Review paper

Use of out-of-field contact shielding on patients in medical imaging: A review of current guidelines, recommendations and legislative documents

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ABSTRACT

The use of patient contact-shielding has become a topic of intensive scientific debate. While it has been common practice during the last decades, some studies have questioned the efficiency of using such shielding while others have highlighted the inconsistencies in its application. The objective of this work is to review current recommendations and legislative documents on the use of out-of-field shielding in X-ray imaging, including those from national authorities and from international and national organisations and professional bodies.

The review, performed within the framework of the activities of EURADOS Working Group 12, covers available recommendations on use of contact shielding in adult, pregnant and paediatric patients in general radiography, fluoroscopy, computed tomography, mammography and dental radiology. It includes a comprehensive search of 83 documents from 32 countries and 6 international organisations over the last 39 years. In general, using shielding is recommended only under two conditions: if it does not compromise the diagnostic task and the performance of the procedure and/or if it reassures the patient and comforters that they are appropriately protected against potentially harmful effects of radiation. There are very few specific regulatory requirements to use shielding in a particular imaging modality, although they may consider use of shielding either as part of good radiological practice or as requirements for availability of protective or ancillary tools, without further specification of their use. There is a wide variety of positions among documents that recommend out-of-field shielding, those that do not recommend it and those that are not specific. Therefore, evidence-based consensus is still needed to ensure best and consistent practice.

Introduction

Radiation protection of patients is a critical issue of medical practice

and a requirement of relevant international standards [1,2]. Over many decades, it has been common practice among radiology professionals to place shielding material directly on the patient during various X-ray

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imaging procedures with the intention of reducing the dose to the organs not targeted by the examination [3,4]. For example, shielding the gonads, especially when imaging children, has been widely accepted as good practice since its introduction approximately 60 years ago. The main objective was to protect this organ in order to minimise hereditary risks from radiation exposure [4–7].

The practice of patient shielding has not changed much despite the significant advances in the development of X-ray imaging equipment and increased scientific knowledge about effects of ionising radiation. Modern X-ray equipments have improved means of collimation and detector sensitivity, increased amount of beam filtration, more powerful generators that allow for shorter exposure times and an efficient automatic exposure control (AEC). Today, the majority of examinations are indeed performed using AEC in radiography and mammography. Automatic brightness control is used in fluoroscopy and tube current modulation in computed tomography (CT). All of these systems enable optimal selection of exposure parameters. Furthermore, the dynamic range of digital image receptors and image processing techniques enable more efficient optimisation of protection. Thus, patient absorbed doses have been significantly reduced during the last decades [8].

On the one hand, there are evident expectations from patients and professionals to continue shielding practice. On the other hand, an increasing number of studies have raised concerns regarding the benefit of shielding [8,9], in particular in modern X-ray equipment, as there is evidence of significant decrease of radiation dose and risks to patients in certain imaging modalities. Moreover, a major drawback of patient shielding is the shadow of the shielding impinging on the AEC sensor to any degree. The X-ray equipment in this case increases the exposure, which thus increases the radiation dose to the patient. There is also a decrease in image quality if the shielding devices intercept the primary beam [10,11].

In particular, the exposure of reproductive organs has been one of the main concerns of patient exposure due to the larger associated risk of hereditary effects. Nevertheless, since “no human studies provide direct evidence of a radiation-associated excess of heritable disease” [12], the recommendation on use of patient shielding in this case has become a topic of intensive scientific debate. Some studies have questioned the efficiency of using such shielding [8] while others have highlighted the inconsistencies in its application [13]. Even data about fetal dose suggest that at radiation doses of < 100 mGy, the risk to an embryo or fetus is either small or nonexistent [14]. In the case of female gonads, their anatomical location can vary significantly, mainly in paediatric patients, which limits the benefits of shielding. Furthermore, for a pelvis X-ray exam, a properly positioned female gonadal shield directly covers active AEC sensors, increasing radiation to the unshielded anatomy. The problem of inaccurate placement of gonad shields in children has been investigated in numerous studies [15–20], while numerous guidelines state that a female gonadal shield should not be used in conjunction with AEC [6,21–24].

