RESEARCH

A preliminary study to determine the diagnostic reference level using dose–area product for limited-area cone beam CT

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Objectives: The aim of this study was to measure the dose–area product (DAP) of limited-area cone beam CT (CBCT) units used by dental offices, and to evaluate the rationale of the DAP with an aid of optically stimulated luminescence (OSL) dosimeter in measuring radiation dose.

Method: The DAPs of 21 CBCT units used in the dental offices of Tokyo and the surrounding areas from five different manufacturers were measured using OSL nanoDot dosimeter. An assembly of OSL dosimeters with an X-ray film was exposed by CBCT units at exposure parameters commonly used in each dental office. DAP values were then calculated as expressed in mGy cm².

Results: DAP values ranged from 126.7 mGy cm² to 1476.9 mGy cm², depending on the units used.

Conclusion: OSL dosimeter coupled with film can be utilized for a large-scale study to measure DAP. The DAP values for individual CBCT units depend not only on the field of view, but also on the exposure parameters adapted by the dental offices.

Dentomaxillofacial Radiology (2013) **42**, 20120097. doi: 10.1259/dmfr.20120097

Cite this article as: Endo A, Katoh T, Vasudeva SB, Kobayashi I, Okano T. A preliminary study to determine the diagnostic reference level using dose–area product for limited-area cone beam CT. *Dentomaxillofac Radiol* 2013; **42**: 20120097.

Keywords: diagnostic reference level; dose–area product; cone beam CT; optically stimulated luminescence dosimeter

Recent technological advancements in oral and maxillofacial imaging have made possible the three-dimensional (3D) assessment of craniofacial anatomy. The most recent of these imaging technologies is cone beam CT (CBCT) for dental use.^{1,2} CBCT is extensively used in many dental specialties such as implant dentistry,³ impacted teeth removal,⁴ maxillofacial surgery,⁵ endodontics,⁶ periodontics,⁷ temporomandibular joint assessment⁸ and orthodontics.⁹ The recent SEDENTEXCT Project evidence-based guidelines proposed new referral criteria for CBCT in oral and maxillofacial radiology.¹⁰ The choice of imaging modality should provide maximum information about the patient's condition and, at the same time, it should follow the “as low as reasonably achievable” principle. CBCT imaging uses X-rays, which provide invaluable diagnostic information, but excessive use of

X-rays could lead to an increased risk of cancer. Therefore, the measurement of radiation dose and the optimization of radiological protection for the patient is an important component of a radiological procedure. In 1996 the International Atomic Energy Agency proposed guidance levels for dose and dose reductions for radiological procedures.¹¹ In the same year, the International Commission on Radiological Protection recommended the use of diagnostic reference levels (DRLs) for patients.¹² The DRL is an easily measured quantity, usually the absorbed dose in air, or in a tissue-equivalent material at the surface of a simple standard phantom or representative patient. The patient dose can be optimized for the diagnostic procedures by using the DRL.¹² The DRL indicates whether the patient dose is high or low for a particular imaging procedure. If the diagnostic procedure is found to exceed the DRL, there should be a review of the radiographic units to determine the adequacy of optimization of the radiation protection and subsequent implementation of dose reduction measures. DRL values are advisory in nature and supplement professional

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Received 14 March 2012; revised 27 July 2012; accepted 1 August 2012

judgment. The International Commission on Radiological Protection recommends that the DRL values should be country- or region-specific, selected by professional bodies and reviewed periodically.¹³ The International Atomic Energy Agency has set 7 mGy as the DRL for intraoral radiography.¹¹ Several countries have conducted national surveys of patient entrance dose in dental radiography.^{14,15} The 2004 European guidelines on radiation protection in dental radiology have summarised the outcomes of these studies.¹⁵ The mean dose from a mandibular molar projection as entrance surface dose was 3.3 mGy with a range of 0.14–45.7 mGy in a study from the UK.¹⁴ The third quartile dose was 3.9 mGy. The proposed DRL was then set at 4 mGy.¹⁴ DRLs for panoramic radiography were determined by measuring the dose–width product or dose–area product (DAP) using a dosimeter and film.^{14–16} The results of the study, for instance, from the UK, reported the third quartile value as 66.7 mGy mm, with a range of 1.7–328 mGy mm. The proposed DRL was set at 65 mGy mm.¹⁴ On the other hand, for CT, CT dose index (CTDI) and dose–length product are recommended.¹⁷ This is a measurement of the dose integrated across the dose profile along the patient's length.¹⁷ The use of CTDI for CBCT, however, is not appropriate because in CBCT the beam size is large and the dose distribution is asymmetrical.¹⁰ The DRLs for CBCT gain significance in the present scenario. CBCT differs in parameters such as X-ray system design, exposure conditions (kV, mA, time of exposure), field of view (FOV) and reconstruction algorithms. The recent SED-ENTEXCT European guidelines on CBCT for dental and maxillofacial radiology recommend the use of DAP and have proposed 250 mGy cm² as the achievable dose for CBCT imaging for the placement of upper first molar implant in a standard adult.¹⁰

