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Use of patient radiation protection equipment in the diagnostic application of X-rays on humans

Recommendation by the
German Commission on Radiological Protection

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Empfehlung der Strahlenschutzkommission und wissenschaftliche Begründung

Content

1 Introduction 2

2 Recommendations 2

3 Technical basics, present recommendations, and legal regulations 5

4 Justification for the use of patient radiation protection equipment in more frequently performed CT examination types 7

4.1 CT examination of the cranium (CCT) 7

4.2 CT examination of the paranasal sinuses and the visceral cranium 8

4.3 CT examination of the thorax and thoracic spine 8

4.4 CT examination of the pelvis/abdomen 9

5 Justification for the use of patient radiation protection equipment in more frequently performed projection types 9

5.1 Radiography of the head 9

5.2 Radiography of the thorax 9

5.3 Radiography of the lumbar spine 10

5.4 Radiography of the pelvis and the hip joint 10

5.5 Radiography of the abdomen 10

5.6 Radiography of the extremities 10

5.7 Radiography of the shoulder or the clavicle 11

5.8 Mammography 11

5.9 Radiography in dentistry 11

6 References 12

1 Introduction

By far the largest part of the civilizational radiation exposure of the German population is caused by X-ray procedures. A reduction of the radiation exposure of the patient, especially next to the examined body areas, can be achieved, among other things, by the proper use of patient radiation protection equipment.

On the other hand, the excessive use of efficient protective products without reasonable radiation exposure reduction or the incorrect use of protective equipment can reduce the acceptance of both the medical personnel involved in the application and the patients and thus counteract optimal radiation protection.

Therefore, in a consultation request to the Commission on Radiological Protection (SSK; Strahlenschutzkommission), the Federal Environment Ministry has asked for a recommendation as to which patient radiation protection equipment should be used for the various procedures used in X-ray diagnostics. The benchmark for the reasonable use should be whether it is possible to reduce radiation exposure with adequate effort, taking into account the state of the art. In particular, the recommendation should take into account the specificities of the various X-ray examination techniques (e. g. computed tomography, dental procedures, and radiological interventions), the body parts examined, and the particular protection needs of certain patient groups (e. g. persons under 18 years of age or pregnant women). The evaluation of patient radiation protection equipment should also take into account the respective effort involved in their use.

For dose reduction when using X-rays in image-guided radiotherapy, the recommendation of the SSK on radiation hygiene requirements for image-guided radiotherapy (IGRT) (SSK 2010) must be taken into account.

2 Recommendations

The Commission on Radiological Protection recommends

- using patient radiation protection equipment in accordance with Table 1
- not using patient radiation protection equipment in the beam path during fluoroscopy
- clarifying the use of the patient radiation protection equipment with a medical physics expert on site and within the scope of the work instructions in order to optimise (where possible) the implementation of the procedure in such a way that (where appropriate) the use of patient radiation protection equipment can be dispensed with
- using patient radiation protection equipment in particular for dose-intensive radiological and cardiological interventions. The explanations on the individual examination procedures contain information on the use of patient radiation protection equipment; these can be transferred to the interventions. In any case, optimising the radiation exposure during the examination is important and necessary
- to use patient radiation protection equipment in all examinations if the patient expressly requests this but only if this is not associated with disadvantages for the examination and is clinically applicable
- to take into account the higher risk associated with exposure to radiation in individuals under 18 years of age and pregnant women (e. g. by using patient radiation protection equipment to cover the abdomen during CT examination of the thorax)

– to follow the recommendations of the respective CT manufacturer when using patient radiation protection equipment in the examination area or in the immediate vicinity in CT examinations

Tab. 1: Application of patient radiation protection equipment in various types of examinations and the achievable dose reduction.[1]

