White paper based on the study

Experimental Determination of the Effective Dose from Dental CBCT Scans

University of Hamburg Eppendorf

Authors: Dr. E. Gargioni, Dr. C. Scheifele, C. Busse, J. Waschkewitz

dentsplysirona.com

THE DENTAL
SOLUTIONS
COMPANY™

Dentsply Sirona

1. Study objective

Prof. Ludlow et al. of the University of North Carolina conducted numerous manufacturer-independent effective dose studies of dental panoramic X-ray and CBCT devices over the last several years. After his retirement, a search was conducted for a suitable institution to continue establishing these important parameters for dental 3D X-ray diagnostics for new devices.

Dr. Christian Scheifele at the University of Hamburg Eppendorf and his team developed a slightly modified procedure to establish effective doses.

The aim of this study is to confirm the comparability of both methods.

Preface

Nowadays, X-ray examinations are part of any standard medical procedures and provide important information to support medical diagnoses and treatments. Compared with radiological diagnostics in human medicine, dental radiology works with much lower dose values in certain circumstances.

More than 148 million X-ray examinations are performed annually in Germany. Statistically speaking, each German is X-rayed by a physician at least once per year [1].

In Germany, about 43% of all X-rays are performed for dental diagnostic purposes. However, the collective effective dose generated is only 0.4% (see Fig. 1). By far, the largest “dose cause” is computer tomography with approx. 67% [1].

In the United States, computer tomography makes up approx. 50% of the collective dose [2]. In Europe, the results of numerous investigations fluctuate from 0.33–2 mSv/a [3].

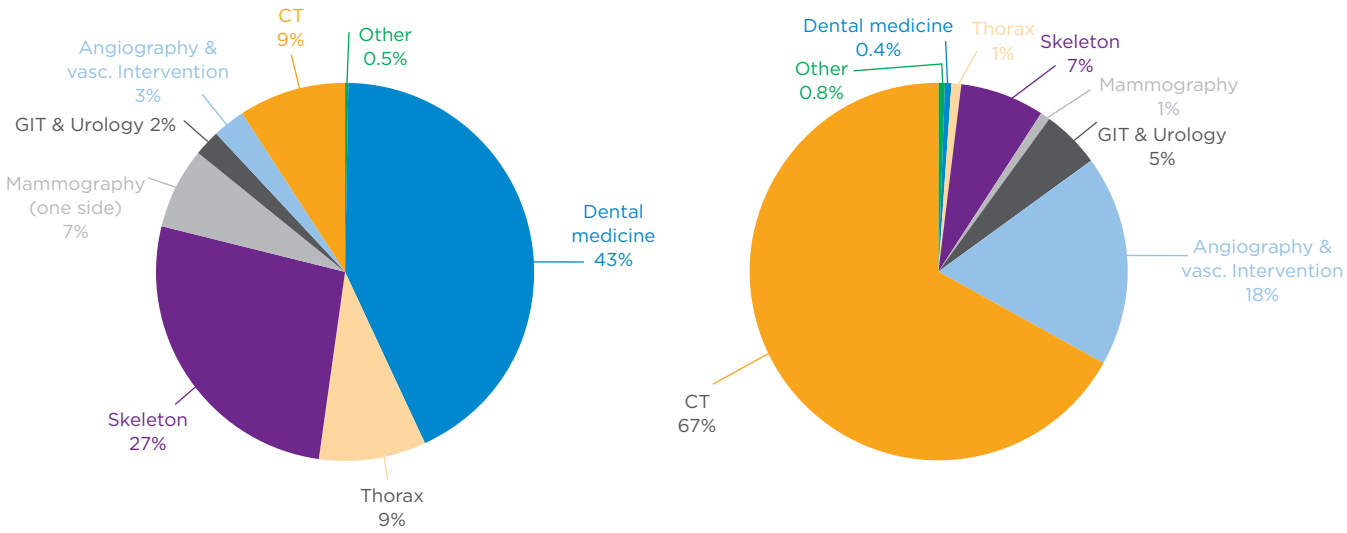


Fig. 1: Percentage of the different types of examinations representing the total number (left) and the collective effective dose (right) for the year 2016 in Germany [1].