Optically stimulated luminescence (OSL) dosimetry is a technique used in many areas of radiation dosimetry, including occupational and environmental monitoring, *in vivo* dosimetry, and for generating dose profiles in the estimation of CTDI.^{18–21} Numerous advantages of OSL over thermoluminescence dosimetry have been cited.²² Some of these include greater stability over time, greater reproducibility, the ability to read the OSL dosimeter multiple times, and increased reliability of the reader and ease of handling during processing. OSL can also be employed in dose measurement of dental and maxillofacial imaging modalities.^{23,24}

The purpose of the study was to measure the DAP of the limited-area CBCT units used by dental offices for

assessment of the impacted mandibular third molar and evaluate the rationale of the DAP with the aid of an OSL dosimeter for measuring radiation dose.

Materials and methods

21 dental offices with CBCT imaging facilities in Tokyo and the surrounding areas were chosen for the study. The study was explained to each of the dentists working in these offices, and their consent to participate in the study was obtained. The models of CBCT used in the study are shown in Table 1. These include the 3D Accuitomo (J Morita, Kyoto, Japan), the Kodak 9000 3D (Trophy, Croissy-Beaubourg, France), the Veraviewepocs 3D (J Morita), the ProMax 3D (Planmeca OY, Helsinki, Finland) and the AZ3000 (Asahi Roentgen Industry, Kyoto, Japan). The study included five units for the 3D Accuitomo, three units for the Kodak 9000 3D, five units for the Veraviewepocs 3D, five units for the ProMax 3D and three units for the AZ3000. A 25.4 × 30.5 cm sheet of X-OMAT V X-ray film (Carestream, Rochester, NY) was used to measure the exposed area. Landauer nanoDot OSL point dosimeters (Landauer Inc., Glenwood, IL) with external dimensions of 1 × 1 cm and 2 mm thickness were used to measure the absorbed dose to air at a specific point. Four of the nanoDot dosimeters were placed in the centre of each film. In addition, two Landauer CT OSL strip dosimeters (Landauer Inc.) were added on the same film packet to measure the dose profile both horizontally and vertically, as shown in Figure 1. This film/dosimeter assembly was attached on the detector side of the CBCT unit, as shown in Figure 2. The exposure parameters were selected based on the exposure for the assessment of impacted third molar in a standard adult using a small area FOV in each dental office. After the exposure these film packets were returned to the department of radiology at Showa University School of Dentistry for film processing and dose reading. The nanoDot dosimeters were read using a Landauer microStar reader provided by Nagase-Landauer (Nagase-Landauer Limited, Tsukuba, Japan), and the CT OSL strip dosimeters were read using a dedicated OSL strip reader (Landauer Inc.). The irradiated area was calculated as a product of the lengths of the x- and y-axes on the film images, measured by a millimetre-calibrated ruler. The margins were defined as an area of maximum density. The dose–area product of each was calculated as the product of the dose on the nanoDot dosimeter and the irradiated area.

