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EFFECTIVENESS OF PROTECTIVE PATIENT EQUIPMENT FOR CT: AN ANTHROPOMORPHIC PHANTOM STUDY

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Protective patient equipment for CT examinations is not routinely provided. The aim of this study was to determine whether, and if so what, specific protective equipment is beneficial during CT scans. The absorbed organ doses and the effective doses for thorax, abdomen/pelvis and brain CT investigation with and without the use of protective patient equipment have been determined and compared. All measurements were carried out on modern multislice CT scanner using an anthropomorphic phantom and thermoluminescence dosemeters. The measurements show that protective equipment reduces the dose within the scattered beam area. The highest organ dose reduction was found in organs that protrude from the trunk like the testes or the female breasts that can largely be covered by the protective equipment. The most reduction of the effective dose was found in the male abdomen/pelvis examination (0.32 mSv), followed by the brain (0.11 mSv) and the thorax (0.06 mSv). It is concluded that the use of protective equipment can reduce the applied dose to the patient.

INTRODUCTION

According to the Radiation Protection Ordinance of 20 January 1998[(1)], every X-ray facility in Switzerland must have the necessary protective equipment. The following equipment is the minimum required to protect patients, staff and third parties:

(1) Full apron/coat apron,
(2) Demi apron,
(3) Testicular and ovarian shields,
(4) Covering materials.

Opinions diverge in certain areas of radiology on whether this equipment should be used to protect patients. In particular, their effectiveness in CT is disputed.

The aim of this study was to determine the dosimetric data needed to evaluate whether, and if so what, specific protective equipment is beneficial. The results provide a basis for giving institutions appropriate advice on matters relating to CT audits.

MATERIALS AND METHODS

Phantom

All measurements were carried out on an anthropomorphic Alderson RANDO phantom, which consists of a human skeleton embedded in plastic that has equivalent radiological properties to human tissues. The lungs are made of a plastic that matches the density of human lungs in the mid-stage of inspiration. The phantom represents the trunk of a standard male patient, without arms or legs, 175 cm tall and weighting 73.5 kg. It can be dismantled into thirty-six 2.5 cm-thick sections numbered from 0 at the cranial end to 35 at the caudal end (Figure 1). The slices contain a grid of pre-drilled holes at intervals of 1.5×1.5 cm into which thermoluminescence dosemeters (TLDs) can be inserted.

The female breast measurements were recorded on a breast phantom. This piece of equipment can be attached to the male Alderson phantom level with slices 15–18 using an adapter. The breast phantom consists of 2.5 cm-thick plastic slices with holes arranged at intervals of 2×2 cm.

Dosimetry

TLD100 thermoluminescence detectors made from LiF and spiked with Mg and Ti were used for the dose measurements. According to the manufacturer, the TLD100 has a measuring range of between 10 μGy and 10 Gy. The square TLDs measure $3.2 \times 3.2 \times 0.9$ mm and fit into the holes of the above-mentioned phantom.

The TLDs were thermally prepared (annealed) in a programmable oven before each exposure to radiation. This involved heating the TLDs at 400°C for 60 min before cooling them to 100°C in a controlled manner following a specified constant gradient. The TLDs were then kept at this temperature for 120 min, after which the oven was switched off and the TLDs were left to cool to room temperature.

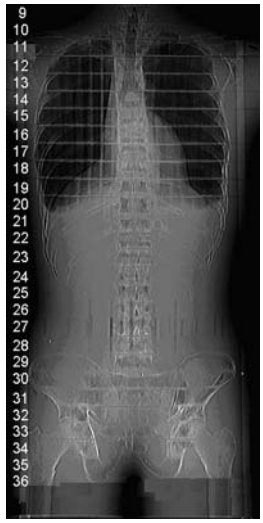

Figure 1. Topogram of the Alderson phantom (without head) with slice numbers.

The TLDs were stored at room temperature for 12 h after each radiation exposure and then heated again for 10 min to 100°C (pre-annealing) before they were evaluated. They were then read out within the following hours. A Harshaw-type 5500 TLD automatic reader was used for this purpose.