If only the collective dose applied by the dental diagnosis is considered, it is noticeable that the dose values are relatively low. However, radiation is still capable of causing health issues even at a very low dose. This risk needs to be assessed against the actual benefit of each application.

The doses for the same type of exam fluctuate considerably from one case to the next. This is due to differences between individual patients such as varying physical builds, weight, medical conditions and diagnostic requirements. Another essential contributing factor is the experience of the doctors and the medical-technical radiology assistants. Additionally, diagnostic X-ray exams are performed with different techniques, which also leads to varying dose exposures.

1.1 Effects of radiation

When ionizing radiation makes contact with the human body, radiation exposure takes place. This means that the radiation causes an interaction with the body tissue and is absorbed to varying degrees. The effect of the radiation absorbed by the body is expressed in terms of dose [4].

X-rays fall under ionizing radiation and have so much energy that they can penetrate matter and change it in the process. It is able to break chemical bonds. When a body is exposed to radiation, a small part of the X-ray energy is transferred to the body. Several physical phenomena come into play here.

Radiation effects are divided into deterministic effects, which occur above certain dose threshold values and stochastic effects, which occur with a certain dose-related probability after a longer latency period [4].

Typically, the threshold value for deterministic effects is at approx. 500 millisievert (mSv) [4]. Due to the low dose, we only have to deal with stochastic effects with dental X-rays.

Stochastic radiation effects are based on random events, meaning that, depending on the dose amount, these radiation effects will occur with a certain probability, or they may not occur at all.

The radiation effect can change the information in the nucleus of a cell without impacting cell viability.

If the organism cannot adequately repair this, the change can be passed on to subsequent cells.

Depending on the dose, these radiation effects occur with a certain probability. The time between radiation exposure and the occurrence of symptoms (latency period) can take from a few years to several decades. Depending on the cell type, changes in the genetic makeup or malignant neoplasms can occur.

The term damage risk expresses the probability of a stochastic radiation effect occurring. The risk is assessed based on the observed disease frequencies in exposed population groups.

1.2 Effective dose

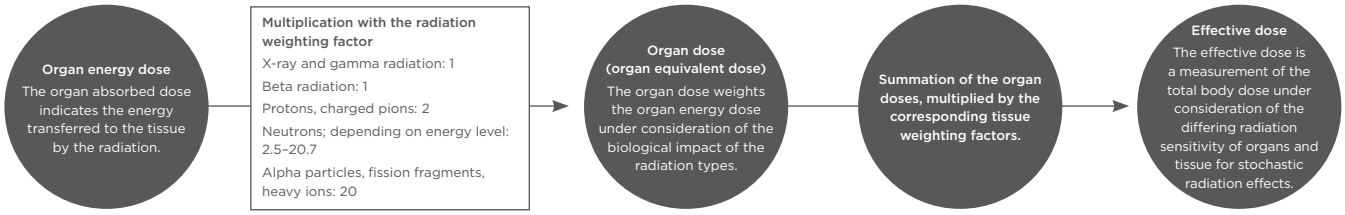
To evaluate and compare radiation exposures, the term “effective dose” was established. The effective dose takes the differing radiation sensitivity of organs and tissue into consideration and is expressed in Sievert or millisievert (mSv).

Human organs and tissue have differing sensitivities in regards to radiation effects (Fig. 2). The human skin, for example, is less sensitive to ionizing radiation than some interior organs.

To take these differences into account, the risk of the occurrence of possible stochastic effects on exposure of individual organs, tissues or the entire body is assessed by determining an effective dose. The dose of the exposed organs and tissues is multiplied by tissue weighting factors, representing a measure of the contribution of the exposed organ to the risk of damage to the entire body.

