TECHNICAL REPORT

Comparison of manual and dose reduction modes of a MORITA R100 CBCT

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Objective: To compare effective dose differences when acquiring (1) dose reduction mode and (2) manual mode in a MORITA R100 CBCT.

Methods: 24 exposure protocols with different technique factors were performed in both the dose reduction mode and the manual mode in a Veraviewepocs 3D R100 cone beam CT device. 48 TLD were placed in a RANDO head phantom at 24 different sites. Effective doses were calculated according to the formalism published in the 103rd ICRP report.

Results: Effective doses for the dose reduction mode protocols ranged from 14 to 156 µSv [mean = 57 µSv, standard deviation (SD) = 37 µSv], whereas effective doses for the manual mode protocols ranged from 22 to 267 µSv (mean = 94 µSv, SD = 65 µSv). Thus, across all protocols, the dose reduction mode leads to a drop of the effective dose by 38 % (SD = 6 %).

Conclusions: The estimated effective doses are significantly lower if dose reduction protocols are acquired.

Dentomaxillofacial Radiology (2019) **48**, 20180009. doi: [10.1259/dmfr.20180009](https://doi.org/10.1259/dmfr.20180009)

Cite this article as: Rottke D, Dreger J, Sawada K, Honda K, Schulze D. Comparison of manual and dose reduction modes of a MORITA R100 CBCT. *Dentomaxillofac Radiol* 2019; **48**: 20180009.

Keywords: cone-beam computed tomography; radiation dosage; thermoluminescent dosimetry

Introduction

Cone-beam computed tomography (CBCT) is an established technique of three-dimensional (3D) imaging in the head and neck region. The current market shows a large variety of different manufacturers that offer systems with different features for the user.¹ Several studies were carried out to collect information about the patient's stochastic risk to cancer and to evaluate the span of different dose values from CBCT examinations.^{2–4} In order to be able to compare data from different modalities, the concept of effective dose (*E*) calculation was introduced. Since then, *E* calculations have found wide application in the evaluation of dose values for medical exposures.⁵

Modifications of tissue-weighting factors resulted in a 10% increase of *E* for examinations in the head and neck area. In 2007, the International Commission

on Radiological Protection (ICRP) added the oral mucosa, salivary glands, and the extrathoracic airways to the list of radiosensitive tissues and proposed specific weighting factors in its 103rd publication.⁶ This affected the estimated *E* at the time of acquisition of images that included specific tissues in the mentioned region.⁷

More recently, radiation protection issues and the optimization of CBCT examination protocols, in particular, were addressed to the manufacturers.⁸

Hence, several innovations and technical features like evolving detectors, iterative reconstruction, beam-shaping collimators, optimized filtering, and tube current modulation were introduced.⁹ The latest generation of CBCT units offers a pre-programmed profile of tube current adjustment in order to reduce the *E*. Whereas the tube current is constant during the acquisition in manual mode (MM), it is modified in the implemented dose reduction mode (DRM) depending on the C-arms' relation to the patient's head.¹⁰ The terms MM

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Received 09 January 2018; revised 14 August 2018; accepted 26 August 2018

Figure 1 Dose profiles of DRM and MM. DRM, dose reduction mode; MM, manual mode.

and DRM are acronyms defined by the manufacturer (J. Morita Corp., Kyoto, Japan) of the device investigated in the present study and might be named different in other CBCT systems. However, the effect on the resultant E for the examined patient has not been investigated in detail for different examination protocols.

Therefore, the aim of our study was to estimate the E for the DRM and the MM, and compare the results. 24 different examination protocols, all with different technique factors, volume sizes, and locations were evaluated in a Veraviewepocs 3D R100 (J. Morita Corp., Kyoto, Japan).

Methods and materials

Dose profile

To measure the dose profiles for the DRM and the MM a PTW Nomex multimeter (PTW Freiburg, Freiburg, Germany) was employed. Figure 1 shows the dose rate over the exposure time. Calculating both areas under the curve through integration over the full interval of both profiles suggested a reduction of 41 %, when performing a scan in DRM, according to the following equation:

$$\text{red}_{\text{per}} = \frac{(\text{AUC}_{\text{DRM}} - \text{AUC}_{\text{MM}})}{\text{AUC}_{\text{MM}}} * 100$$

where red_{per} is the percentage reduction.