The sensitivity factors of the individual TLDs were determined with an Sr90/Y90 irradiator performing 100 rotations. The measured results divided by the mean of all evaluated TLDs were taken as a reference value for the sensitivity of the individual TLDs. This individual sensitivity was factored into the dose calculation.

The radiation quality-dependent calibration factors were determined on a radiotherapy unit at a tube voltage of 125 kV and filtration of 2.5 mmAl + 0.1 mmCu. This filtration closely approximates to that of CT scanners. A Farmer chamber (PTW Fribourg, TM30013) calibrated by the Institut Universitaire de Radiophysique Appliquée (calibration agency for radiation protection measuring devices authorised by the Swiss Confederation) served as the reference system. The calibration measurements were carried out on a Perspex phantom. The calibration factors were determined within the primary beam field at depths of 0.7, 2.7, 5.7, 10.7 and 20.7 cm. Calibration in the scattered beam area was carried out at a depth of 7 cm and at intervals of 2.5, 5, 10 and 20 cm from the edge of the primary beam. Reproducibility was between 3 and 5 %.

The glow curves resulting from the read-outs were subjected to visual spot checks so as to rule out any system errors in the evaluation.

In all evaluations, a number of TLDs that had not been exposed to radiation were read in order to determine background radiation. This was then deducted from each of the measured results.

Protective equipment

The protective equipment listed in Table 1 was used for the individual investigations. For the thorax investigation, the demi apron was wrapped around the phantom's trunk caudal to the primary beam and for the abdomen/pelvis cranial to the primary beam. The coat apron used for the brain investigation covered the complete trunk of the phantom all around.

A gap between the primary beam window and the protective equipment (edge of the lead) of 1 1/2 or 2 phantom slices (3.75 or 5 cm) was selected for the thoracic investigations, a gap of 5 cm for the pelvic/abdomen investigations and, for the brain investigations, a gap of 3.75 cm between the field edge at the level of the mastoid process and the upper edge of the thyroid protector. The exact location of the protection with respect to the slice numbers are listed in Table 2.

The items of protective equipment used were scanned manually for damage and breaks and examined visually with the aid of a CT scan to ensure correct functioning.

CT scanners and investigations

The measurements were carried out on two different Siemens CT scanners: a Siemens Somatom Sensation Cardiac 64 (64 slices) and a Siemens Somatom Sensation 16 (16 slices). Both are latest-generation multislice spiral CT scanners.

The investigations were selected on the basis of the list published[2], which lists the most frequent CT investigations/issues for adults and the five most frequent ones for children. The following three investigations were selected from this list in view of their clinical relevance: Cranial/brain (no. 1), thorax (vessels) (no. 9) and abdomen/pelvis (no. 13).

The thoracic, abdominal/pelvic and brain investigations were all conducted on the 64-slice CT scanner. A further thoracic investigation was carried out with the 16-slice CT scanner.

In addition to a general overview scan (topogram), several (5 or 10) series of tomographies were recorded for each investigation. This procedure had the advantage of accumulating higher doses at the measuring sites, thereby increasing the measuring accuracy. In addition, geometry-dependent phenomena such as the start point of the X-ray tube were also flattened. For the purpose of the analyses, measurements were taken for each investigation with and without protective equipment. All measurements were taken at the same exposure settings.

Table 1. Overview of protective equipment used.

Protective equipment	Lead equivalent (mm)	Thorax	Abdomen/pelvis	Brain
Wrap-around demi apron	0.5	×	×	
Coat apron	0.5			×
Thyroid protector	0.5		×	×
Testicular capsules	1		×[a]	

[a]For technical reasons the testicular capsules were not used, but the results from ref. (7) were applied to the measured results.

Table 2. Overview of investigations and exposure settings.

