc or its associated attachments.⁵

The current standard of care at our institution for imaging the osseous structures of the TMJs is cone beam CT (CBCT), as this modality offers both a reduced radiation dose and a superior image quality compared with helical CT.^{6,7} Our current protocol utilizes the Hitachi CB MercuRay™ cone beam CT unit (Hitachi Medical Systems, Tokyo, Japan) with a 9 inch (22.9 cm) field of view, operating at 100 kVp and 10 mA. This technique acquires images of both joints simultaneously and produces images with an isotropic voxel size of 0.29 mm.

Previous dosimetry data indicate a significant difference in the effective radiation dose between the Hitachi CB MercuRay and Kodak 9000® 3D (Carestream, Rochester, NY) CBCT units,^{8,9} but the radiation doses have not been specifically measured when the small fields-of-view are centered about the TMJs. The

*Correspondence to: Dr Ernest W N Lam, Discipline of Oral and Maxillofacial Radiology, Faculty of Dentistry, University of Toronto, 124 Edward Street, Room 260, Toronto, ON M5G 1G6, Canada. E-mail: ernest.lam@dentistry.utoronto.ca
Dr. Lam is the Dr. Lloyd and Mrs. Kay Chapman Chair in Clinical Sciences.
Received 26 February 2013; revised 1 September 2013; accepted 16 September 2013

purpose of this study was to compare the radiation dose of our current institutional protocol for TMJ imaging (Hitachi CB MercuRay, 9 inch field of view, 100 kVp and 10 mA) with an alternative technique utilizing two individual limited field of view CBCT acquisitions of the right and left TMJs using the Kodak 9000 3D unit. This system offers a field of view size measuring 5.0 cm in diameter by 3.7 cm in height, operating at a number of technical settings: 68 kVp and 6.3 mA (child), 70 kVp and 8 mA (adolescent/small adult) and 70 kVp and 10 mA (adult).

Materials and methods

25 optically stimulated luminescence (OSL) InLight® nanoDot™ dosimeters (Landauer, Glenwood, IL) placed in various locations in an anthropomorphic RANDO® Man phantom (Alderson Research Laboratories, Stanford, CT) were used to measure the absorbed radiation doses for tissues of the head and neck, using both the Hitachi CB MercuRay and Kodak 9000 3D units (Figure 1). The dosimeter sites of placement were selected to represent radiosensitive organs and regions

Figure 1 Placement of OSL dosimeters in the anthropomorphic RANDO® Man (Alderson Research Laboratories, Stanford, CT) phantom. OSL, optically stimulated luminescence

relevant to dental imaging, following the methods described by Ludlow *et al.*⁹ To offset our determinations for background radiation, unexposed control dosimeters were also read, and these results were subtracted from the experimental dosimeters.

The RANDO Man phantom was positioned in the CB MercuRay machine with the occlusal plane parallel to the floor and the midsagittal plane centered mediolaterally in the image field. The condylar heads were centered superoinferiorly in the centre of the image field. A single CBCT acquisition was performed using a 9 inch field of view and technique factors of 100 kVp, 10 mA and 9.6 s exposure time.

Positioning of the RANDO Man phantom in the Kodak 9000 3D CBCT unit required greater exactness to ensure that both the temporal and condylar components of the TMJ were completely imaged and centered within the volume. Bilateral indicator guides affixed to the surface of the anthropomorphic phantom were aligned with the temporal supports to maintain consistency in the vertical and horizontal positioning between successive acquisitions. The image sensor was first oriented parallel to the mid-sagittal plane to align the rotational centre of the cone beam unit with the TMJ region of interest. Anteroposterior localization was determined by positioning the laser indicator light approximately 1 cm anterior to the external auditory meatus. The superoinferior position was defined by centering the midpoint of the 3.7 cm vertical field of view light over a point corresponding to the level of the condylar head in the closed mouth position. Finally, the mediolateral position was set using the Kodak 9000 3D module software, placing the crosshair immediately medial to the condylar head of interest (right or left). These alignment parameters produced a dataset with the RANDO Man condylar head omnidirectionally centered within the imaging volume.

