RESEARCH

Influence of lead apron shielding on absorbed doses from panoramic radiography

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Objectives: This study investigated the absorbed doses in a full anthropomorphic body phantom from two different panoramic radiography devices, performing protocols with and without applying a lead apron.

Methods: A RANDO[®] full body phantom (Alderson Research Laboratories Inc., Stamford, CT) was equipped with 110 thermoluminescent dosimeters at 55 different sites and set up in two different panoramic radiography devices [SCANORA[®] three-dimensional (3D) (SOREDEX, Tuusula, Finland) and ProMax[®] 3D (Planmeca, Helsinki, Finland)] and exposed. Two different protocols were performed in the two devices. The first protocol was performed without any lead shielding, whereas the phantom was equipped with a standard adult lead apron for the second protocol.

Results: A two-tailed paired samples *t*-test for the SCANORA 3D revealed that there is no difference between the protocol using lead apron shielding ($m = 87.99$, $s = 102.98$) and the protocol without shielding ($m = 87.34$, $s = 107.49$), $t(54) = -0.313$, $p > 0.05$. The same test for the ProMax 3D showed that there is also no difference between the protocol using shielding ($m = 106.48$, $s = 117.38$) and the protocol without shielding ($m = 107.75$, $s = 114.36$), $t(54) = 0.938$, $p > 0.05$.

Conclusions: In conclusion, the results of this study showed no statistically significant differences between a panoramic radiography with or without the use of lead apron shielding. *Dentomaxillofacial Radiology* (2013) **42**, 20130302. doi: 10.1259/dmfr.20130302

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Introduction

Widespread and easy to use, panoramic radiography (PR) is still the most important imaging modality in dentistry. It can provide an overview of the jaws, teeth and other tissues in the facial area, making it a popular method worldwide. Although the number of examinations performed is very high, the ratio of the effective dose to the population is very low. Collimation, filtration and more effective image receptors in digital PR devices are technical features that contribute to lowering

the dose required to produce an image. According to the “as low as reasonably achievable” radiation protection principle, the decision to perform radiographs must be evaluated carefully for each patient. After all, “not doing the image” is the best radiation protection. In some countries, the use of lead aprons in dental radiography is popular for historic reasons, despite the questionable effect of the absorbed doses in the human body.

From the beginning, radiation protection research in dentistry was predominantly concentrated in this area. Thermoluminescent dosimeter (TLD)-based simulations and Monte Carlo simulations were performed to

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evaluate the effective dose received by a patient. PR devices were also developed further, improving image quality and dose-information efficiency.

As radiation protection is an important issue, there has been intense discussion about whether a lead apron is needed during a PR. A lead apron positioned on the patient's shoulder does not influence the primary X-ray beam. Furthermore, scattering generally occurs when the photons are already in the patient, mostly because of the Compton effect. In addition, most aprons do not protect the thyroid from radiation exposure. Previous studies have shown that lead apron shielding has only little relevance for the absorbed doses in a patient's torso.¹ The European Academy of DentoMaxilloFacial Radiology supports these results with its recently published Radiation Protection No. 172 guideline.² At the same time, however, there is only little supporting evidence.

The aim of this study was to evaluate possible differences in the absorbed doses in a human full-body phantom using PR (a) with and (b) without lead apron shielding.

Materials and methods

A RANDO[®] full body phantom (Alderson Research Laboratories Inc., Stamford, CT) was equipped with 110 TLDs at 55 different sites. After that, the phantom was set up in two different PR devices and exposed. Two different protocols were performed in the two devices. The first protocol was performed without any lead shielding, while the phantom was equipped with a standard adult lead apron (RD635E; MAVIG GmbH, Munich, Germany) for the second protocol. Subsequent to the exposures, the TLDs were read out and the values obtained were evaluated statistically. All of the exposures, as well as the read out process, took place in the Dental Diagnostic Center, Freiburg, Germany. In this way, it was possible to exclude many influencing factors like transportation, time or mailing of TLD, or at least assume them to the same for all of the protocols performed.