	Investigation/settings			
	Thorax 64S[a]	Thorax 16S	Abdomen/pelvis 64S	Brain 64S
Tube voltage	120 kV	120 kV	120 kV	120 kV
Tube current	103/112[b] mAs	100 mAs	165 mAs	380 mAs
Pitch	1.15	1.15	1.15	—
Rotation time	0.5 s	0.5 s	0.5 s	1 s
Collimation	24×1.2 mm	16×1.5 mm	24×1.2 mm	24×1.2 mm
Tube current modulation	Yes	No	No	No
Series of tomographies	5	10	10	10
$CTDI_{vol}$	7.01/7.95 mGy	7 mGy	11.11 mGy	51.93 mGy
DLP	292/317 mGy cm	299 mGy cm	472 mGy cm	753 mGy cm
Recording length	37 cm	37 cm	37 cm	14 cm
Primary beam area	Slice no.10–middle no. 24	Slice no.10–no. 24	Slice no. 20/23–no. 34[c]	Slice no. 0–middle no. 5[d]
Position of protective equipment	Slice no. 26–no. 35	Slice no. 27–no. 35	Slice no. 8–no. 17	Slice no. 8–no. 35
Gap between edge of primary beam and edge of protective equipment	3.75 cm	5 cm	5 cm	1.25–7.5 cm[e]

[a]Refers to the number of slices (64S or 16S) of the scanner type.
[b]Differing effective mAs for the investigations with and without protective equipment are caused by the tube current modulation. This also results in the differing $CTDI_{vol}$ and DLP figures.
[c]A separate measurement of the female breast was carried out with the same exposure settings. However, the recording window only extended from slice nos. 23–34. This allowed a gap of 5 cm to be maintained between the lower breast line and the edge of the primary beam, and the breast was completely covered by the protective equipment.
[d]With 11.5° inclination.
[e]Differing gaps because the doses were recorded with an inclined gantry.

In order to obtain measurements that matched practical conditions as closely as possible, the exposure settings (Table 2) were derived from the results of previous CT audits conducted and evaluated by the Federal Office of Public Health. The means of the recorded settings were used

Automatic tube current modulation

The automatic tube current modulation option (known as 'Care Dose' on Siemens scanners) was used for the first measurements (thoracic investigation with 64-slice CT), in line with standard practice. However, this resulted in a deviation of 8 % in the effective tube current for the two investigations with and without protective equipment (103 mAs without and 112 mAs with protective equipment). The automatic tube current modulation was switched off for the remaining measurements in order to improve comparability. This is the standard procedure in any case for brain investigations.

Measuring points

Within each phantom slice, the dose was measured at the centre and at four peripheral measuring points

(two ventral and two dorsal; Figure 2). Wherever possible the measuring points were selected along the body axis (z-axis) at the same position in all slices.

A deviation from this procedure was made for certain specific slices, e.g. at the level of the thyroid. Since few holes were available, representative measuring points were selected within the relevant organs. Where slices contained organs of special interest, e.g. at the ovary level, additional points were measured within these organs. To measure the dose received by the testes, four TLDs were placed on the inner aspect of each thigh.

The slices in the middle and at the edge of the primary beam field were taken into account when the measurement planes were selected. In the scattered beam area, measurements were recorded in several successive slices adjacent to the primary beam field. Thereafter, they were recorded in every other slice, and the missing values were determined by linear interpolation. This procedure yielded a total of between 40 and 60 measuring points per investigation.

Plastic pins with notches were used to position two TLDs in holes in the phantom slice at each measuring point. Superficial doses were measured by placing the TLDs in small plastic bags and securing them to the phantom with adhesive tape.

Positions of the organs in the phantom

The vertebral body in each slice was identified on the basis of a CT scan of the Alderson phantom. Since one-to-one allocation was not always possible, several vertebral bodies or just parts of one vertebral body were allocated to one slice, e.g. slice no. 22 contains a quarter of thoracic vertebral body T11 and a third of T12.