The Kodak 9000 3D acquisitions were made using preset patient size hotkeys. The technique factors used were 68 kVp and 6.3 mA (child), 70 kVp and 8 mA (adolescent/small adult), and 70 kVp and 10 mA (adult). Each acquisition, regardless of the patient size, used a scan time of 10.8 s. Each acquisition was performed in triplicate for each set of OSL dosimeters to ensure absorbed dose quantities exceeded the lower limit of detection, and each series was performed between three and seven times.

Table 1 summarises the anatomical sites of the OSL dosimeters placed throughout the phantom. Effective tissue doses for each of the imaging modalities were calculated using the 2007 International Commission on Radiological Protection (ICRP)¹⁰ tissue weighting factor recommendations (Table 2). Estimated percentages of the proportion of tissue irradiated were calculated using the values provided by Ludlow *et al.*⁹ which were initially derived for 12 inch field of view scans. These represented liberal estimates for the purposes of this study.

Mean tissue effective and total effective doses were calculated for the CB MercuRay protocol, as well as for

Table 1 Anatomical correlates of optically stimulated luminescence (OSL) dosimeters in RANDO[®] Man (Alderson Research Laboratories, Stanford, CT) anthropomorphic phantom

Phantom level	Anatomical location	OSL ID
2	Anterior calvarium	1
	Midbrain	2
	Posterior calvarium	3
3	Left calvarium	4
	Pituitary fossa	5
4	Right lens	6
	Right orbit	7
	Left lens	8
5	Left orbit	9
	Right cheek	10
6	Right parotid gland	11
	Right ramus	12
	Left parotid gland	13
	Left ramus	14
	Cervical spine	15
7	Right mandibular body	16
	Right submandibular gland	17
	Right sublingual gland	18
	Left sublingual gland	19
	Left mandibular body	20
	Left submandibular gland	21
	Left back of neck	22
	Right thyroid surface	23
9	Thyroid midline	24
	Pharynx	25

ID, identification.

bilateral TMJ acquisitions using the Kodak 9000 3D system. The absorbed dose data (measured in millirad, mrad) as measured by OSL dosimeters for each acquisition were first converted to equivalent dose units by the following formulae. For the sake of conversion, 0.01 Gy is equivalent to 1 rad, and 10 μ Gy is equivalent to 1 mrad.

$$D_T (\mu\text{Gy}) = D_T (\text{mrad}) \times (10 \mu\text{Gy}/1 \text{mrad})$$

where D_T is the absorbed dose measured in microgray (μ Gy) for tissue type T; and

$$H_T (\mu\text{Sv}) = D_T (\mu\text{Gy}) \times w_R$$

where H_T is the equivalent dose measured in microsieverts (μ Sv) for tissue type T, and w_R is the radiation weighting factor for the particular type and energy of radiation involved (for diagnostic X-rays, $w_R = 1$).¹¹

Effective tissue doses were then calculated using the tissue weighting factors recommended by the 2007 ICRP guidelines. Mean effective tissue doses for each organ or tissue derived from each individual scan were calculated, along with the respective standard deviations. The total mean effective dose (measured in microsieverts, μ Sv) was summated for all mean effective tissue doses for each of the imaging modalities.

Statistical analysis was performed using SPSS[®] Statistics software v. 17.0 (SPSS Inc., an IBM Company, Chicago, IL). Data were deemed statistically different when $p < 0.05$.

