Experimental Determination of the Effective Dose from Dental CBCT Scans

Jonathan Waschkewitz
j.waschkewitz@uke.de

Caroline Buss
caroline.buss@gmx.net

Dr. Elisabetta Gargioni
e.gargioni@uke.de

Dr. Christian Scheifele
c.scheifele@uke.de

July 2020

The quantification of radiation exposure plays an important role in the dental field. Therefore, the aim of this work was to determine the effective dose experimentally, using a standardised anthropomorphic head phantom and a wide selection of CBCT programs. These programs cover all available field sizes as well as the three modes, high definition (HD), standard definition (SD), and low dose (Low).

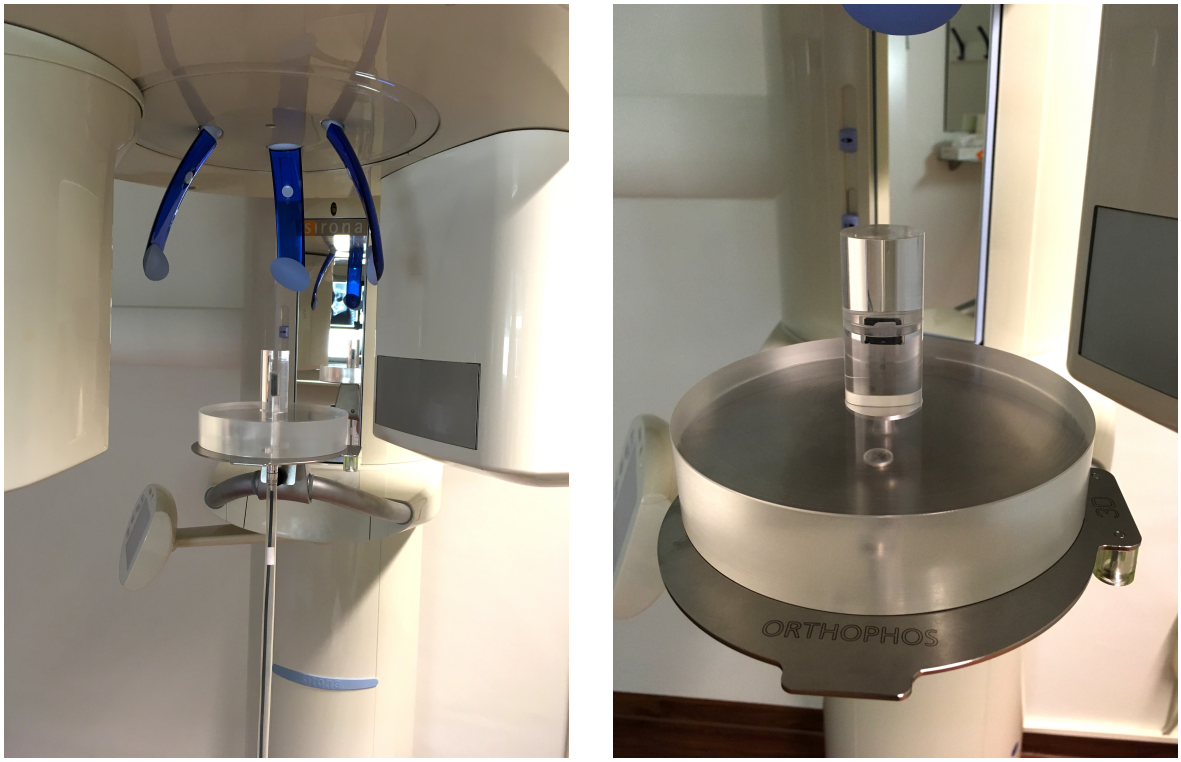
Materials and Methods

Summary

The dose measurements were done by using optically stimulated luminescence dosimeters made from beryllium oxide (BeO-OSL dosimeter), placing 24 calibrated dosimeters in an anthropomorphic Alderson head phantom (**table 1**, **figure 2**, **figure 3**), and determining the organ doses per scan at these positions. Subsequently, the effective dose was determined.
Both, the determination of the effective dose, as well as the positioning of the dosimeters were carried out in accordance with Ludlow and Walker [4].