Examination type	Patient radiation protection equipment	Possible dose reduction (organ-equivalent dose)
Computed tomography		
CT of cranium (CCT [a)])	Eye lens protection when the eyes are in the direct radiation field	Eye lens: approx. 20 mSv (Bulla et al. 2012, Keil et al. 2008)
	Thyroid protection	Thyroid: approx. 0.5 mSv (Beaconsfield et al. 1998, Ngaile et al.2008)
	Breast protection (covering the breast in female patients)	Breast: approx. 0.15 mSv (Beaconsfield et al. 1998, Ngaile et al. 2008)
CT of paranasal sinuses [b)]/ visceral cranium CBCT [c)] paranasal sinuses	Thyroid protection	Thyroid: approx. 0.6 mSv (Goren et al. 2013)
	Eye lens protection when the eyes are in the direct radiation field	Eye lens: approx. 20 mSv
CT of thorax	Thyroid protection (not for paediatric examinations)	Thyroid: approx. 2.5 mSv (Buchgeister et al. 2012)
	Lead shield around the abdomen in pregnant women	Uterus: approx. 0.02 mSv (Danova et al. 2010, Iball und Brettle 2011)
CT of pelvis/abdomen	Males: Testicle pouch if artefacts are not disturbing	Gonads: approx. 1 mSv (Price et al. 1999, Hohl et al. 2005, Hidajat et al. 1996, Dauer et al. 2007) in the direct radiation field > 1 mSv (Price et al. 1999, Hohl et al. 2005, Hidajat et al. 1996, Dauer et al. 2007)
CBCT in dentistry	No protection necessary	Thyroid: < 0.02 mSv (Rottke et al. 2013a, Rottke et al. 2013b)
Projection images		
Head	No protection necessary	Thyroid: approx. 0.01 mSv (Calculation with XL dose with data from (Drexler et al 1993))
Shoulder	No protection necessary	no reliable data available

[1] Because the dose reduction strongly depends on the examination device, the examination technique, and the situation, the application of the radiation protection equipment should be clarified on site with a medical physics expert.

Examination type	Patient radiation protection equipment	Possible dose reduction (organ-equivalent dose)
Thorax a.p./p.a. [d] and laterally	No protection necessary	Testes: approx. 0.0002 mSv (Roth et al. 2001, Njeh et al. 1996) Ovaries: approx. 0.00002 mSv (Roth et al. 2001, Njeh et al. 1996)
Thoracic and lumbar spine	No protection necessary	no reliable data available
Pelvis and hip joint	Males: Testicle pouch, possible only if artefacts in images are acceptable Females: Ovarian coverage Children: if possible	Testes: in direct beam approx. 0.8 mSv, otherwise approx. 0.08 mSv Ovaries: approx. 0.150 mSv (Doolan 2004, Franzen 2004, ICRP 2013, Liu et al. 2008, Clancy et al. 2010)
Abdomen	No protection necessary	Breast: approx. 0.08 mSv (Mekis et al. 2013, Liu et al. 2008) Testes: approx. 0.08 mSv (Roth et al. 2001, Njeh et al. 1996)
Extremities	No protection necessary	no reliable data available
Mammography	No protection necessary	Thyroid: approx. 0.001 mSv (Sechopoulos und Hendrick 2013, Sechopoulos 2008) Contralateral breast: approx. 0.02 mSv (Sechopoulos 2008)
Dentistry	No protection necessary	Thyroid: < 0.01 mSv (Rottke et al. 013a, Rottke et al. 2013b)

a) cranial computed tomography (CCT)
b) Paranasal sinuses
c) cone beam computed tomography (CBCT)
d) anterior posterior (a. p.) / posterior anterior (p. a.)

3 Technical basics, present recommendations, and legal regulations

In radiation protection, the radiation exposure caused by an X-ray examination must be restricted to the extent compatible with the requirements of medical science. In particular, areas of the body that do not have to be exposed to the useful radiation during the intended application of X-ray radiation must be protected as far as possible from radiation exposure. This can be clearly supported by the sensible use of patient radiation protection equipment. In addition to covering radiation-sensitive organs in the primary beam path, it can also be useful to cover adjacent areas to protect them from interference radiation (scattered radiation and extrafocal radiation).