Table 2 Equivalent tissue dose calculation parameters

Tissue/organ	Tissue weighting factor ^a	Estimated fraction irradiated ^b	OSL ID number(s)
Bone marrow	0.120	16.5%	
Mandible		1.3%	12, 14, 16, 20
Calvarium		11.8%	1, 3, 4
Cervical spine		3.4%	15
Thyroid	0.040	100.0%	23, 24
Oesophagus	0.040	10.0%	25
Skin	0.010	5.0%	6, 8, 10, 22
Bone surface	0.010	16.5%	
Mandible		1.3%	12, 14, 16, 20
Calvarium		11.8%	1, 3, 4
Cervical spine		3.4%	15
Salivary glands	0.010	100.0%	
Parotid		100.0%	11, 13
Submandibular		100.0%	17, 21
Sublingual		100.0%	18, 19
Remainder	0.009 each ^c		
Lymphatic nodes		5.0%	11–21, 24, 25
Muscle		5.0%	11–21, 24, 25
Extrathoracic airway		100.0%	7, 9, 11–21, 24, 25
Oral mucosa		100.0%	11–14, 16–21

ID, identification; OSL, optically stimulated luminescence.

^aBased on 2007 International Commission on Radiological Protection recommendations.^bBased on the work by Ludlow *et al*.⁹^cRemainder tissue/organs tissue weighting factor 0.12 total, divided by 13 possible tissues/organs.

Results

An illustration comparing the field of view size differences of the two systems is shown in [Figure 2](#). The effective radiation dose for the CB MercuRay technique (100 kVp/10 mA) was $223.6 \pm 1.1 \mu\text{Sv}$. For the Kodak 9000 3D techniques, which incorporated two acquisitions (one for each TMJ), we found the effective radiation doses to be $9.7 \pm 0.1 \mu\text{Sv}$ using the child preset (68 kVp/6.3 mA), $13.5 \pm 0.9 \mu\text{Sv}$ for the adolescent/small adult preset (70 kVp/8 mA) and $20.5 \pm 1.3 \mu\text{Sv}$ for the adult preset (70 kVp/10 mA). The difference in the mean effective dose between groups was significant at $p < 0.0001$ determined using one-way analysis of variance. Tukey post-hoc analysis showed that all bilateral acquisition groups significantly differed from one another ($p < 0.05$). These results are summarised in [Table 3](#).

Discussion

The dosimetry data demonstrate that utilization of separate right and left TMJ limited field of view CBCT acquisitions using the Kodak 9000 3D system results in a more than ten-fold reduction in effective radiation dose compared to the larger single field Hitachi CB MercuRay acquisition. Moreover, the dose decrease is even more significant if lower tube potential and mA

Figure 2 Axial cone beam CT images acquired at the level of the temporomandibular joint(s) in the anthropomorphic RANDO® Man phantom (Alderson Research Laboratories, Stanford, CT) using (a) the Hitachi CB MercuRay™ system (Hitachi Medical Corporation, Tokyo, Japan) and (b) the Kodak 9000® 3D system (Carestream, Rochester, NY)

settings are used, as recommended for children and adolescents/small adults. This reduction is related to a restricted volume of irradiated tissue, the lower operating technique factor settings of the Kodak system compared with the Hitachi unit and the pulsed nature of radiation emission of the Kodak unit.

The estimated tissue fractions used to calculate effective doses are based on 12 inch field of view CBCT

estimates, and these may be frank overestimates. Therefore, the dose reduction may, in fact, be even greater than indicated by our calculations. The effective radiation dose is comparable to that of typical digital panoramic radiographic system, which has been reported to range between $14.7 \mu\text{Sv}$ and $24.5 \mu\text{Sv}$ for the Sirona Orthophos® XG (Sirona Dental Systems, New York, NY) and Planmeca ProMax® (Planmeca Oy, Helsinki, Finland) units, respectively.¹² In addition to generating high-resolution three-dimensional images of the TMJs, our protocol also offers those dental practitioners equipped with only a limited field of view CBCT capability an opportunity to provide TMJ imaging for their patients at a radiation dose comparable to a typical digital panoramic radiograph.