The reasons that may justify this historic change in patient management are based on current scientific evidence about two issues: the risks derived from exposure to X-rays, showing that the benefit from shielding is negligible, and the potentially wrong use of this shielding, which can compromise the image quality and/or interfere with the AEC, as explained above.

Out-of-field patient shielding

Out-of-field shielding refers to protection means made of highly attenuating material (usually materials with high atomic number Z) placed over the patient, but outside of the imaging field of view (FOV). The protection is used to reduce the dose to the most radiosensitive organs such as gonads, breasts or thyroid.

There are several points to be analysed when considering out-of-field shielding. For the anatomy outside the imaging FOV, radiation exposure results almost entirely from internal scatter generated within a patient

[8], whereas the shielding reduces the dose from external X-ray beams or external scatter, therefore limiting the benefit of protection placed over the patient. Factors such as the imaging modality or position and depth of the organ in the body have to be considered [16] and might make shielding challenging to apply in clinical practice. For instance, the effectiveness of a shield for the ovaries will be reduced as the gap between the shield (on the surface of the body) and the gonads increases [16].

With reference to the above facts and challenges, the objective of this work is to review published guidelines and recommendations on the use of out-of-field shielding in X-ray imaging, including those from relevant national authorities and legislators and from international and national organisations and professional bodies. It is out of the scope of this paper to include the review of scientific papers or provide specific recommendations. The review was performed within the framework of the activities of the European Radiation Dosimetry Group (EURADOS) Working Group 12 – Dosimetry in Medical Imaging.

Methods

This review is related to the radiation protection shielding applied directly on a patient's body during X-ray procedures, outside the primary beam. It does not include in-beam patient shielding or shielding built into the imaging equipment. It is based on an extensive search for the most recent recommendations, guidelines and obligations addressing patient radiation protection in X-ray imaging, whether including out-of-field shielding or not, from national legislation and authorities, and international organisations and professional bodies. The documents were obtained via direct contact with national experts from our network. The list of analysed relevant documents is provided in the Appendix of this paper. They are referenced here as “[A-xx]”, where xx is the sequential number assigned to each reference.

The review is organised in sections describing the use of out-of-field shielding in specific imaging modalities, for specific organs at risk and specific groups of patients. More precisely, it covers available recommendations on use of shielding in adult, pregnant and paediatric patients in most of X-ray modalities. A standardised approach was applied to all imaging modalities, reporting the following elements: 1) countries and organisations, 2) imaging protocols, 3) patient types, 4) shielded organs, 5) year of publication and 6) details related to the use of out-of-field shielding. The following imaging X-ray modalities were included in the analysis: radiography, fluoroscopy, computed tomography, mammography and dental radiology.

The documents were classified into three categories: documents recommending the use of out-of-field shielding, documents recommending not using out-of-field shielding and documents not specific or not referring to out-of-field shielding.

No meta-analysis was performed due to the nature of the analysed documents. The synthesis of the results is therefore descriptive.

Results

General findings

A comprehensive search identified a total of 83 documents from 32 countries (mainly European) and 6 international organisations, from which 34 are legislative documents and 49 are recommendations. The analysed documents were published in the period 1982–2021, with 84% of them published in the last 10 years. Fig. 1 shows the distribution of reviewed documents per geographic region and year of publication. A summary of recommendations is presented in Figs. 2 and 3.

In Figs. 2 and 3, as well as in several tables, the terms “All organs” or “All sensitive organs” both imply that the recommendations are general (without specifying any organ) or are specific for the most radiosensitive organs. Some documents give general recommendations, but then add one or more exceptions. If this is the case, the reference may appear

Fig. 1. Distribution of the reviewed documents per a) geographic region and b) year of publication.

twice or more in these figures and the corresponding tables, as different position statements, in different groups of organs. The terms “all ages” or “age not specified” refer to references that either do not indicate an age group, refer to all patients, or refer to all patients up to 50 years old, whereas the term “paediatric patients” means that the recommendations are specific for this group. Some of the reviewed documents provide general recommendations, others refer to some specific organs, and others provide general statements including some exceptions. When a

reference is classified in the group “shielding not recommended”, it means either that shielding has been considered unnecessary or that its use should be discontinued.