This makes it possible to compare radiobiological risks of different radiation types and applications.

Relationship between absorbed dose, organ dose and effective dose for assessing the radiation risk



The International Commission on Radiological Protection (ICRP) suggests the worldwide use of tissue weighting factors, which were established in 1977 and last updated in 2007 [5].

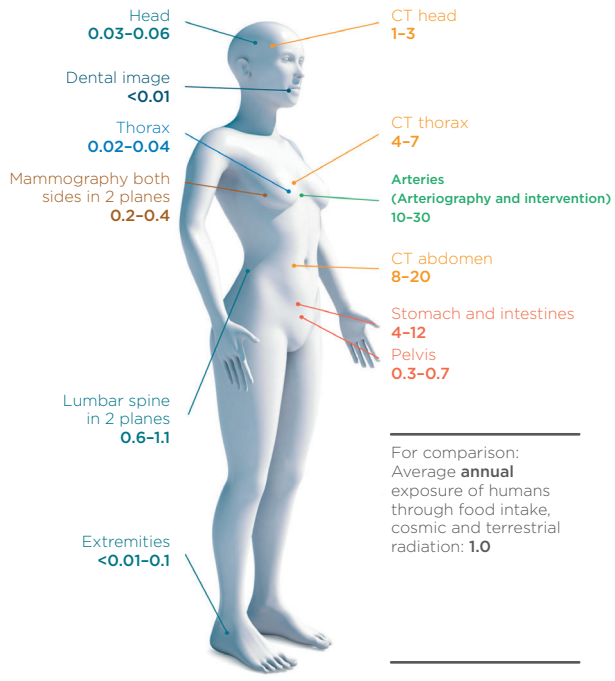
When determining the effective doses of dental applications, this concerns mainly organs in the head area such as the thyroid, eye lenses or salivary glands.

Determining the effective dose is technically demanding and costly.

Prof. Ludlow et al. of the University of North Carolina conducted numerous manufacturer-independent effective dose studies of dental panoramic X-ray and CBCT devices over the last several years.

Dr. Christian Scheifele of the University of Hamburg Eppendorf and his team developed a procedure that can also be applied to establish effective doses.

Mean effective doses with X-ray applications
in mSv on standard patients with an approx. bodyweight of 155 lbs (70 kg)