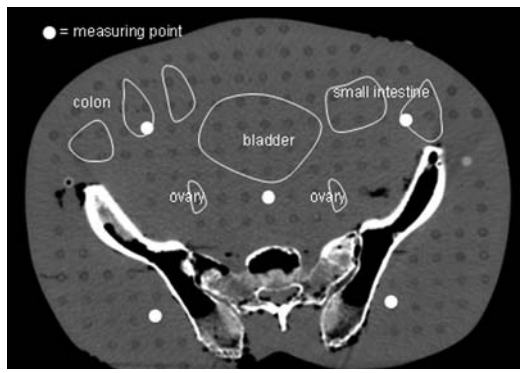

Figure 2. CT tomogram with organs and measuring points drawn in.

After the vertebral bodies were identified, the organ masses were allocated to the slices on a pro rata basis using the procedure described in ref. (3), e.g. 25 % of the liver is located at the level of T11 and 17 % at T12. Accordingly, slice no. 22 contains 11.92 % of the liver.

The positions of the organs within a slice were drawn with the aid of an anatomical atlas[4] and the specimens in the anatomical collection of the University of Zurich. They were then verified by an experienced radiologist (see Figure 2 for an example).

A position indicator was then assigned to each organ, i.e. c for organs in a primarily central location and p for organs that were represented primarily by the peripheral measuring points. The central organs (c) were the ovaries, bladder, oesophagus and red bone marrow. All other organs were assigned the peripheral position indicator (p).

The dose for the organs skin, bone surface and 'remainder' (other organs) was calculated on the basis of the distribution across phantom slices described in ref. (5). Uniform distribution across slices 3–9 was assumed for the salivary glands and across slices 0–6 for the brain.

Standardisation of the absorbed dose

Since the average absorbed dose in the primary beam area was not always the same (even after the automatic tube current modulation had been switched off) when measurements were taken with and without protective equipment—despite the fact that the investigations were identical, the exposure settings were the same and the phantom was always in the same position—the doses measured with and without the protective equipment were converted to the same primary beam field reference dose for ease of comparison.

Calculation of the organ dose

First the resulting absorbed dose per measuring point was determined for all investigations. This was then divided by the number of acquired tomography series in the investigation. The dose proportions in the topogram accounted for by these doses were accordingly assigned to the individual series of tomographies.

In order to calculate the organ dose (equivalent dose in an organ), for each slice the mean of the peripheral measuring points ($\bar{M}_p$) or the mean of the central measuring points ($\bar{M}_c$)—depending on the position indicator of an organ in each slice—was weighted with the relative organ mass f_i of the slice i as a proportion of the total organ, and multiplied by the beam-weighting factor w_R for photons (=1) according to ICRP 103[6]. The means of slices with

no measuring points were determined by interpolation from adjacent slices as follows:

$$\overline{H}_{\text{organ slice } i} = \bar{M}_{i,j} \cdot f_i \cdot w_R, \quad \text{where } j = p \text{ or } c.$$

The mean organ dose was calculated by adding together the weighted dose proportions per slice for each organ as follows:

$$\overline{H}_{\text{organ}} = \sum_{\text{slice } i} \overline{H}_{\text{organ slice } i}$$

The mean organ dose in the scattered beam area was calculated by considering the proportions of the organs located outside the primary beam field and covered by the protective equipment separately. For the purposes of this calculation, the proportion of the mass of the organ parts covered by protection was assumed to be 100 %.

$$\overline{H}_{\text{organ scattered radiation}} = \sum_{\text{slices}s} \overline{M}_{s,j} \cdot f_s \cdot w_R,$$

where $s =$ slice in protective equipment area

and $j = p$ or c.

Protection factors

Two different protection factors were introduced. The physical protection factor describes the protective effect at the individual measuring points as a function of their position within the phantom slice and as a function of the distance from the primary beam field. It is calculated as follows from the means of the measuring points in a slice i in the scattered beam area:

$$\text{PF}_{\text{phys } i,j} = 1 - \frac{\bar{M}_{i,j \text{ with protective equipment}}}{\bar{M}_{i,j \text{ without protective equipment}}},$$

where $j = p$ or c.