All measurements were accomplished in a Veraviewepocs 3D R100 CBCT device. The system worked in a range of 60–90 kVp and between 1 and 10 mA. The exposure time was constant at 9.4 s. The operator could choose between four cylindrical volumes, where the smallest was 4 by 4 cm and the largest was 8 by 8 cm. Additionally, three patented 3D Reuleaux Full Arch field of

view volumes were available; all these field of view were triangular shaped in horizontal expansion and 4, 5, or 8 cm in vertical expansion. All protocols were available both in MM and DRM.

Phantom

An anthropomorphic male RANDO head phantom (The Phantom Laboratory, NY) was used to simulate the attenuation and scattering characteristics of the human anatomy. The phantom consisted of a human skull embedded in a soft tissue-equivalent material. It was transected into 10 axial layers, each 2.5 cm thick and with individual drilled holes in specific positions to place the thermoluminescent dosimeter (TLD) chips.

Dosimeters

All measurements were performed using solid TLD GR-200A chips (Fimel, Fontenay aux Rose, France). The reset and annealing process of the TLD chips was accomplished in a microprocessor-controlled PTW TLDO annealing oven (PTW Freiburg, Freiburg, Germany). The readout process was achieved in a LTM Manual TLD Reader (Fimel, Fontenay aux Rose, France).

In each case, two TLD chips were inserted in custom-made PMMA (polymethyl methacrylate) containers and brought in eight different layers of the phantom.

The TLD chips were placed in 24 different positions in the head and neck area.

Table 1 shows the particular location (tissue/organ) and layer of each PMMA container.

Four TLD chips remained unexposed to measure the background radiation R_{back} and other potential influencing factors. Therefore, a total number of 48 + 4 TLD chips, as per protocol, were exposed.

All TLD chips were irradiated with a defined dose D_{def} of $2.15 \times 10^5 \mu\text{Gy}$ and read-out afterwards. A calibration factor K was calculated for each individual TLD chip. All calculated calibration factors K were averaged. TLD chips with a calibration factor K outside twice the standard deviation were omitted and exchanged.

Measurement protocols

A total of 24 protocols were measured in both DRM and MM. The protocols were split into eight sets. Each set included three protocols for a specific region and volume size with a variation of technique factors (Table 2).

Exposure time was set to 9.4 s. The equipped phantom was arranged in the CBCT device according to the manufacturer's instructions. Each protocol was repeated 10 times to improve the overall statistical outcome. For the read-out procedure, all TLD chips were placed on couples and read-out separately. The glow curves were displayed and the values were exported to a ".txt" file. After the readout process, the TLD chips were reset in the annealing oven and prepared for the next protocol.

Table 1 Description of TLD positions in the phantom

<i>Organ/tissue</i>	<i>Position</i>	<i>Phantom layer</i>
Calvaria, ventral	1	2
Calvaria, left	2	2
Calvaria, dorsal	3	2
Midbrain	4	3
Orbita, right	5	4
Orbita, left	6	4
Pituitary	7	4
Parotid gland, left	8	5
Ramus, left	9	5
Parotid gland, right	10	5
Ramus, right	11	5
Cheek, right	12	5
Cervical spine	13	6
Mandible, left	14	7
Submandibular gland, left	15	7
Mandible, right	16	7
Submandibular gland, right	17	7
Neck	18	7
Sublingual gland, central	19	8
Esophagus	20	9
Thyroid, internal	21	9
Thyroid, surface	22	external
Lens, left	23	external
Lens, right	24	external

TLD, thermoluminescent dosimeter;

Calculations were performed using Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA). To estimate the absorbed doses D_{abs} for a specific position s (1–24), the following equation was used:

$$D_{abs}^s = \frac{K \times \frac{1}{2} (TLD_1^s) + (TLD_2^s - R_{back})}{n}$$

The mean of the two TLD chips from each position was built and multiplied by K . The background radiation R_{back} was subtracted and the result was divided by the number of performed scans n . To calculate organ doses D_{org} , the following formalism was used:

$$D_{org} = p_{tissue} \times \frac{1}{\sum_{s \in tissue} 1} \sum_{s \in tissue} D_{abs}^s$$

All absorbed doses D_{abs} representing one organ were averaged and multiplied by the factor p_{tissue} , which specified the irradiated proportion of an organ (tissue) compared to its distribution throughout the whole body. For those organs that were not entirely exposed to the primary beam, the radiated fraction factors were selected close to the distribution values of tissues and organs proposed in the 89th publication (Basic anatomical and physiological data for use in radiological protection: reference values) of the ICRP.¹¹

For bone marrow in the lower jaw, the factor was 0.013, for bone marrow in the skull 0.118 and for bone marrow in the cervical vertebra 0.034 respectively. The factor for the exposed oesophagus was 0.1. For the part of the exposed skin, lymphatic nodes and muscles a factor of 0.05 was selected.