In addition to good positioning (which can also influence the choice of patient radiation protection equipment), the fixation of non-cooperating patients, and the fine-tuning, correct object- and question-related masking in projection radiography is of the utmost importance. This is particularly important for children (in accordance with this recommendation, children are persons under 18 years of age with age-appropriate weight) because the percentage field size increase is higher the smaller the initial format – especially in neonatal radiology. The masking must be visible on the image. Additional lead covering (e. g. gonad aprons, lead rubber mats, or radiation protection aprons) of the sections of the body trunk adjacent to the edge of the radiation field is particularly important for children and younger patients. In male patients, after the testicles have descended, a testicle pouch must be used in all radiographic examinations, including computed tomography of the abdomen, urinary tract, gastrointestinal tract, pelvis, and lumbar spine insofar as they do not lead to interfering artefacts or overlapping of the exposure measuring chamber (see also guideline of the BÄK 2007).

In female patients, the use of ovarian protection must always be required for examinations in which the ovaries lie in the path of radiation insofar as this does not significantly limit the information content of the examination or the likelihood of repeat imaging is not significantly increased. Whenever possible, the dorsoventral radiation path should be chosen for female patients when imaging the thoracic region and the abdomen in the left lateral position because of the radiation-sensitive mammary tissue (BÄK 2007).

In paediatrics, special attention must be paid to the exact masking of the useful radiation field with recognisable field boundaries and lead coverage of the adjacent trunk sections and gonads (BÄK 2007).

In pregnant women, the risk associated with radiation exposure for the unborn child must be taken into account (e. g. through the use of patient radiation protection equipment in CT examination of the thorax because the uterine dose of the pregnant woman is assumed to be the body dose of the unborn child).

When using patient radiation protection equipment, the position of the patient (e. g. standing or lying) should be taken into account.

Some computer tomography scanners use the overview radiogram (called differently depending on the manufacturer of the CT system e. g. Scout, Topogram, Scanogramm) to determine the attenuation by the patient and to control the tube current. In an overview radiogram with patient radiation protection equipment in the relevant area, this can lead to higher tube currents and associated higher exposures for some devices. Depending on the CT device, it may make sense to apply the patient radiation protection equipment only after the examination has been planned by an overview radiogram. A change in the patient’s position may have to be accepted. The resulting disadvantages must be weighed against the benefits of using the patient radiation protection equipment.

In computer tomography, depending on the device used, it may be advisable to avoid the topogram in the a. p. direction if possible, in order to expose the radiation-sensitive organs (eye lens, thyroid gland, mamma) to a lower radiation dose (SSK 2011).

For interventional examinations, it must be checked in advance whether the patient's radiation protection equipment is located in the path of radiation and, as a result, could cause an increase in the patient’s dose as a result of automatic dose rate control. Thus, the positioning of patient radiation protection equipment in the beam path must be avoided or, if this is not possible, at least the automatic dose rate control must be switched off.

Information on the requirements for patient radiation protection equipment can be found in the standards. Qualified patient radiation protection equipment must meet the requirements of DIN EN 61331-1:2016-09 (Determination of attenuation properties of materials) and DIN EN 61331-3:2016-09 (Protective clothing, eyewear and protective patient shields). The above standards take into account the use of lead-reduced or lead-free protective clothing. Lead-free radiation protection equipment is divided into four protection classes for which the protective effect corresponds to lead rubber clothing from 0.25 mm to 1.0 mm. Unless otherwise stated, these apply to 60 kV to 150 kV. In the case of gonad aprons, a lead equivalent value of at least 0.5 mm is required to be regarded as a cover outside the useful beam field. In the case of testicle pouches/ovary protection, a lead equivalent value of at least 1 mm is required to be regarded as a cover in the useful beam field.

Not all lead covers are currently available in the most suitable form (e. g. 120 cm × 30 cm lead blankets with 0.5 mm lead equivalent value for CT examinations as all-round protection in the scan area of adjacent areas). Manufacturers are encouraged to provide such lead covers.

In addition to the protective effect of the patient radiation protection equipment, consideration must also be given to how their use is to be taken into account in the work flow and which hygienic requirements are to be observed.