Table 1 Cone beam CT models from five different manufacturers with corresponding field of view

Model	Manufacturer	Field of view (diameter × height, cm)
3D Accuitomo	J Morita, Kyoto, Japan	4 × 4
Kodak 9000 3D	Trophy, Croissy-Beaubourg, France	5 × 3.7
Veraviewepocs3D	J Morita, Kyoto, Japan	4 × 4
ProMax 3D	Planmeca OY, Helsinki, Finland	5 × 5
AZ3000	Asahi Roentgen Industry, Kyoto, Japan	5.1 × 5.1

Figure 1 Schematic representation of position of optically stimulated luminescence nanoDot (Landauer Inc., Glenwood, IL) point dosimeters and CT strip dosimeter on the film packet

Results

The exposed films are shown with the dose profiles obtained using the CT OSL strip dosimeter in [Figure 3](#). The images and dose profiles show relatively homogeneous dose distribution within approximately 20%

Figure 2 Film packet with dosimeter on cone beam CT unit for dose measurement. A, top of the horizontally placed dosimeter (black) in the white foamed styrol

variation between the edges and the centre of the beam. The relative dose shows a sharp increase in the centre when compared with the periphery. The results are shown in [Table 2](#) with the corresponding exposure parameters that were used. The exposed area ranged from 28.32 cm² to 95.06 cm². The average of the absorbed doses in air measured on four nanoDot dosimeters was taken, and the value ranged from 2.78 mGy to 15.53 mGy among 21 units. The DAP, as a result, was found to range from 126.7 mGy cm² to 1476.9 mGy cm².

Discussion

The application of CBCT technology in the field of oral and maxillofacial imaging has changed the way that dentists manage common pathological processes affecting the oral and maxillofacial region. This imaging modality is now frequently used in most dental specialties. Therefore it is important to know the reference dose of CBCT systems so that dentists can prescribe the appropriate imaging protocol. The present study aimed at determining the DAP of CBCT units used by dental offices using the film/nanoDot dosimeter. The nanoDot dosimeter is compact, easy to handle and inexpensive, and may be suitable for reference dose examination at regional or national levels. In addition, the dose profile was measured using CT OSL strip dosimeters along the horizontal and vertical axes, as shown in [Figure 1](#). Using this experimental approach, we were able to determine that the dose profile derived from the measurement of the dose from the CT strip dosimeter was almost homogeneous.

We measured the DAP for five different CBCT models. The DAP was found to range from 126.7 mGy cm² to 1476.9 mGy cm², with the lowest value in the 3D Accuitomo model and highest value in the AZ3000 model. The area depends not only on the size of FOV, but also the geometry, such as the focus to the centre of FOV distance and distance from the centre of FOV to the detector. In our study the area of the 3D Accuitomo model was half of the AZ3000 model. One of the reasons for this could be the differences in FOV. We cannot comment about the influence of the geometry on the area because of limited information available about the geometrical details of the models. The absorbed dose in air measured by nanoDot differed among CBCT units, ranging from 2.78 mGy to 15.53 mGy. This variation that could be due to several factors such as tube potential, tube current, exposure time, geometry, sensitivity of the detector, pulsed or continuous X-ray exposure, and other reasons. Most of the clinicians use default exposure settings based on the manufacturer's recommendation, and some may have used dose reduction mechanisms. In the case of the 3D Accuitomo model, there was variation between the five CBCT units in the dose in air. The measured doses in air in two CBCT units using half-scan mode were 2.78 mGy and 4.79 mGy ([Table 1](#)). The dose in air from a full-scan mode would be almost twice this

Figure 3 Exposed films after processing (top) and corresponding dose profiles (bottom) of 3D Accuitomo (J Morita, Kyoto, Japan) on the left and AZ3000 (Asahi Roentgen Industry, Kyoto, Japan) on the right side. Dose profile is the graphical representation of radiation dose for the CT dosemeter plotted against its position on the film. The irradiated area shows relatively constant dose distribution and at the periphery the dose tapers to almost zero. Though the relative dose is minimal at the peripheries, there is a small amount of radiation which is detected by the CT dosemeters

value. The value of dose in air of the latter unit is significantly high when compared with the other units with similar exposure parameters. The dose in air measured from the second unit in the 3D Accuitomo model was 3.58 mGy, which is significantly lower than the other CBCT units in the same group. The exposure parameters are similar except for a slightly lower tube current setting used in this unit. This may partly explain the lower dose in air measured from this CBCT unit, but there may be other factors responsible for the reduction in the measured dose in air, such as dose reduction mechanisms. Generally the dose reduction mechanisms include decreasing the exposure parameters (such as current) within optimal limits. In addition, in CBCT units another parameter called the beam-on time (exposure time) can be reduced.²⁵ However, we do not have information regarding the possible dose reduction mechanisms used in these CBCT units. When we examine the data from AZ3000 CBCT units, it can be observed that there is a difference in the measured dose in air between the units. This is due to the difference in current. On comparison

of AZ3000 CBCT units and 3D Accuitomo units, we observe that the dose in air for AZ3000 units is higher. This difference could be due to dentists with the AZ3000 unit using higher exposure parameters, thus increasing the dose in air and DAP values.