E was calculated using the proposed tissue-weighting factors specified in ICRP publication 1036, published in 2007, and according to the following equation:

$$E = \sum_{tissue} W_{tissue} \times D_{org}$$

Results

For the MM, E ranged from 22 to 267 μ Sv [mean = 94 μ Sv, standard deviation (SD) = 65 μ Sv]. For the DRM, E ranged from 14 to 156 μ Sv (mean = 57 μ Sv, SD = 37 μ Sv).

Detailed E estimations are displayed in Table 2. Scans performed in DRM showed significantly lower E between a reduction of 24 and 45 % (mean = 38 %, SD = 6 %) compared to the MM.

Table 3 shows the mean D_{org} of all protocols in DRM and MM.

Discussion

Our study showed a wide range of E , depending on the performed scan protocol. The E given to patients could be reduced significantly by performing scans in the implemented DRM of the device. Protocols with larger acquired volumes showed a wide range with higher absorbed doses. A comparison of the protocols 13–15 (triangular-shaped volumes, 10 × 8 cm) with the protocols

16–18 (cylindrical volumes, 8 × 8 cm) revealed that the smaller volumes showed higher E . This outcome could be explained by the fact that the C-arm during the acquisition of a triangular-shaped volume does not rotate on an orbit (isocentric); instead, it rotates along a triangular path. Thus, the source- to-object distance varies depending on the position of the C-arm in relation to the patient. Following the inverse square law, larger source-to-object distances result in lower absorbed doses.

Reducing the vertical volume expansion results in a lower E . Acquiring one full vertical volume (8 cm) in MM leads to a reduction of 1–7 % in E , compared to two single, z-axis-shifted volumes of half the vertical size (4 cm). The reduction is even more relevant (12–16 %) when two single volumes, each 5 cm in vertical expansion, with an overlap are acquired. The reduction of E is similar or even higher for protocols performed in DRM. If image-quality parameters like resolution, contrast and signal-to-noise ratio are constant, a vertically further extended volume has advantages over two single z-axis shifted volumes.

Table 2 Performed protocols and results of ED calculations

Protocol	Volume size $d \times h$ [cm]	Region	[kV]	[mAs]	ED MM [μ Sv]	ED DRM [μ Sv]	Δ [%]
1	10 × 5	Lower jaw	90	75.2	144	89	−38
2	10 × 5	Lower jaw	85	47	77	51	−34
3	10 × 5	Lower jaw	80	28.2	39	27	−31
4	10 × 4	Lower jaw	90	75.2	129	78	−40
5	10 × 4	Lower jaw	85	47	71	48	−33
6	10 × 4	Lower jaw	80	28.2	35	24	−31
7	10 × 5	Upper jaw	90	75.2	150	91	−40
8	10 × 5	Upper jaw	85	47	81	48	−41
9	10 × 5	Upper jaw	80	28.2	44	25	−43
10	10 × 4	Upper jaw	90	75.2	132	76	−43
11	10 × 4	Upper jaw	85	47	73	42	−42
12	10 × 4	Upper jaw	80	28.2	39	22	−45
13	10 × 8	Both jaws	90	75.2	259	153	−41
14	10 × 8	Both jaws	85	47	137	80	−42
15	10 × 8	Both jaws	80	28.2	69	39	−44
16	8 × 8	Both jaws	90	75.2	267	156	−42
17	8 × 8	Both jaws	85	47	145	83	−43
18	8 × 8	Both jaws	80	28.2	75	42	−43
19	4 × 4	Upper right molar	90	75.2	81	52	−36
20	4 × 4	Upper right molar	85	47	42	27	−36
21	4 × 4	Upper right molar	80	28.2	22	14	−37
22	4 × 4	Lower right molar	90	75.2	86	53	−39
23	4 × 4	Lower right molar	85	47	45	33	−26
24	4 × 4	Lower right molar	80	28.2	24	18	−24

DRM, dose reduction mode; ED, effective dose; MM, manual mode;

The measurements showed that, in all 24 protocols, organ doses from bone marrow, thyroid gland, salivary gland, and the remaining tissues contributed the highest parts to the E . Earlier studies showed that changes in the tissue-weighting factors and the inclusion of salivary glands as a weighted tissue in the ICRP 2007 recommendations resulted in increased E .¹²

Table 3 Mean organ dose [μ Sv]

	DRM	MM
Bone marrow	10	15
Thyroid	8	13
Oesophagus (10%)	1	1
Skin (5%)	0	1
Bone surface	1	1
Salivary glands	13	22
Brain	3	4
Remaining tissues	21	37
Mean E [μ Sv]	57	94

DRM, dose reduction mode; MM, manual mode;

In this study, an anthropomorphic adult male phantom was used to measure absorbed doses. However, E will be higher in children or smaller adults. Thus, the calculation could either overestimate or underestimate the E for an individual patient. Further, RANDO phantoms are individually manufactured and are in no way standardized. Therefore, comparison between two studies where different RANDO phantoms were employed is difficult and can only serve as an indicator of different dose values.