Numerous studies have evaluated the relative dose burden imparted on patients by various diagnostic imaging procedures involving the craniofacial region, with particular attention focused around comparative dosimetry of multidetector medical CT vs CBCT. The average effective dose for an adult head CT is approximately $2000 \mu\text{Sv}$.¹³ Adapting a specific TMJ protocol to multidetector CT through field of view limitation, the effective dose is reduced to about $600 \mu\text{Sv}$.¹⁴ Although no previous studies have measured the radiation doses of CBCT units when the field of view is specifically centered on the TMJs, our data generally agree with other CBCT comparative dosimetry studies. Ludlow and Ivanovic⁶ investigated dosimetry of eight large field of view CBCT units, including the Hitachi CB MercuRay. The CBCT devices were compared using varying field of view sizes, and ICRP tissue weighting factors were based on the 2007 guidelines. The effective doses for the Hitachi CB MercuRay operating at “maximum quality” settings of 120 kVp and 15 mA were $407 \mu\text{Sv}$ (6 inch field of view), $560 \mu\text{Sv}$ (9 inch field of view) and $1073 \mu\text{Sv}$ (12 inch field of view), respectively. The effective dose of the system operating at 100 kVp and 10 mA was only determined using the 12 inch field of view. This technique produced an effective radiation dose of $569 \mu\text{Sv}$, which represents an approximately 47% reduction in dose compared to the “maximum quality” technique factor setting. The Hitachi CB MercuRay produced the highest effective dose of all the CBCT units when the 9 inch field of view was used. This result was largely due to the continuous radiation emission operation of the Hitachi system compared with other systems such as the Imaging Sciences iCat (Imaging Sciences International, Hatfield, PA). If the effective dose for a 9 inch field of view acquisition of $560 \mu\text{Sv}$ operating at 120 kVp and 15 mA from the Ludlow and Ivanovic study is scaled by the same 47% dose reduction, this would yield a theoretical effective dose of approximately $297 \mu\text{Sv}$. The present study demonstrated an effective dose of $223.6 \mu\text{Sv}$ for a 9 inch field of view CB MercuRay TMJ study, which is in reasonable agreement with this hypothetical value. Jadu *et al*¹⁵ reported effective radiation doses for CBCT sialography, centering the field of view on either the

Table 3 Mean equivalent tissue doses and summated mean effective doses for each of the temporomandibular joint (TMJ) imaging modalities

Tissue type	Mean equivalent tissue dose (μSv) ^a			
	Imaging modality			
	Hitachi 100 kVp/10 mA	Kodak child 68 kVp/6.3 mA	Kodak adolescent/small adult 70 kVp/8 mA	Kodak adult 70 kVp/10 mA
Bone marrow	58.23	1.54	2.17	3.28
Thyroid	18.90	0.51	0.92	1.87
Oesophagus	1.99	0.06	0.12	0.22
Skin	2.25	0.40	0.49	0.49
Bone surface	4.87	0.14	0.18	0.27
Salivary glands	36.73	1.67	2.31	3.83
Brain	30.32	1.58	2.18	2.42
Remainder				
Lymphatic nodes	1.51	0.07	0.10	0.16
Muscle	1.51	0.07	0.10	0.16
Extrathoracic airway	32.00	2.06	2.75	4.09
Oral mucosa	35.29	1.60	2.22	3.72
Mean effective dose (μSv) $\pm$ SD ^b	223.6 $\pm$ 1.1 μSv	9.7 $\pm$ 0.1 μSv	13.5 $\pm$ 0.5 μSv	20.5 $\pm$ 1.3 μSv

SD, standard deviation.

^aBased on 2007 International Commission on Radiological Protection tissue weighting factor recommendations.^bMean effective dose = Σ mean equivalent tissue doses (μSv).

The Hitachi CB MercuRay™ unit is manufactured by Hitachi Medical Systems, Tokyo, Japan, and the Kodak 9000® 3D system is manufactured by Carestream, Rochester, NY.

parotid or submandibular salivary glands within the image field. When the parotid gland was centered within the image field and the system was operating at 100 kVp and 10 mA, the effective doses were reported to be 97 μSv (6 inch field of view), 275 μSv (9 inch field of view) and 466 μSv (12 inch field of view). By contrast, when the submandibular gland was centred within the field of view, effective doses of 261 μSv (6 inch field of view), 275 μSv (9 inch field of view) and 466 μSv (12 inch field of view) were produced. The increased effective dose during submandibular gland imaging using a 6 inch field of view was explained by the increased exposure of the radiosensitive thyroid gland. Dosimetric measurements from the present study certainly fall within the range of values reported by previous studies.