The protective effect for the organs is described by the organ-specific protection factor. This refers exclusively to the proportions of organs that are within the scattered beam area and covered by the protective equipment. This effect is expressed as a percentage as follows:

$$\text{PF}_{\text{organ}} = 1 - \frac{\overline{H}_{\text{organ scattered radiation, with protective equipment}}}{\overline{H}_{\text{organ scattered radiation, without protective equipment}}} \cdot 100\,\%.$$

RESULTS

Within the scattered beam area, the measurements from all the investigations show that protective equipment reduces the overall dose. This applies at measuring points on the periphery of the slices as well as at the centrally located measuring points.

In the thoracic investigations performed with the 64-slice CT, there was a statistically significant dose difference ($p < 0.001$) in the means of the recorded measuring points within a slice only from a distance of 5 cm from the edge of the protective equipment (edge of the lead). In the 16-slice CT for the thoracic investigation a statistically significant difference was perceptible from a distance of 2.5 cm from the edge of the lead ($p < 0.001$) and for the abdominal/pelvic investigation from a distance of 7.5 cm ($p < 0.001$), whereas the differences for the brain investigation were apparent right from the edge of the lead.

Physical protection factors

The protective equipment's ability to reduce the dose in the phantom during the investigations is illustrated in Figure 3, which shows the physical protection factor as a function of distance from the edge of the lead.

The physical protection factor tends to be greater at the periphery than at the centre and grows as the measuring points' distance from the edge of the lead increases.

Organ-related results

Table 3 provides an overview of the position of the organs in relation to the primary and scattered beam areas. The measured mean equivalent dose in the primary beam area is shown in Table 4 and was calculated from the means of all measuring points of the layers at the centre and at the edge of the primary beam field. Table 5 illustrates the effect of the protective equipment on the organs/organ parts within the scattered beam area during the various investigations. Only those parts of the organs covered by the protective equipment are taken into account. The absolute reduction in the mean organ dose as a result of using protective equipment is shown in Table 6.

DISCUSSION

The aim of this study was to determine the dosimetric data needed to evaluate whether, and if so what, specific protective equipment is beneficial during CT scans.

CT scans generate not only the primary radiation that is essential for image acquisition, but also the