It is the responsibility of the radiation protection officer(s), the qualified physician(s), and the technical user(s) to keep the dose to the patient as low as possible. Because the dose reduction strongly depends on the examination device, the examination technique, and the situation, the application of the patient radiation protection equipment should be coordinated on site with a medical physics expert.

4 Justification for the use of patient radiation protection equipment in more frequently performed CT examination types

4.1 CT examination of the cranium (CCT)

In most clinics, CT examination of the cranium is the most frequently performed cross-sectional diagnostic procedures and is accompanied by the highest local doses compared with CT examinations of other body parts. When using multi-line spiral CT scanners with wide detector arrays, the eye lens is often in the direct beam path range a result of over-ranging and over-beaming. If no protective measures are taken and the eye lens is positioned in the volume of the image, the eye lens will receive a dose of 30 mSv or more. Because of the reassessment of the sensitivity of the eye lenses to radiation with regard to cataract formation, this is a relatively high dose; measures should therefore be taken to protect the eye lenses. The eye lenses should thus be positioned outside the primary beam path by means of gantry tilting or slight elevation with a foam wedge and bending of the head; because of the over-ranging and over-beaming, a safety distance should be planned (SSK 2011).

If this is not possible, eye lens protection should be used. The artefacts occurring in this case do not limit the diagnostic significance if the distance between the shielding and the cranium is sufficient (Raissaki et al. 2010). Alternatively, a tube current modulation in which no direct or very little radiation reaches the eye lens can be used. The reduction by eye lens protection is approx. 50 %; the dose can also be reduced by up to 50 % if the upper angle range is blanked during exposure (Bulla et al. 2012, Keil et al. 2008, May et al. 2012).

The application of a thyroid protection reduces the dose of the thyroid gland (approx. 1 mSv) by 45 %; the use of a breast protection reduces the dose of the breast (approx. 0.3 mSv) by up to 75 % (Beaconsfield et al. 1998, Liebmann et al. 2014, Ngaile et al. 2008). The use of a thyroid protector and a breast protector is sensible.

If possible, thyroid protection should be applied in individuals eight years and older. For children under the age of eight, it can be useful to put on a narrow lead blanket over the thyroid because of the shorter neck.

4.2 CT examination of the paranasal sinuses and the visceral cranium

In this examination, the eye lens is in the direct beam path. For devices for digital volume tomography (cone beam computed tomography, CBCT), a 180° rotation should therefore be used to protect the eye lens. This allows the dose of the eye lens to be reduced by up to 80 % (from 15 mSv to 3 mSv) (Güldner et al. 2013).

When using CT systems, eye lens protection should be applied to the patient unless diagnostic image quality is compromised. Alternatively, a tube current modulation in which no direct radiation reaches the eye lens can be used. The reduction by eye lens protection is approx. 50 % (Keil et al. 2008). The dose can also be reduced by up to 50 % by blanking the upper angle range during recording (Bulla et al. 2012).

In other studies, it was shown that by wearing lead glass goggles, the dose of the eye lens was reduced from 4.0 mSv to 1.5 mSv and that by applying thyroid protection in CBCT, the thyroid dose was reduced from 1.6 mSv to 0.9 mSv (Goren et al. 2013, Liebmann et al. 2014).

A thyroid protection should be used, whereby the organ dose is clearly reduced. With CBCT systems, the 180° rotation should be used so that the eye lenses are not exposed to the unattenuated beam.

4.3 CT examination of the thorax and thoracic spine

A patient cover (lead blanket) around the abdomen reduces the radiation exposure of the uterus by approx. 30 % (the authors indicate a reduction of the organ dose by 23 µSv) (Danova et al. 2010, Iball and Brettle 2011). A comparable reduction of the other abdominal organs (e. g. colon, bladder, ovaries, prostate) and the red bone marrow in the abdominal area is also achieved. Because the uterine dose in pregnant women is similar to the effective dose of the unborn child, the abdomen of pregnant women should be shielded with a lead cover.