In general, guidelines and recommendations regarding the use of out-of-field shielding come from national and international scientific societies. However, in most countries there are no specific regulatory requirements related to the use of shielding in a particular imaging modality.

In most countries, both legislative documents and recommendations are not specific enough. For instance, in some countries, during exposure of asymptomatic patients for the health screening, it is stated that ancillary equipment should be used, without further specification of the properties of such equipment and its use in clinical environment [A-49]. The term “ancillary” equipment originates from the previous version of the European Directive (Council Directive 97/43 Euratom) and has been reconfirmed more recently in art. 61 of the Directive 2013/59 [1], without further clarification of its meaning. Similarly, in Slovenia the regulation states that the radiographer shall use “appropriate means for patient protection” [A-48]. In Switzerland, the legislation requires that hospitals have the necessary radiation protection means available, but it is the responsibility of the radiation protection expert to regulate its judicious use [A-65]. In Spain the facilities must have adequate protective clothing in order to protect the patient if necessary [A-52] without specifying in which cases it is considered necessary. That is also the case of legislative documents [A-58, A-59] and derived legislation [A-76] in Germany, but in this country there is also a specific recommendation of the radiation protection commission [A-8]. The legislation in Iceland [A-6] requires that appropriate apron must be available where X-ray machines are in use, without any further specification either. For the purpose of analysis, these cases have been listed in the category “Not specific or not mentioning out-of-field shielding”.

The list of countries where the use of out-of-field shielding is not specifically considered in the legislation or it is not specific is provided in Table 1.

There are several reviewed documents that recommend the general use of out-of-field shielding without specifying the imaging modality. For example, in the Brazilian regulation [A-69], the use of at least 0.5 mm Pb equivalent lead shielding for gonads, eye lens and thyroid is recommended for all patient categories, when these organs are exposed

Fig. 2. Number of position statements from the reviewed documents on the use of out-of-field shielding in different imaging modalities, age groups and radio-sensitive organs.

Fig. 3. Number of position statements from the reviewed documents on the use of out-of-field shielding in different imaging modalities as a function of the organ shielded.

Table 1

List of the countries where out-of-field shielding is not specifically mentioned in their legislation or it is mentioned without further specifications on its specific use. The references are listed in the Appendix.

Australia (2019) [A-67]	Iceland (2015) [A-63]
Austria (2020) [A-62]	Ireland (2018) [A-49]
Belgium (2020) [A-11]	Italy (2020) [A-47]
Bosnia & Herzegovina (2010) [A-43]	Jordan (2019) [A-56]
Bulgaria (2016) [A-20]	Netherlands (2018) [A-26a&b]
Chile (1984) [A-61]	New Zealand (2018) [A-36]
Costa Rica (1998) [A-80]	Norway (2017) [A-68]
Cyprus (2019) [A-55]	Portugal (2018) [A-51]
France (2018) [A-54]	Slovenia (2018) [A-48]
Germany (2017) [A-58], (2018) [A-59]	Spain (2009) [A-52]
Greece (2018, 2019) [A-50]	Sweden (2018) [A-64a&b]
	Switzerland (2017) [A-65]