Dosimetry System and Calibration

The BeO-OSL dosimeters were used in combination with the reader "myOSLchip" (RadPro International GmbH, Wermelskirchen, Germany).
Important characteristics of these dosimeters are a reproducibility of less than $\pm$ 5% and linearity in the dose range 50 µGy - 10 Gy. The sensitivity of each individual dosimeter is dependent on the exact composition of the material and can vary by a factor 3. Furthermore, the dosimeters energy dependence in the range of diagnostic x-ray spectra needs to be accounted for. Therefore, every dosimeter was calibrated at the utilised beam quality.
The calibration of the dosimeters was done with an FC65-G Farmer-chamber (**figure 1a**) in combination with a "Dose1" electrometer (both: IBA Dosimetry, Schwarzenbruck, Germany). This was carried out separately (**figure 1b**) with the respective CBCT systems and the required beam qualities (i.e.: 85kV;0,3/1 mm Cu, <2,5mm Al for HD/SD/LOW mode Orthophos, Dentsply Sirona, Bensheim, Germany).



(a) Ionisation chamber

(b) OSL dosimeter

Figure 1: Calibration setup

Anthropomorphic Head Phantom

An anthropomorphic adult head phantom (Alderson-Rando, RSD Inc, CA, USA) was used for the dose measurements. The phantom consists of a human skull embedded in a tissue equivalent material and is divided into 10 horizontal layers (numeration: 0-9, see **figure 2**). 24 BeO-based OSL dosimeters were placed at anatomically representative sites inside the phantom (listed in **table 1**). The exact positioning can be seen in **figure 3**.

Number	Layer	Position
1	1	Calvarium anterior
2	1	Mid brain
3	2	Calvarium left
4	2	Mid brain
5	3	Calvarium Posterior
6	3	Pituitary
7	3	Right lens of eye
8	3	Left lens of eye
9	4	Etmoid
10	5	Left maxillariy sinus
11	6	Oropharyngeal airway
12	6	Right parotid
13	6	Left parotid
14	6	Right ramus
15	6	Left ramus
16	7	Left back of neck
17	7	Right submandibular gland
18	7	Left submandibular gland
19	7	Center sublingual gland
20	7	Center C spine
21	8	Lateral neck - left
22	9	Thyroid - left
23	9	Thyroid - right
24	9	Esophagus

Table 1: Dosimeter positions

Figure 2: Alderson phantom

CBCT Systems and Measurement Programme

The measurements were done with three different CBCT systems (Orthophos XG, Orthophos SL and Axeos (Dentsply Sirona, Bensheim, Germany)). An overview of the measurements is given in **table 2**.

No.	Mode	FoV (cm x cm)	Position	Current (mA)	Exposure Time (s)	#Scans/ Measurement
Axeos						
1.	HD	17x13	centre	7	16.7	3 x 1
2.	SD	17x13	centre	13	5.9	2
3.	Low	17x13	centre	13	3.9	6
Orthophos XG						
4.	HD	8x8	front	7	14.3	3 x 3
5.	SD	8x8	front	13	5	6
6.	SD	5x5	mandibula front	13	5	10
7.	HD	5x5	maxilla molar left	7	14.3	3 x 4
Orthophos SL						
8.	Low	11x10	front	13	2.2	10
9.	Low	8x8	front	13	2.2	10
10.	Low	5x5	maxilla molar left	13	2.2	20

Table 2: Overview of parameters of the CBCT programs that were examined in this work. Listed are modes, FoV, field positions, device parameters and number of necessary measurements needed for comparable dose values inside the useful beam.