Tube current modulation can be used to reduce the radiation exposure of the mamma; alternatively, with some CT devices, a sectoral switch-off/reduction of the tube current in the anterior angle range is possible. The use of breast shields is not recommended because this will degrade the image quality and dose reduction is more efficient by using tube current modulation or by sectorally reducing the tube current at comparable image quality (Colletti et al. 2013, Foley et al. 2013, Vollmar und Kalender 2008). Through tube current modulation and sector scanning, the dose can be reduced by approx. 10 %; the mean dose of the mamma can be reduced from approx. 10.6 mSv to 6.1 mSv (40 %) for sector scanning and 9.6 mSv (10 %) for tube current modulation.

By using thyroid protection, the organ dose can be reduced from 8.37 mSv to 5.78 mSv (31 %); by using eye lens protection, the corresponding organ dose can be reduced from 0.32 mSv to 0.22 mSv (31 %) (Buchgeister et al. 2012). Protection of the thyroid gland is not practical in all paediatric age groups because of the proportions of the very short neck.

4.4 CT examination of the pelvis/abdomen

Covering the male gonads or a testicle pouch reduces the radiation exposure of the gonads (1 mSv to 2 mSv outside the radiation path) by a factor of 2 to 20 (Dauer et al. 2007, Hidajat et al. 1996, Hohl et al. 2005, Price et al. 1999). Because of artefacts, patient radiation protection equipment should not be in the path of radiation, especially when assessing the pelvis (Dauer et al. 2007). When the automatic exposure control is switched on, this would also lead to an increase in the tube current and thus the gonad dose. If, when examining the pelvis, exposure of the gonads is unavoidable, an organ-based tube current modulation should be used; this can lead to a reduction of up to 50 % in the number of near-surface, radiation-sensitive organs (May et al. 2012).

It makes sense to use a testicle pouch in men as long as it is not in the image area. For boys, a testicle pouch should be used depending on the individual stage of development.

5 Justification for the use of patient radiation protection equipment in more frequently performed projection types

In addition to good positioning and – in the case of non-cooperating patients – fixation if necessary, correct object and question-related masking in projection radiography is of the utmost importance. This is particularly important for children because the percentage field size increase is higher the smaller the initial format – especially in neonatal radiology. The masking must be visible on the image. Additional lead covering (e. g. gonad, lead rubber mats, or radiation protective clothing) of the sections of the body trunk adjacent to the edge of the radiation field is important for children and younger patients (BÄK 2007).

5.1 Radiography of the head

In any case, there are only a few clear indications for this examination. If it is actually required, a thyroid protector or lead apron with 0.5 mm lead equivalent may be used (BÄK 2007). The application of a thyroid protection has a low protective effect, reduces the already low dose (0.02 mSv) of the thyroid, and is therefore not absolutely necessary (Gall et al. 1992, Mazonakis et al. 2004). A lead cover can be placed on the trunk of the body for patient imaging in the lying position.

5.2 Radiography of the thorax

Studies show that the gonadal dose during p. a. imaging is approx. 0.0002 mSv (i. e. negligible). In adults, the testicular dose can be reduced by 75 % (approx. 0.0002 mSv), and the ovarian dose by 10 % (0.00002 mSv) in standard thoracic imaging (p. a.) on the vertical tripod using a gonad apron on the side facing the detector. The gonad apron on the side facing the tube would reduce the testicular dose by only 12 % and the ovarian dose by only 5 % (Njeh et al. 1996, Roth et al. 2001).

Infants are not X-rayed p.a. but rather a.p. in a hanging position. For patients from approx. one and a half years up to the age of 10, thoracic imaging is performed p.a. in the seated position with a children’s tripod, without a scattered radiation grid, and with an imaging voltage of 75 kV to 80 kV. A gonad protection close to the detector or an “all-round lead rubber protection” is therefore not necessary and not practical in early years. The gonad protection must therefore be attached to the front until the age of 10.

In neonatal radiography, the lead rubber cover should not be placed in the incubator directly on the patient but rather on the incubator. The reasons for this are serious hygienic concerns (e. g. nosocomial infections, MRSA, and ESWL bacteria) and compression of the upper abdomen with impairment of respiration.

Because it is easy to use gonad protection for thoracic imaging, this can still be done on the side facing the detector or with an all-round apron. An all-round apron can be used for pregnant women. When imaging in bed or in the incubator, the lead cover on the tube side should be used.