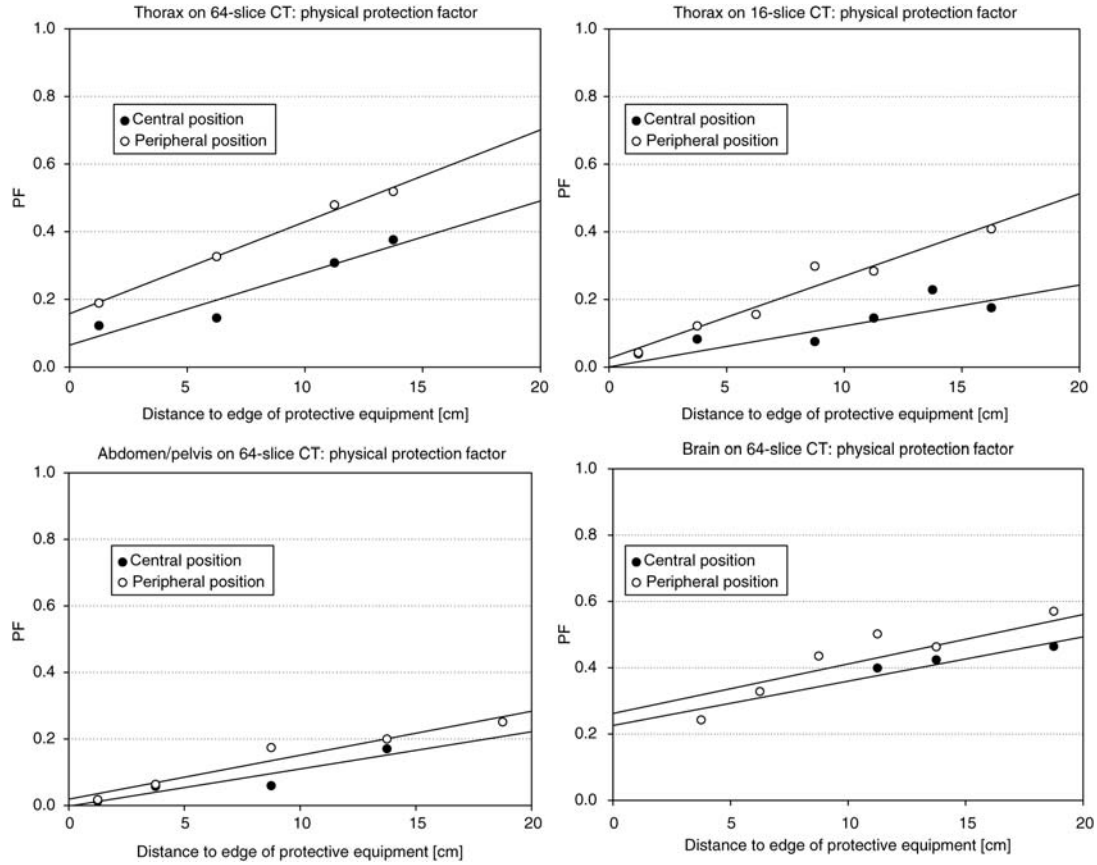

Figure 3. Physical protection factors in the scattered beam area.

Table 3. Overview of organ distribution across primary and scattered beam areas.

Organ	Organ proportion in primary beam area/organ proportion in scattered beam area (total of 1)			
	Thorax 64S	Thorax 16S	Abdomen/pelvis 64S	Brain 64S
Thyroid	1/0	1/0	0/1	0/1
Breast female	1/0	1/0	0/1	0/1
Breast male	1/0	1/0	0/1	0/1
Oesophagus	1/0	1/0	0.15/0.85	0/1
Lung	1/0	1/0	0.15/0.85	0/1
Stomach	1/0	1/0	0.65/0.35	0/1
Liver	0.93/0.07	0.97/0.03	0.82/0.18	0/1
Kidney	0.25/0.75	0.4/0.6	1/0	0/1
Colon	0.075/0.925	0.09/0.91	1/0	0/1
Small intestine	0.02/0.98	0.03/0.97	1/0	0/1
Ovaries	0/1	0/1	1/0	0/1
Bladder	0/1	0/1	1/0	0/1
Testes	0/1	0/1	0/1	0/1
Red bone marrow	0.465/0.535	0.48/0.52	0.61/0.39	0.09/0.91

scattered radiation that represents additional absorbed dose load for the body. This scattered radiation can be subdivided into two categories. The first is the internal scattered radiation, which is generated as a result of interactions between photons and electrons along the body's axis. The second is the external scattered radiation, which is generated by so-called overranging and by leakage of radiation from the scanner. Overranging is the term applied to the additional rotations beyond the start and end of the imaged volume that are required to reconstruct the tomogram. Radiation leakage refers to the radiation that escapes from the tube housing. Superficial protective equipment had no effect either on the dose caused by the primary beam or on the internal scattered radiation. However, it is capable of protecting the body from the external scattered radiation to a large extent.

Table 4. Mean equivalent dose in the primary beam area.

Thorax 64S	Thorax 16S	Abdomen/pelvis 64S	Brain 64S
9.03 mSv	10.88 mSv	20 mSv	47.96 mSv

Several aspects need to be considered when evaluating the effectiveness of protective equipment. One of the criteria employed was the ability of the

Table 5. Overview of organ-specific protection factors in the scattered beam area.