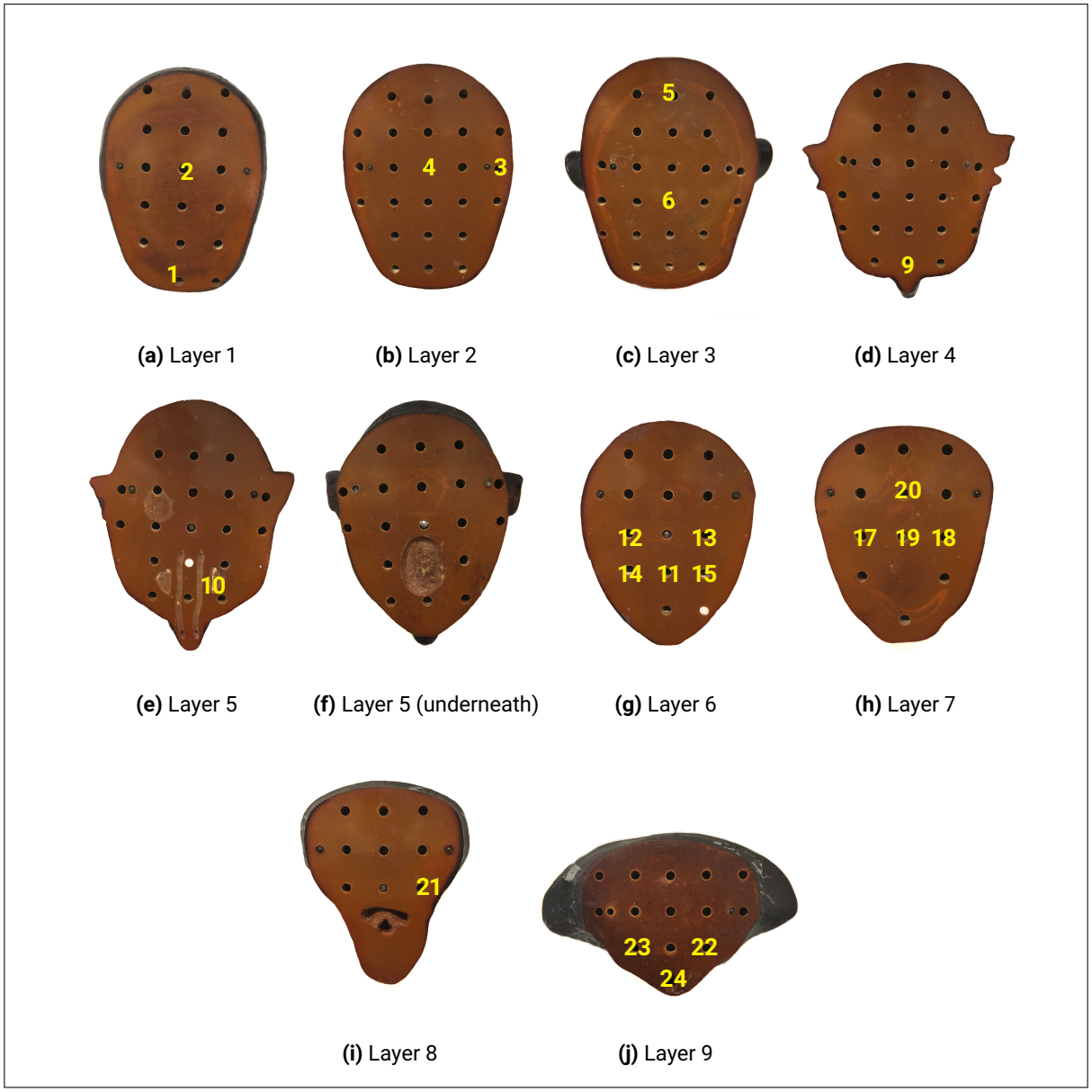


Figure 3: Positions of the dosimeters inside the phantom layers.

Determination of the Effective Dose

At least 3 scans were performed for every measurement to compensate for tolerances in the x-ray generation process. The number of scans was chosen so that the dosimeters inside the useful beam received at least 10 mGy to guarantee a high reproducibility of the measured values. Thus, the number of scans per measurement varied between 3 and 10.

Organ/Tissue	Irradiated fraction [%]	OSL number	ICRP 2007 w_T
Bone marrow	12.2		0.12
Mandible	0.8	14, 15	
Calvaria	7.7	1, 3, 5	
Cervical spine	3.8	20	
Thyroid	100	22, 23	0.04
Esophagus	10	24	0.04
Skin	5	7, 8, 16	0.01
Bone surface	16.5		0.01
Mandible	1.3	14, 15	
Calvaria	11.8	1, 3, 5	
Cervical spine	3.4	20	
Salivary glands	100		0.01
Parotid	100	12, 13	
Submandibular	100	17, 18	
Sublingual	100	19	
Brain	100	2, 4, 6	0.01
Remainder			0.12
Lymphatic Nodes	5	11-13, 17-19, 21-24	
Muscles	5	11-13, 17-19, 21-24	
Extrathoracic Region	100	9-13, 17-19, 21-24	
Oral Mucosa	100	11-13, 17-19	

Table 3: Irradiated fraction of tissue/organs and tissue weighting factors w_T

According to the number of iterations of the scan program, evaluated dose values were normalised to one scan. Using the ICRP 2007 tissue weighting factors (**Table 3** [4]), the ED was calculated from the individual dose values per scan in the following way:

Dose values were averaged if measurements were taken at multiple positions of one type of organ/tissue (e.g. left and right side), in order to get the average dose per tissue type.

In accordance with Ludlow and Walker a correction factor, the bone-to-muscle attenuation coefficient $\mu_{BM} = -0.0618 \cdot kVp \cdot 2/3 + 6.9406$, was applied to the components mandibular, skull and cervical vertebra to estimate the dose applied to the bone surface.

The organ/tissue doses of bone marrow (components: mandibular, skull, cervical vertebra), bone surface (component: mandibular, skull, cervical vertebra) and salivary glands (components: parotid, submandibular, sublingual) were calculated as the sum of the doses to the individual components.