Percentage per type of examination of the

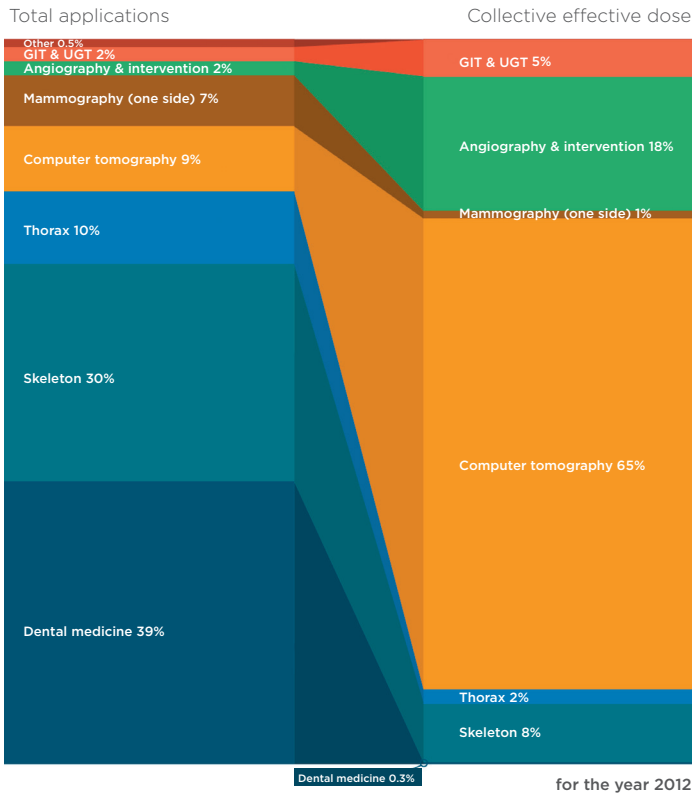


Fig. 2: Examples of effective dose values

2. Dose measurement method according to Scheifele et al.

A phantom of an adult head (Alderson phantom) is used to measure the effective dose in the dental region. The phantom consists of a human skull that has been encased in a material that is equivalent to tissue and divided into ten horizontal layers. The advantage of the tissue-like material is that its absorption and scattering behavior response to an X-ray is comparable to that of a patient (Fig. 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 eyes
8	3	Left lens of eyes
9	4	Etmoid
10	5	Left maxillary 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

Fig. 3: Alderson phantom

The ten layers contain drilled holes through which thermoluminescence dosimeters can be inserted (Fig, 4).

As with the comparison studies by Ludlow et al., 24 relevant organs in the head region have been defined. For each of these organs, a thermoluminescence dosimeter is placed inside the corresponding phantom layers (Tab. 1).

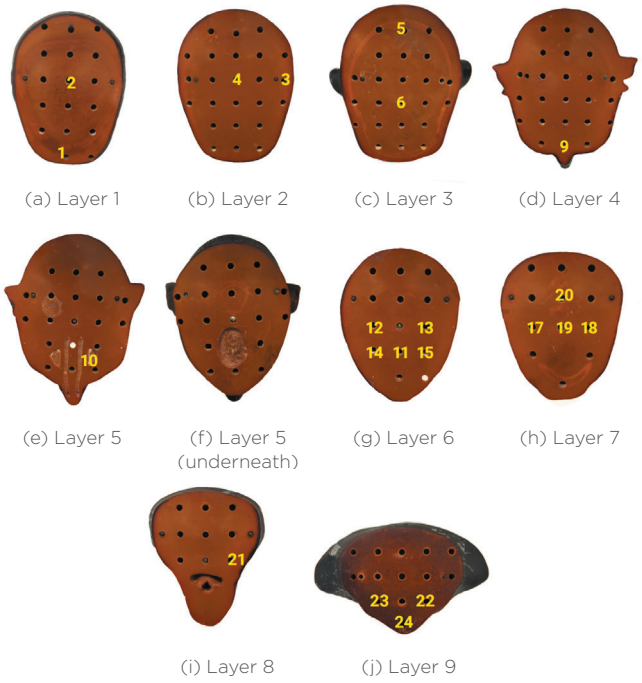


Fig.: 4: Positions of the dosimeters in the phantom layers

Thermoluminescence dosimeters (TLD) consist of crystalline structures made of lithium or calcium fluoride. Through the impact of ionizing radiation, the orbital electrons of their lattice atoms are elevated to a higher energy level from which they can't spontaneously return to their original position. The excited electrons can only return to their original position when heated to several 100°C under emission of visible light. This small amount of light can be measured photometrically and assigned an energy dose value through determined energy-dependent calibration factors.

3. Procedures and method comparability

The aim of the study is to demonstrate that with comparable trial design and procedure as the studies performed by Ludlow et al., the measuring results of the effective dose are comparable.

To accomplish this, knowledge and insights from measurements with Dr. Ludlow are included. The phantom used in this study (Fig. 3) is equivalent to the phantoms used in the studies published by Prof. Ludlow in relation to size and decaying depth. The number of thermoluminescence dosimeters, as well as their position in the phantom layers, are exact replications. Each one of these dosimeters must be calibrated regularly.

A thermoluminescence dosimeter fortified with beryllium (BeO OSL dosimeter) and a corresponding reader are applied for the first time to make this process more stable. It is exactly these modifications compared with the Ludlow method that are to be verified.