All scans were performed at the same location (Digital Diagnostic Center, Freiburg, Germany) where the readout process took place. Therefore, many influencing factors such as transportation or shipping of the TLD could be avoided. If there were any influencing factors present, they can be considered as equal for all protocols. Even if systematic errors were taken into consideration, the relation between calculated E would still be valid.

The high impact of the thyroid gland on the E is still questionable: In the present study, as well as in earlier studies, the irradiated fraction of the thyroid is always

considered to be 100%. Following this concept may lead to an overestimation of the thyroid organ dose and *E*. Nevertheless, earlier studies demonstrated, that the thyroid *Dorg* can be reduced when lead equivalent thyroid shielding is applied during the acquisition of a CBCT, despite the way, the thyroid *Dorg* calculated.^{13–15} On the other hand, a regular commercial lead apron will not reduce the thyroid skin dose, because it does not cover this specific region.¹⁶ In general, the concept of fraction irradiated should be reconsidered. Perhaps, in the future, more complex computer simulations will help to solve this issue.

Changes in image quality dependent on selected exposure parameters were not evaluated in our study. However, it can be assumed that a higher choice of technique factors will result in a better signal-to-noise and contrast-to-noise ratio.¹⁷ *In vivo*, this could lead to a better or worse image quality than is needed to answer this question. Therefore, the selection of technique factors, volume size, and location should be carefully chosen for each individual patient. As in this study, a RANDO phantom was used to perform the measurements, a wide range of technique factors was employed in order to evaluate the *E* changes and not the medical image quality. Of course, following the ALADA-principle (as low as diagnostically acceptable) the operator should be qualified to select the right technique factors for each scan according to the indication.¹⁸

When there is a need for high contrast images the technique factors should be selected accordingly, whereas on the other hand over exposed images should be avoided. Sometimes this can be a difficult task to fulfill, because there is still no evidence-based research on the needed image quality in CBCT for different diagnostic questions.

TLD-based measurements can be related with great uncertainties depending on the exact location of the TLD chips. Not only could the position of the TLD chip in the phantom be incorrect but also the distribution of radiosensitive tissues could vary from patient to patient. This is an important fact to keep in mind when applying the results of this study to actual patients. Today, TLD measurements serve as indicators when

transferring the results of *in vitro* studies to *in vivo* situations. It should be considered to re-evaluate the distribution and amount of radiosensitive tissues in the human body to tackle this issue. Moreover, training opportunities for non-dentomaxillofacial radiologists are the path to follow in order to improve quality and make better choices for our patients

The results of the 24 dose measurements in MM and DRM match the wide range of *E* published in the literature.^{2–4,7,19} A study comparing TLD with metal-oxide semiconductor field-effect transistors showed that the external read-out process of TLD is time consuming; moreover, dismantling and repositioning the phantom can lead to inaccuracy.¹⁹ Nonetheless, the calculated *E* in both the studies were similar. A former *ex vivo* study evaluated the accuracy and the image quality of scans performed in MM and DRM in a 3D Accutomo model (J. Morita Mfg. Corp., Kyoto, Japan). In this specific study, the detection of simulated periapical lesions revealed good results in diagnostic accuracy and the authors reported a dose reduction between 51 and 54 %.¹⁰ In the future also optically stimulated luminescence dosimeters might be used to measure and evaluate *E* from CBCT examination, but for now the published data are not sufficient to give us the opportunity to compare these few studies to the existing base of many TLD based studies. Finally, the authors expect a little more time to pass before the TLD- technology is replaced in general. However—and this should be considered an important issue to be solved—owing to different study designs, various methodologies and several pre-programmed exposure settings, a general comparison of *E* in CBCT is rather limited.

Conclusion

The study showed that using the DRM in a Veraviewepocs 3D R100 device could reduce *E* significantly—up to 45 %—in comparison to acquisitions performed in MM, depending on the selected scan protocol. Thus, if a slightly reduced image quality is acceptable, the DRM should be selected.

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