The phantom

A RANDO full body phantom was used to simulate the soft tissues and hard tissues of a human body. The phantom was constructed by using a natural human skeleton embedded in a material that corresponded to soft tissue with a physical density of 0.997 g cm^{-3} .³ The phantom was sliced into 2.5 cm horizontal sections with drilled holes for TLD placement. The sections were numbered from 0 to 35 from head to hip. The fully compounded phantom simulated an average male patient with a height of 175 cm and a weight of 73.5 kg.

The thermoluminescent dosimeter

The absorbed doses were measured using 110 solid TLD-100H chips, $4.5 \times 0.8 \text{ mm}$ in size (Thermo Fisher Scientific, Waltham, MA). The measuring range of the

Table 1 Thermoluminescent dosimeter (TLD) distribution in the phantom

Section	Tissue, area	TLD serial
1	Calvaria, left	1
3	Ethmoidal cells	2
	Midbrain	3
	Lens, left	51
	Lens, right	52
4	Pituitary gland	4
	Orbital cavity, left	5
	Orbital cavity, right	6
5	Cheek, right	53
	Cheek, left	54
6	Mandible, left	7
	Mandible, right	8
7	Submandibular gland, left	9
	Neck, left	10
	Mouth base, central	11
8	Oesophagus, cervical 4	12
9	Thyroid, central	13
	Thyroid, skin surface	55
10	Trachea, cervical 7	14
11	Lymph node, cervical 7	15
12	Oesophagus, cervical 8	16
14	Lung, left	17
	Lung, right	18
	Heart, left	19
	Heart, right	20
15	Breast, left	21
	Breast, right	22
17	Lymph node, thoracic 7	23
18	Spleen, ventral	24
	Spleen, dorsal	25
19	Liver, ventral	26
	Liver, dorsal	27
	Adrenal gland, left	28
	Adrenal gland, right	29
20	Stomach, left	30
	Stomach, right	31
	Kidney, left	32
	Kidney, right	33
	Gall bladder, left	34
	Gall bladder, right	35
21	Colon, left flexure	36
	Colon, right flexure	37
	Pancreas, left	38
	Pancreas, right	39
22	Lymph node, lumbar 2	40
26	Small intestine, left	41
	Small intestine, right	42
29	Ovaries, left	43
	Ovaries, right	44
30	Colon, left	45
	Colon, right	46
32	Bladder, ventral	47
	Bladder, dorsal	48
	Uterus, left	49
	Uterus, right	50
	Reference: TLD	56
		57
		58
		59
		60

TLD was between $1 \mu\text{Gy}$ and 10 Gy with negligible fading. All the TLDs were calibrated using a defined exposure (D_{def}) with $5.05 \times 10^5 \mu\text{Gy}$ at 90 kV. After the

Table 2 Performed protocols

Protocol	Device	Mode	kV	mA	Time (s)	Shielding
1	ProMax® 3D (Planmeca Oy, Helsinki, Finland)	Panoramic mode	68	13	19	None
2	ProMax 3D (Planmeca Oy)	Panoramic mode	68	13	19	Apron
3	SCANORA® 3D (SOREDEX, Tuusula, Finland)	Panoramic mode	73	8	15	None
4	SCANORA 3D (SOREDEX)	Panoramic mode	73	8	15	Apron

readout process, the detected energy (A_{det}) was used to calculate a calibration factor (K):

$$K = \frac{D_{\text{def}}}{A_{\text{det}}} \quad (1)$$

The calculated calibration factors of all available TLD were averaged to $K = 3.73 \times 10^{-2}$ [$n = 120$; standard deviation (SD) = 6.87×10^{-4} ; SD% = 1.84] TLD outside the range of twice the standard deviation were excluded and replaced. Tissues possibly affected by radiation exposure were selected. Table 1 shows the 55 sites of TLD placements in the phantom according to these tissues. Five additional TLD remained unexposed and were kept outside the influence of radiation from the devices to detect background radiation or other influencing factors.

Panoramic radiography devices

Two different PR devices were used in this study to exclude device-dependent factors that influenced the dose distribution: the SCANORA® 3D (SOREDEX, Tuusula, Finland) and the ProMax® 3D (Planmeca, Helsinki, Finland). Table 2 shows the selected exposure parameters and the shielding used. 50 scans per protocol were performed and divided by the number of scans performed to stabilize the absorbed dose values that were measured. Figure 1 shows the phantom with the apron in one of the devices.