3.1 Implementation and calculation of values

For each measurement, a minimum of three scans is performed to compensate for fluctuations during the X-ray generation. The number of 3D X-ray images is selected so that the dosimeters within the useful beam will receive a total of at least 10 mGy for one measurement. This serves to ensure a high reproducibility of the measurements. Especially with the Low Dose mode of the Dentsply Sirona X-ray devices or with a small FOV, numerous scans must be performed to achieve 10 mGy. Therefore, the number of images per measurement varied from 3 to 20.

From these images, the mean dose per image is determined. Based on the requirements of the International Radiation Commission tissue weighting factors (ICRP 2007), the effective doses are determined from the individual doses in the next step (Table 2).

The average dose per tissue type is determined by averaging the doses, measured from several positions of the same organ/tissue type. In accordance with Ludlow et al., a correction factor, the muscle-bone-damping coefficient μBM = - 0.0618 x kVp x 2/3 + 6.9406 is applied to the mandible, skull and cervical vertebrae to estimate the impact dose.

The organ/tissue doses of bone marrow (components: mandible, skull, cervical vertebrae), bone surface (components: mandible, skull, cervical) and salivary glands (components: parotis, submandibular, sublingual) are determined as the sum of the doses of the individual components.

During the next step, the equivalent dose is determined from the organ doses based on the proportion (Table 1) of the irradiated organs/tissue. The different types of radiation cause differing levels of impact in the body tissue. For example, suppose tissue is exposed to alpha radiation and another time to beta radiation. In that case, the biological impact of the alpha radiation at the same energy dose is about 20 times higher than the biological impact of the beta radiation. With X-rays, the radiation impact factor equals: 1.

By multiplying the determined doses (energy dose) with the radiation weighting factor, the organ equivalent dose is determined.

For the final determination of the effective dose E, the equivalent doses HT are multiplied with the ICRP tissue weighting factors and totaled across all organs.

$$E = \sum w_T \times H_T$$

4. Results

The measured doses per scan for all positions are listed in Table 2 for all Hamburg measurements and for the study by Ludlow et al. Deviations of the Orthophos SL measurements (1–3) for all positions average 3.1% within the radiation range, and 8.6% within the scatter range. The deviations between Orthophos SL and Orthophos XG display a mean value of 16.7% and are highest in the thyroid region and the left sinus cavity.

The effective doses determined from the doses per scan are listed in Table 3:

	Ludlow	**SL** (3)	**SL** (2)	**SL** (1)	**XG**
Effective dose [µSv]	188.7	208.6	201.1	195.1	168.7

Tab. 3: Determined effective doses

Thus, the effective dose as measured with the Orthophos SL deviates from the Ludlow measurement by 6.8%. The measurement of the effective dose with the Orthophos XG differs from the Ludlow measurement by 10.6%.