Organs	Mean organ dose[a] in the scattered beam area without protective equipment (mSv)	Mean organ dose in the scattered beam area with protective equipment (mSv)	PF_{organ} (%)
Thorax on 64-slice CT			
Kidney	1.40	1.10	22
Colon	0.77	0.56	27
Small intestine	0.45	0.29	35
Ovaries	0.14	0.09	40
Bladder	0.12	0.07	41
Testes	0.05	<0.01	93
Red bone marrow	0.44	0.33	25
Thorax on 16-slice CT			
Kidney	1.74	1.67	4
Colon	0.80	0.71	11
Small intestine	0.56	0.47	18
Ovaries	0.21	0.17	19
Bladder	0.17	0.14	18
Testes	0.06	0.01	76
Red bone marrow	1.52	1.44	5
Abdomen/pelvis on 64-slice CT			
Thyroid	0.25	0.19	25
Breast female[b]	0.45	0.21	53
Breast male	2.62	2.48	5
Oesophagus	1.38	1.28	7
Lung	1.74	1.59	9
Testes	4.55	0.82[c]	82[d]
Red bone marrow	1.22	1.13	8
Brain on 64-slice CT			
Thyroid	1.34	0.90	33
Breast female	0.25	0.02	91
Breast male	0.26	0.10	61
Oesophagus	0.43	0.24	44
Lung	0.32	0.15	54
Stomach	0.09	0.03	71
Liver	0.03	0.02	73
Kidney	0.03	<0.01	84
Colon	0.02	<0.01	84
Red bone marrow	0.25	0.16	36

[a]Organ mass proportions in the protective equipment area=100 %.
[b]Calculated from a separate measurement; see also Table 2.
[c]Calculated with protection factor for testicular capsules from ref. (7).
[d]Protection factor for testicular capsules from ref. (7).

Table 6. Absolute organ dose reduction in the scattered beam area.

Organ	Dose reduction (mSv)			
	Thorax 64S	Thorax 16S	Abdomen/pelvis 64S	Brain 64S
Thyroid	—	—	0.06	0.44
Breast female	—	—	0.24[a]	0.22
Breast male	—	—	0.14	0.16
Oesophagus	—	—	0.10	0.19
Lung	—	—	0.15	0.17
Stomach	—	—	—	0.06
Liver	—	—	—	0.06
Kidney	0.30	0.07	—	0.02
Colon	0.20	0.09	—	0.01
Small intestine	0.16	0.1	—	<0.01
Ovaries	0.06	0.04	—	<0.01
Bladder	0.05	0.03	—	<0.01
Testes	0.05	0.05	3.73[b]	<0.01
Red bone marrow	0.11	0.08	0.09	0.09

[a]Calculated from a separate measurement; see also Table 2.
[b]Calculated with the protection factor for testicular capsules from ref. (7).

Table 7. Overview of effective doses.

Investigation	Effective dose without protective equipment (mSv)	Effective dose with protective equipment (mSv)	Dose reduction (mSv)
Abdomen/pelvis male	11.40	11.08	0.32
Abdomen/pelvis female	12.31	12.27	0.04
Brain	1.91	1.81	0.11
Thorax	5.61	5.55	0.06

protective equipment to reduce the dose at a defined point in the scattered beam area. The physical protection factor was introduced for this purpose. It depends on the exposure parameters and on the gap between the edge of the primary beam field and the protective equipment (edge of the lead) and varies according to the location of the respective measuring point. Furthermore, organ size and position have a significant impact on efforts to evaluate the protective effect for individual organs. The organ-specific protection factor was defined for this purpose. Finally, if one wants to quantitatively compare the efficiency of protective equipment with other types of radiation exposure in radiology, it is not sufficient to simply consider the relative dose reduction. For this reason, absolute dose reduction values were also determined in this study, i.e. the mean organ dose and the effective dose according to ICRP 103[(6)], which takes into account the different radiation sensitivities of the organs (Table 7).