Oven and reader

A microprocessor-controlled TLD oven (PTW, Freiburg, Germany) was used to reset and anneal all the TLDs at the same time and in a reproducible procedure. Prior to exposure, all the TLDs were heated to 400 °C and cooled down to 100 °C for 1 h.

After the exposure, they were cooled down to room temperature. The whole procedure took about 5 h. The readout process was performed in a Fimel LTMWin oven (Fimel, Fontenay-aux-Roses, France) with a standard planchet that enables measurements of TLD with 5 mm or less. Each TLD was placed in the oven, and the readout process under nitrogen atmosphere was initialized. The result of the process (digits) was displayed and exported to a .txt file. These digits multiplied by the calibration factor K yielded the absorbed doses for each TLD. The values of the two TLD at each site were averaged, the detected background radiation was subtracted and then divided by the number of the scans performed.

Results

As shown in Tables 3 and 4, no statistically significant difference was found between the two protocols in the two devices evaluated. A two-tailed paired samples *t*-test for the SCANORA 3D revealed that there is no difference between the protocol using shielding (mean = 87.99, STDV = 102.98) and the protocol without shielding (mean = 87.34, SD = 107.49), $t(54) = -0.313$, $p > 0.05$. The same test for the ProMax 3D likewise showed no difference between the protocol using shielding (mean = 106.48, SD = 117.38) and the protocol without shielding (mean = 107.75, SD = 114.36), $t(54) = 0.938$, $p > 0.05$. Another two-tailed paired samples *t*-test also yielded no difference between the two TLDs at each site ($p > 0.05$).

Discussion

TLD-based measurements for evaluating the doses absorbed in a patient during an X-ray examination have been

Figure 1 Phantom with apron set up in the device

Table 3 Absorbed doses for the SCANORA® 3D (SOREDEX, Tuusula, Finland)

<i>Thermoluminescent dosimeter serial</i>	<i>SCANORA 3D with</i>	<i>SCANORA 3D without</i>	<i>Δ (%)</i>
1	130.6	140.1	7.3
2	118.1	114.2	−3.3
3	56.5	62.9	11.3
4	77.1	55.8	−27.6
5	47.6	84.3	77.1
6	107.0	106.1	−0.8
7	247.7	273.9	10.6
8	247.8	266.0	7.3
9	59.2	54.2	−8.4
10	59.6	80.8	35.6
11	382.3	387.8	1.4
12	368.4	362.9	−1.5
13	449.3	472.2	5.1
14	220.4	210.2	−4.6
15	420.1	425.6	1.3
16	93.1	111.2	19.4
17	93.6	85.9	−8.2
18	65.2	75.7	16.1
19	40.1	32.8	−18.2
20	29.2	43.2	47.9
21	5.1	2.3	−54.9
22	36.6	27.4	−25.1
23	45.7	25.9	−43.3
24	8.6	10.3	19.8
25	8.7	14.0	60.9
26	72.7	50.9	−30.0
27	9.7	14.0	44.3
28	33.3	11.2	−66.4
29	57.0	32.9	−42.3
30	27.6	14.9	−46.0
31	29.3	8.6	−70.6
32	34.0	25.6	−24.7
33	34.3	41.6	21.3
34	39.5	47.1	19.2
35	62.1	39.2	−36.9
36	79.7	81.6	2.4
37	42.7	29.9	−30.0
38	23.4	31.0	32.5
39	26.5	20.9	−21.1
40	56.5	54.8	−3.0
41	73.3	80.9	10.4
42	85.4	82.6	−3.3
43	48.5	80.8	66.6
44	54.8	68.4	24.8
45	70.3	27.3	−61.2
46	25.9	29.2	12.7
47	58.3	37.7	−35.3
48	51.3	46.4	−9.6
49	53.8	39.0	−27.5
50	35.9	31.8	−11.4
51	37.4	28.2	−24.6
52	22.0	26.0	18.2
53	49.8	44.3	−11.0
54	52.4	68.7	31.1
55	74.4	82.4	10.8
		Mean	−2.5
		SD	32.2

SD, standard deviation.

performed and described in prior published research.^{4–22} These TLD-based measurements are generally assumed to be accurate in an exactable range, so that they were appropriate for the present research.