In comparison, there has been little published on the effective dose from limited field CBCT systems. Pauwels *et al*¹⁶ evaluated comparative dosimetry for the 3D Morita Accuitomo® 170 (J. Morita Corp., Tokyo, Japan), the Kodak 9000 3D and the Pax-Uni3D (VaTech Co. Ltd., Seoul, Republic of Korea) systems and found effective doses ranging from 19 μSv to 44 μSv , depending on the region imaged and the CBCT system used. Ludlow⁸ compared effective radiation doses for the anterior and posterior regions of the maxilla and mandible using the Kodak 9000 3D unit operating at 70 kVp and 10 mA. Effective doses ranged from 5.3 μSv for the anterior maxillae to 38.3 μSv for the posterior mandible. Conceivably, the posterior maxilla would most closely represent the TMJ region of interest in the present study, which was measured at 9.8 μSv by Ludlow. This is certainly comparable with our bilateral measurements of 20.5 $\pm$ 1.5 μSv for the 70 kVp and 10 mA adult setting.

In addition to the significant dose reduction offered by this TMJ imaging technique, the benefit of a smaller voxel size for the Kodak 9000 3D unit (0.076 mm vs

0.29 mm for the 9 inch field of view CB MercuRay) and thus improved spatial resolution makes it an attractive option for evaluating the TMJ osseous structures. Although the superior spatial resolution of the Kodak system may offer improved image quality, the clinical significance of this difference has not yet been reported. A clinical study is currently underway to investigate the effect of spatial resolution on diagnostic efficacy of osseous changes related to temporomandibular degenerative joint disease.

A potential limitation of this study is our use of a single anthropomorphic phantom intended to simulate an average-sized adult male patient. Our institution did not have access to a child, adolescent/small adult or large adult phantom. Therefore, all of the experiments used the same adult male phantom regardless of the technique factors chosen. As a phantom increases in size, there is a greater volume of tissue between the surface and centre of the phantom, and the absorbed radiation dose at the centre is roughly half of that measured at the surface.¹⁷ Conversely, a smaller phantom resembling a paediatric subject would demonstrate more uniform surface and central doses as a result of less peripheral attenuation of the X-ray beam. This equates to a higher absorbed dose in a smaller subject and ultimately a higher calculated effective dose.¹⁸ However, head diameter varies relatively little between paediatric and adult subjects, relative to other anatomical sites such as the abdomen.¹⁹ Thus, the use of a 16 cm phantom for head CT scans is generally considered acceptable for the purpose of calculating comparative dosimetry values in all age groups.²⁰ While our effective radiation dose data for the child and youth technique factor settings would likely be marginally increased if the respective-sized phantoms were utilized, we believe that our design is still valid within the present body of dosimetry research.

In conclusion, the use of bilateral TMJ acquisitions using the Kodak 9000 3D CBCT unit offers a significant effective radiation dose reduction compared with large field of view cone beam imaging systems. While the dose reduction may be ascribed to the pulsed nature of the radiation emission

from the Kodak system or the small field of view size, the use of similar small field of view systems should be considered as an attractive dose-reducing alternative to conventional larger field of view CBCT techniques for the visualization of the osseous structures of the TMJs.