5.3 Radiography of the lumbar spine

For lumbar spine imaging, the dose is approx. 0.5 mSv for the uterus and approx. 0.04 mSv for testicles. The doses can only be reduced slightly by using patient radiation protection equipment at the lower radiation field limit (Clancy et al. 2010, Liu et al. 2008). In wide-faded images, covering the breast reduces the dose of the breast from approx. 0.4 mSv to approx. 0.08 mSv (Mekis et al. 2013). However, a correct masking has a much better protective effect.

Because of the limited protective effect, a lead rubber cover of the immediately adjacent sections of the body trunk is optional for adults but should always be used for children.

5.4 Radiography of the pelvis and the hip joint

Patient coverage of the gonads in the direct radiation path reduces the gonad dose of the man (0.8 mSv) by approx. 95 %, and that of the woman (0.2 mSv) by more than 50 %. Outside the useful beam, the gonadal dose is less than 0.1 mSv, but can be significantly reduced in men with a testicle pouch (Clancy et al. 2010, Liu et al. 2008).

The gonad protection is often incorrectly positioned, especially in girls and women; this can lead to faulty images (Kenny und Hill 1992, Warlow et al. 2014). Exact positioning of the ovarian protection is essential; if the positioning is uncertain, this should be avoided.

A testicle pouch can significantly reduce the low to medium dose of testicles in men that occurs during this examination; it should also be used when the testicle is not within the range of the shot or when artefacts are not disturbing. In women, a small dose of the ovaries can be reduced if the ovary protection is precisely positioned. In children, adjacent parts of the body must also be protected.

5.5 Radiography of the abdomen

The reduction of the gonad dose through the use of patient radiation protection equipment is comparable to that of pelvic X-ray. Here, the testicles are not in the direct beam (< 0.1 mSv). The ovaries are in the diagnostically relevant range; they can therefore not be covered.

A covering of the breast reduces the radiation exposure of the breast (0.1 mSv) by approx. 80 % (Liu et al. 2008, Mekis et al. 2013).

A testicle pouch can be used for boys and men. A covering of the breast can be useful. In children, adjacent parts of the body (thorax) must also be protected.

5.6 Radiography of the extremities

No studies on the reduction of radiation exposure by patient radiation protection equipment can be found for investigations of the extremities. A rough estimate shows that the gonadal dose saved by the use of radiation protection equipment is negligible except for imaging of the thigh in men. When imaging the thigh, the gonads of the man must be protected. In all other examinations, organs at risk are protected as far as possible by the positioning. For children, a lead rubber cover should be applied to the immediately adjacent body sections (BÄK 2007).

5.7 Radiography of the shoulder or the clavicle

No studies on the reduction of radiation exposure by patient radiation protection equipment can be found for investigations of the shoulder or clavicle. A rough estimate shows that the dose saved by the use of patient radiation protection equipment is negligible. A gonad apron can be used. If necessary, other organs at risk (e. g. thyroid gland and breast) can be covered, especially in children and adolescents.

5.8 Mammography

Studies show that there is no significant increase in thyroid cancer with increasing number of mammographies (Sechopoulos und Hendrick 2013). The thyroid dose is conservatively estimated at 0.04 mSv (Whelan et al. 1999). Recent studies show average dose values of 0.002 mSv (Sechopoulos et al. 2008). The use of thyroid protection is therefore not necessary. The average organ dose for the eye is 0.002 mSv, for the contralateral breast, 0.02 mSv, and for the uterus, < 0.00003 mSv. Here too, no further protective measures are necessary (Sechopoulos et al. 2008).

5.9 Radiography in dentistry

The radiation energies and field sizes used in dentistry only generate scattered radiation fields with small doses.

Examinations of panoramic images and dental cone-beam CT showed no significant dose reduction as a result of wearing a patient apron (Rottke et al. 2013a, Rottke et al. 2013b, Schulze et al. 2016). One study (Qu et al. 2012) showed savings of 0.015 mSv in the organ equivalent dose of the thyroid gland.

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