Position	**Ludlow**	**SL (3)**	**SL (2)**	**SL (1)**	**XG**	Mean SL
Calvarium anterior	0.05	0.03	0.04	0.02	0.03	0.0297 ± 0.0001
Mid brain	0.06	0.06	0.06	0.07	0.06	0.0617 ± 0.0000
Calvarium left	0.06	0.04	0.05	0.07	0.05	0.0537 ± 0.0001
Mid brain	0.13	0.11	0.19	0.13	0.14	0.1436 ± 0.0011
Calvarium posterior	0.07	0.06	0.08	0.07	0.07	0.0682 ± 0.0000
Pituitary	0.25	0.23	0.27	0.25	0.27	0.2494 ± 0.0002
Right lens of eyes	0.32	0.20	0.20	0.22	0.27	0.2084 ± 0.0001
Left lens of eyes	0.31	0.18	0.25	0.23	0.28	0.2227 ± 0.0008
Etmoid	0.52	0.27	0.32	0.36	0.38	0.3190 ± 0.0012
Left maxillary sinus	2.58	0.96	1.09	1.25	2.21	1.0993 ± 0.0143
Oropharyngeal airway	3.48	4.05	3.86	4.14	4.02	4.0139 ± 0.0135
Right parotid	4.67	4.87	4.43	4.35	4.17	4.5488 ± 0.0509
Left parotid	4.17	4.22	4.09	3.83	3.63	4.0467 ± 0.0258
Right ramus	5.06	4.46	4.60	4.49	4.84	4.5162 ± 0.0037
Left ramus	5.08	4.17	4.40	4.56	4.60	4.3762 ± 0.0248
Left back of neck	4.06	4.81	4.66	4.79	4.51	4.7540 ± 0.0044
Right submandibular gland	5.48	5.73	5.73	5.53	4.52	5.6660 ± 0.0092
Left submandibular gland	5.52	5.65	5.38	5.25	4.50	5.4271 ± 0.0275
Center sublingual gland	4.29	4.66	4.70	4.54	3.78	4.6344 ± 0.0047
Center C spine	3.04	3.16	3.18	3.22	2.85	3.1882 ± 0.0005
Lateral neck – left	5.03	5.06	5.26	4.93	4.04	5.0822 ± 0.0180
Thyroid – left	0.86	1.37	1.21	1.17	0.86	1.2515 ± 0.0072
Thyroid – right	0.90	1.20	1.12	1.03	0.74	1.1149 ± 0.0049
Esophagus	0.94	0.71	0.69	0.66	0.89	0.6883 ± 0.003
Mean	2.37	2.34	2.33	2.30	2.16	2.3235 ± 0.0004

Tab. 2: Dose per scan [mGy]

5. Discussion

Except for the sinus cavity, the measurements show a maximum deviation of 15.5% and demonstrate a good correlation between the doses per scan and those of Ludlow et al.

Doses with large deviations (≥50%) are those of the dosimeters within the thyroid and sinus cavity. The deviation in the thyroid area could be due to vertically incorrect positioning of the phantom since even a slight shift of the phantom moves the thyroid into the radiation range. The dosimeter inside the sinus cavity has a larger deviation of 50% compared to the Orthophos XG and 57% compared to the measurement by Ludlow. This could have been caused by the dosimeter not being fastened in the cavity, and therefore, its position could have changed between measurements.

6. Conclusion

This study has demonstrated that the determined effective doses, according to Scheifele et al., are comparable to those of Ludlow et al. [6] and within an appropriate range (<11% or 7% resp.).

Therefore, we can conclude that the slightly modified measurement method with BeO – OSL dosimeters can be applied for future effective dose measurements.

References

[1] Bundesamt für Strahlenschutz [German Federal Office for Radiation Protection]; https://www.bfs.de/DE/themen/ion/anwendung-medizin/diagnostik/roentgen/haeufigkeit-exposition.html; 02/2021

[2] J.B. Ludlow; The Risks of Radiographic Imaging; Dimensions of Dental Hygiene, June 2012; 10(6): 56, 59-61

[3] D.Regulla, H.Eder, Patient Exposure in Medical X-Ray Imaging in Europe, Radiation Protection Dosimetry (2005), Vol. 114, Nos 1-3.pp.11-25

[4] Bundesamt für Strahlenschutz; pamphlet “Strahlung und Strahlenschutz” [Radiation and Radiation Protection]; April 2019

[5] ICRP 2007; ICRP Publication 103; The 2007 Recommendations of the International Commission on Radiological Protection

[6] J.B. Ludlow; Dosimetry of Orthophos SL CBCT Unit with Low-Dose Protocol; North Carolina Oral Health Institute Nov. 23,2014

Procedural Solutions

Preventive
Restorative
Orthodontics
Endodontics
Implants
Prosthetics

Enabling Technologies

CAD/CAM
Imaging
Treatment Centers
Instruments

Dentsply Sirona

Sirona Dental Systems GmbH
Fabrikstrasse 31. 64625 Bensheim, Germany
dentsplysirona.com

THE DENTAL
SOLUTIONS
COMPANY™

Dentsply Sirona