These results show that using protective equipment reduces radiation doses. In the interests of efficient protection, it is obviously crucially important for the protective equipment to be positioned as close as possible to the primary beam field. The measurements show that the dose can be reduced to a lesser extent at the centre of the body than at the periphery, i.e. those organs that are closer to the surface, e.g. the thyroid, breasts or kidneys, benefit more from the use of the protective equipment than central organs such as the bladder or ovaries. This is explained by the fact that the external scattered radiation that the protective equipment can reduce is largely absorbed as it penetrates the body and thus contributes less to the dose at the centre of the body than at peripherally located points. The protection factors also increase with the distance of the measuring points to the primary beam. This suggests that the internal scattered radiation along the body's axis declines faster than the external scattered radiation in the air. Thus, the organs that can best be protected are those located far from the primary beam field, that tend to lie near the surface and/or that protrude from the trunk and thus present a smaller area of contact for the internal radiation to penetrate. The surface of such protruding organs can largely be covered by the protective equipment, which will increase the protective effect. This particularly applies to the testes, which can be almost entirely protected by testicular capsules, and to the female breasts, which can be covered by a wrap-around demi apron.

The observed protection factors differ from one investigation to another performed on the same CT scanner. Lower protection factors were found during the abdominal/pelvic investigation than during the other investigations. This is because the internal scattered radiation is absorbed to a lesser extent by the lungs than by the other soft tissues involved in the other investigations by virtue of the lower density of the lungs. The radiation thus penetrates further along the body's axis than during the other investigations. In this investigation therefore, the internal scattered radiation makes a greater contribution to the dose received by organs located further away from the primary beam. In brain investigations, the geometry of the body has a positive effect on the protection factors; the neck has a reduced contact area for the internal scattered radiation to penetrate. Covering the shoulders with protective equipment can also reduce exposure to radiation emerging from the head.

The two thoracic investigations with the 64- and 16-slice CT showed differing protection factors. The lower protection factors with the 16-slice CT are

very probably attributable to the lower radiation leakage from this scanner.

Protective equipment proved most effective when applied to the testes in the form of testicular capsules (results of the measurements from ref. (7–9)). The protection factor here is between 77 and 95 %. The dose reduction is particularly impressive when testicular capsules are used for abdominal/pelvic investigations, because the primary beam passes very close to the testes, and protection may even be provided for part of the dose caused by overranging. This study also found noteworthy dose reductions for the thyroid during the brain investigation (33 %) and the female breast during the brain and abdominal/pelvic investigations (91 and 53 %, respectively). This is relevant particularly because breast protection is rarely provided as a matter of routine in Switzerland. Furthermore, thyroid protectors on patients are only used routinely in isolated cases.

The effective dose for the individual investigations was determined from the measurements. According to ICRP 103[6], this is a suitable parameter for the quantitative comparison of differing diagnostic investigations. The overview in Table 7 shows that the greatest reduction in the effective dose was achieved in the abdominal/pelvic investigation of men, primarily as a result of the protective effect of the testicular capsules. For women, the reduction largely arises as a result of protecting the breasts. During the brain investigation, over half the reduction in the effective dose was achieved by protecting the breasts, lungs and thyroid. For the thoracic investigation, around half of the dose reduction was achieved by protecting the colon.

The relative reduction in the effective dose was very low, amounting to 3 % for male and <1 % for female abdominal/pelvic investigation. The corresponding figures for the brain and thoracic investigations were 5 and 1 %, respectively. The greatest contributions to the effective dose obviously stemmed from the dose generated directly by the primary beam.

However, if the effective dose of a chest X-ray (PA) of 0.06 mSv[10] is taken as a benchmark, the use of protective equipment during abdominal/pelvic CT scans produces, on an average by gender, an absolute dose reduction approximately equivalent to the dose exposure of three chest X-rays. For male patients, a reduction of five chest X-ray equivalents can be assumed and for female patients of less than one chest X-ray; the corresponding reductions for brain and thoracic CT scans are two chest X-rays and one chest X-ray, respectively. This should be taken into account when the effectiveness of protective equipment for CT is evaluated. Of course all other efforts to reduce the dose must be maintained and constantly improved.

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