References

1. Larheim TA. Current trends in temporomandibular joint imaging. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995; **80**: 555–576.
2. Ahmad M, Hollender L, Anderson Q, Kartha K, Ohrbach R, Truelove EL, et al. Research diagnostic criteria for temporomandibular disorders (RDC/TMD): development of image analysis criteria and examiner reliability for image analysis. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009; **107**: 844–860. doi: [10.1259/dmfr/60489374](https://doi.org/10.1259/dmfr/60489374)
3. Barghan S, Tetradis S, Mallya S. Application of cone beam computed tomography for assessment of the temporomandibular joints. *Aust Dent J* 2012; **57**(Suppl. 1): 109–118. doi: [10.1111/j.1834-7819.2011.01663.x](https://doi.org/10.1111/j.1834-7819.2011.01663.x)
4. Ribeiro-Rotta RF, Marques KD, Pacheco MJ, Leles CR. Do computed tomography and magnetic resonance imaging add to temporomandibular disorder treatment? A systematic review of diagnostic efficacy. *J Oral Rehabil* 2011; **38**: 120–135.
5. Westesson PL, Katzberg RW, Tallents RH, Sanchez-Woodworth RE, Svensson SA. CT and MR of the temporomandibular joint: comparison with autopsy specimens. *AJR Am J Roentgenol* 1987; **148**: 1165–1171. doi: [10.2214/ajr.148.6.1165](https://doi.org/10.2214/ajr.148.6.1165)
6. Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; **106**: 106–114. doi: [10.1016/j.tripleo.2008.03.018](https://doi.org/10.1016/j.tripleo.2008.03.018)
7. Honda K, Larheim TA, Maruhashi K, Matsumoto K, Iwai K. Osseous abnormalities of the mandibular condyle: diagnostic reliability of cone beam computed tomography compared with helical computed tomography based on an autopsy material. *Dentomaxillofac Radiol* 2006; **35**: 152–157.
8. Ludlow JB. Dosimetry of the Kodak 9000 3D small FOV CBCT and panoramic unit. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009; **107**: e29.
9. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G, and i-Cat. *Dentomaxillofac Radiol* 2006; **35**: 219–226. doi: [10.1259/dmfr/14340323](https://doi.org/10.1259/dmfr/14340323)
10. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP* 2007; **37**: 1–332.
11. IAEA. *Technical reports series No. 457. Dosimetry in diagnostic radiology: an international code of practice*. Vienna: IAEA; 2007.
12. Ludlow JB, Davies-Ludlow LE, White SC. Patient risk related to common dental radiographic examinations: the impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation. *J Am Dent Assoc* 2008; **139**: 1237–1243.
13. Bushberg JT, Seibert JA, Leidholdt EM, Boone JM. *The essential physics of medical imaging*. 3rd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2012.
14. Wong K, Forster BB, Li DK, Aldrich JE. A simple method of assessing the temporomandibular joints with helical computer tomography: technical note. *Can Assoc Radiol J* 1995; **50**: 117–120.
15. Jadu F, Yaffe MJ, Lam EW. A comparative study of the effective radiation doses from cone beam computed tomography and plain radiography for sialography. *Dentomaxillofac Radiol* 2010; **39**: 257–263. doi: [10.1259/dmfr/62878962](https://doi.org/10.1259/dmfr/62878962)
16. Pauwels R, Beinsberger J, Collaert B, Theodorakou C, Rogers J, Walker A, et al. Effective dose range for dental cone beam computed tomography scanners. *Eur J Radiol* 2012; **81**: 267–271. doi: [10.1016/j.ejrad.2010.11.028](https://doi.org/10.1016/j.ejrad.2010.11.028)
17. Nickoloff E. Current adult and pediatric CT doses. *Pediatr Radiol* 2002; **32**: 250–260. doi: [10.1007/s00247-002-0677-8](https://doi.org/10.1007/s00247-002-0677-8)
18. Huda W. Effective doses to adult and pediatric patients. *Pediatr Radiol* 2002; **32**: 272–279. doi: [10.1007/s00247-002-0680-0](https://doi.org/10.1007/s00247-002-0680-0)
19. Shrimpton PC, Wall BF. Reference doses for paediatric computed tomography. *Radiat Prot Dosimetry* 2000; **90**: 249–252.
20. Thomas KE, Wang B. Age-specific effective doses for pediatric MSCT examinations at a large children's hospital using DLP conversion coefficients: a simple estimation method. *Pediatr Radiol* 2008; **38**: 645–656. doi: [10.1007/s00247-008-0794-0](https://doi.org/10.1007/s00247-008-0794-0)