The study investigated the doses absorbed in a full anthropomorphic body phantom using two different PR devices, and protocols were performed with and without the use of a lead apron. It was proven that examination protocols using a lead apron did not differ from those without an apron.

Table 4 Absorbed doses for the ProMax® 3D (Planmeca Oy, Helsinki, Finland)

<i>Thermoluminescent dosimeter serial</i>	<i>ProMax 3D with</i>	<i>ProMax 3D without</i>	<i>Δ [%]</i>
1	241.1	244.1	1.2
2	117.4	121.1	3.2
3	189.2	187.0	−1.2
4	147.9	150.6	1.8
5	142.9	147.9	3.5
6	53.9	52.7	−2.2
7	332.8	319.0	−4.1
8	312.2	310.6	−0.5
9	83.8	82.9	−1.1
10	64.9	73.8	13.7
11	380.7	372.1	−2.3
12	363.9	350.7	−3.6
13	450.5	439.8	−2.4
14	291.8	282.8	−3.1
15	411.0	412.4	0.3
16	311.2	311.1	−0.0
17	198.6	204.4	2.9
18	65.5	76.5	16.8
19	48.0	43.7	−9.0
20	75.8	98.1	29.4
21	92.8	84.1	−9.4
22	3.8	7.1	86.8
23	71.2	56.6	−20.5
24	4.2	10.0	138.1
25	6.9	11.7	69.6
26	69.7	96.4	38.3
27	13.2	8.9	−32.6
28	6.6	8.0	21.2
29	86.2	89.4	3.7
30	5.3	15.0	183.0
31	13.2	19.4	47.0
32	94.9	80.8	−14.9
33	81.0	76.2	−5.9
34	95.3	95.2	−0.1
35	98.5	94.1	−4.5
36	73.7	75.2	2.0
37	45.8	47.6	3.9
38	31.0	52.2	68.4
39	45.5	40.2	−11.6
40	12.8	13.0	1.6
41	50.4	69.1	37.1
42	7.8	4.6	−41.0
43	81.2	68.3	−15.9
44	78.2	83.9	7.3
45	13.8	11.0	−20.3
46	6.4	7.9	23.4
47	79.9	61.9	−22.5
48	57.0	81.1	42.3
49	17.3	19.8	14.5
50	85.4	75.6	−11.5
51	8.6	10.7	24.4
52	6.1	5.2	−14.8
53	5.2	10.7	105.8
54	59.2	67.9	14.7
55	65.3	86.3	32.2
		Mean	14.2
		SD	40.0

SD, standard deviation.

The wide ranges of temperature during the annealing and readout process and handling may cause damage to the TLD. The TLDs were checked carefully after each heating process and replaced in the event of possible damage to prevent incorrect values in the readout process.

Lead apron shielding in dental imaging is a subject of controversy, which has been discussed intensively. It is interesting to note that there is no overall agreement on this issue in different countries and that only very little research has been performed in the field of radiation protection by lead apron shielding. The findings of this study support the European Academy of DentoMaxilloFacial Radiology guidelines, which emphasize that there is no evidence supporting the routine use of lead apron shielding.

In earlier research, it was shown that TLD-based measurements are reasonable and accurate in the required range. Furthermore, TLDs are simple to use,

equivalent to tissue and small in size.²³ However, there are some limitations, which should be mentioned: transport times, temperature, air pressure, light and other factors that may influence the outcome of the measurement. Therefore, all the protocols and readouts were performed at one location. This made it possible to achieve constant conditions for all the measurements.

Three TLDs broke during the annealing process and had to be replaced by other calibrated TLDs.

TLD-based dose measurements are time consuming. Therefore, future research should investigate alternatives for calculating the doses received by a patient by other dental X-ray examinations.

In conclusion, the results of this study showed no statistically significant differences between a PR with or without the use of lead apron shielding. As predicted in a review article written by Horner¹ in 1994, abdomen lead shielding has only very little influence, if any, on the doses absorbed during a dental PR.

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