The equivalent dose was estimated from the product of the organ doses with the fractions (**Table 3**) of the organs/tissues which were irradiated.

The equivalent doses H_T were multiplied by the ICRP weight factors w_T and summed over all organs, which resulted in the ED:

$$E = \sum w_T \cdot H_T$$

Results

Nr	Protocol				Patient* 1	2	3	4	5	6	7
Orthophos XG											
1	HD	8 x 8	front		115	144	173	**202**	-	-	-
2	SD	8 x 8	front		31	48	70	**90**	-	-	-
3	SD	5 x 5	front	mandibula	16	24	35	**45**	-	-	-
4	HD	5 x 5	left	maxilla molar	71	89	107	**125**	-	-	-
Orthohos SL											
1	Low	11 x 10	front		12	14	20	**27**	-	-	-
2	Low	8 x 8	front		8	9	13	**17**	-	-	-
3	Low	5 x 5	left	maxilla molar	3	4	5	**7**	-	-	-
Axeos											
1	HD	17 x 13	center		98	122	147	171	196	244	**293**
2	SD	17 x 13	center		39	51	73	**95**	-	-	-
3	Low	17 x 13	center		13	15	21	**28**	-	-	-
4	HD	17 x 13	center	collimated to 17 x 7.5	28	35	42	**49**	56	70	84
5	HD	17 x 13	center	collimated to 17 x 10	89	111	133	**155**	177	222	266
6	SD	17 x 13	center	collimated to 17 x 7.5	11	**15**	21	27	-	-	-
7	SD	17 x 13	center	collimated to 17 x 10	37	**49**	70	91	-	-	-
8	Low	17 x 13	center	collimated to 17 x 7.5	4	4	**6**	8	-	-	-
9	Low	17 x 13	center	collimated to 17 x 10	12	14	**21**	27	-	-	-

Table 4: Effective dose in μSv. The measured values are emphasized, all others were calculated from these. (*see **table 5, 6 & 7**)

The Orthophos XG programs chosen were selected to examine the agreement with available literature values [1], [2], [3]. At the systems newer systems, Orthophos SL and Axeos, the additionally available modes were examined (Status: July 2020).

Mode LOW

	kV	mA	Effective beam-on time (s)
Level 1	85	6	3.9
Level 2	85	7	3.9
Level 3	85	10	3.9
Level 4	85	13	3.9

Mode SD

	kV	mA	Effective beam-on time (s)
Level 1	85	7	4.5
Level 2	85	7	5.9
Level 3	85	10	5.9
Level 4	85	13	5.9

Mode HD

	kV	mA	Effective beam-on time (s)
Level 1	85	4	16.7
Level 2	85	5	16.7
Level 3	85	6	16.7
Level 4	85	7	16.7
Level 5	85	8	16.7
Level 6	85	10	16.7
Level 7	85	12	16.7

Table 5: Device parameters of the different levels for the FoV 17x13, Axeos (source: Dentsply Sirona)

Mode SD

	kV	mA	Effective beam-on time (s)
Level 1	85	7	3.2
Level 2	85	7	5.0
Level 3	85	10	5.0
Level 4	85	13	5.0

Mode HD

	kV	mA	Effective beam-on time (s)
Level 1	85	4	14.3
Level 2	85	5	14.3
Level 3	85	6	14.3
Level 4	85	7	14.3

Table 6: Parameters of the different levels for the FoV 5x5 and 8x8, Orthophos XG (source: Dentsply Sirona)

Mode LOW

	kV	mA	Effective beam-on time (s)
Level 1	85	6	2.2
Level 2	85	7	2.2
Level 3	85	10	2.2
Level 4	85	13	2.2

Table 7: Parameters of the different levels for the FoV 5x5, 8x8 and 11x10, Orthophos SL (source: Dentsply Sirona)

References

[1] Rottke, D., Patzelt, S., Poxleitner, P. & Schulze, D., *Effective dose span of ten different cone beam CT devices*, Dentomaxillofac. Radiol. 42, 20120417 (2013).

[2] Soares, M. R., Batista, W. O., Antonio, P. de L., Caldas, L. V. E. & Maia, A. F, *Study of effective dose of various protocols in equipment cone beam CT*, Appl. Radiat. Isot. 100, 21–26 (2015).

[3] Ludlow, J. B. et al, *Effective dose of dental CBCT-a meta analysis of published data and additional data for nine CBCT units*, Dentomaxillofac. Radiol. 44, 20140197 (2015).

[4] J.B. Ludlow and C. Walker, *Phantom dosimetry and image quality of i-CAT FLX cone-beam computed tomography*, Am J Orthod Dentofacial Orthop, 2013 Dec, 144(6): 802–817.