The DAP values in our study were higher than the SEDENTEXCT European guidelines on CBCT for dental and maxillofacial radiology, which recommended 250 mGy cm² as the achievable dose for CBCT imaging for the placement of upper first molar implant in a standard adult.¹⁰ This value is based on a study conducted in the UK, which analysed the DAP data from 41 CBCT units. The exposure parameters and the needs of the image quality for upper molar implant placement in the UK study may be different from the present study. Our study derived the DAP values of limited area CBCT units with exposure parameters used in the assessment of mandibular third molar. We do not have information regarding the CBCT models and the exposure parameters used in the UK study. The DAP values, and consequently the DRL for the CBCT units, depends on the exposure

Table 2 Air dose values and DAP values from different cone beam CT units

Dental office	Model	Tube potential (kV)	Current (mA)	Exposure time (s)	Measured length (cm)	Area (cm ²)	Air dose (mGy)		DAP (mGy cm ²)
							Mean	Standard deviation	
1	A	90	5	9	6.7 × 6.8	45.6	2.78	0.10	126.7
2	A	90	4	17.5	6.9 × 6.5	44.9	3.58	0.27	160.6
3	A	90	5	9	6.9 × 6.8	46.9	4.79	0.45	224.7
4	A	90	5	17.5	6.8 × 6.8	46.2	5.87	0.32	271.4
5	A	90	5	17.5	7.0 × 6.8	47.6	7.55	0.31	359.4
6	B	70	10	10.8	6.0 × 4.9	29.4	10.08	0.28	296.4
7	B	74	10	10.8	5.9 × 4.8	28.3	9.19	0.67	260.3
8	B	70	10	10.8	6.2 × 5.0	31.0	9.11	0.43	282.4
9	C	80	5	9.4	6.8 × 6.5	44.2	6.63	0.33	293.0
10	C	80	5	9.4	7.0 × 6.6	46.2	6.43	0.99	297.1
11	C	80	5	9.4	6.9 × 6.5	44.9	7.28	0.89	326.5
12	C	80	5	9.4	6.9 × 6.6	45.5	7.17	0.88	326.5
13	C	80	5	9.4	7.0 × 6.6	46.2	7.61	0.20	351.6
14	D	84	12	12	8.1 × 8.1	65.6	6.14	0.36	402.8
15	D	84	12	12	8.4 × 8.7	73.1	5.67	0.65	414.4
16	D	84	12	12	8.0 × 8.3	66.4	6.46	1.04	428.9
17	D	84	12	12	8.1 × 8.2	66.4	6.64	0.46	441.0
18	D	84	12	12	8.2 × 9.4	77.1	6.49	0.54	500.2
19	E	85	4	17	9.7 × 9.6	93.1	10.33	0.56	961.9
20	E	85	6	17	9.5 × 9.8	93.1	13.11	0.99	1220.5
21	E	85	6	17	9.7 × 9.8	95.1	15.53	0.56	1476.9

DAP, dose-area product.

Models: A, 3D Accutomo (J Morita, Kyoto, Japan); B, Kodak 9000 3D (Trophy, Croissy-Beaubourg, France); C, Veraviewepocs3D (J Morita); D, ProMax 3D (Planmeca OY, Helsinki, Finland); E, AZ3000 (Asahi Roentgen Industry, Kyoto, Japan).

parameters and the FOV of the unit. The resolution of the images may be an important factor in selecting the exposure parameters for a particular diagnostic task. The clinician using a CBCT unit should aim to maximize the diagnostic information while minimizing the exposure to the patient. Future studies can address the issue of different diagnostic purposes and FOVs to determine DRLs.

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