to the primary field (in-field protection) or up to 5 cm from it, unless the use of such shielding interferes with the procedure itself. A regulation from Croatia [A-25] recommends the use of shielding for all patients and all organs adjacent to the primary beam, in accordance with the advice of a Medical Physics Expert. Similarly, the use of gonadal shielding for patients under the age of 50 is recommended in Denmark if gonads are closer than 5 cm to the primary field [A-7]. The Finish regulation from 2019 [A-3] generally requires the use of radiation shields if radiation exposure to the patient can be significantly reduced. Nevertheless, according to the joint Scandinavian recommendation from the same year [A-6], shielding of male gonads should be performed if the gonads are in the radiation field or closer than 5 cm, unless shielding could compromise visualization of structures of clinical interest or interfere with AEC, thus increasing the risk for re-takes or increased dose. According to the Hungarian standard from 2017 [A-9], lead rubber shielding should be used for examinations if the breasts, gonads or the thyroid are within 5 cm from the direct beam, while taking care that it is not interfering with the procedure itself. In the Serbian regulation from 2012 [A-44], shielding shall be applied for all patients and all organs, according to the local rules. A Swiss recommendation from 2018 [A-12] recommends use of shielding for almost all organs that are not in the radiation field, whenever possible. Similarly, the American Society of Radiologic Technologists [A-18] underline that shielding is particularly important to protect anatomic areas near the exposure field if this does not interfere with diagnostic information. Indeed, properly positioned lead equivalent shielding can significantly reduce radiation exposure to tissues adjacent to the collimated field. At a minimum, it proposes that a patient's gonads should be shielded when within 5 cm of the edge of a properly collimated x-ray beam [A-18]. The recommendation of the German radiation protection commission (SSK) [A-8] cites scientific literature and correspondingly states imaging modalities for which shielding is recommended and modalities for which shielding is not necessary.

In general, use of out-of-field shielding is recommended under two conditions: if it does not mask any diagnostic information or compromise the performance of the procedure (e.g. it does not interfere with the primary beam or influences the AEC system), or if it reassures the patient and comforters in a sense that they feel protected and safe.

For sensitive organs that are near the primary beam (within 5 cm from the field edge), the general recommendation is that shielding may be considered, with caution, because if wrongly placed, it may obscure important information (requiring the image to be repeated) or interfere with the AEC system, thus increasing the radiation doses. For those organs that are further away (greater than 5 cm) from the field edge, no conclusive data can be extracted, although it is acknowledged in some documents that its effect is negligible, and its only benefit may be to produce “peace of mind” in the patients or relatives.

Relevant international organisations as the International Atomic Energy Agency (IAEA) and International Commission on Radiological protection (ICRP) also recommend use of shielding as presented in

Table 2.

There are also documents that discourage the general use of out-of-field shielding. For many of the reasons mentioned above, several associations have followed the Position Statement on the Use of Patient Gonadal and Fetal Shielding of the American Association of Physicists in Medicine (AAPM) [A-15]. According to the AAPM, gonadal and fetal shielding provide negligible, or no, benefit to patients' health and the use of such shielding can negatively affect the efficiency of the exam. For the minimal to nonexistent benefit associated with fetal and gonadal shielding, the AAPM recommends that the use of such shielding should be discontinued. Inevitably, repeated imaging caused by inconsistent or poor use of shielding leads to unnecessary dose and defeats the original intent of the shielding. Very recently, the Italian Association of Medical Physics (AIFM) published a joint position statement [A-30] with the Italian Society of Medical and Interventional Radiology (SIRM) and the Federation of Scientific Associations of Radiological Technicians (FASTeR), affirming that the use of protection tools to shield the fetus and patient's gonads during X-ray imaging procedures should be ceased as a routine practice as it can compromise the benefits.

Recently published guidelines from the British Institute of Radiology, Institute of Physics and Engineering in Medicine, Public Health England, Royal College of Radiologists, Society and College of Radiographers and Society for Radiological Protection, challenge the historical perspective that using contact shielding provides a clear benefit for the patient [A-42]. Furthermore, they suggest that shielding can adversely interfere with the imaging and, if inappropriately used, can actually lead to increased patient radiation exposure. Overall, the findings indicate that contact shielding provides minimal or no benefit. Thus, professionals should concentrate on other areas of radiation protection that are more effective in optimising the patient radiation exposure.

In line with these documents, the Swiss Society of Radiobiology and Medical Physics has just concluded that “the use of such protection garments and/or blankets in radiological routine should be discontinued” [A-77].

In some cases where shielding is not recommended, an exception is made if patients, carers or comforters are anxious. The use of shielding in this case is a means to satisfy individual desires and/or local regulation. For example, according to the AAPM recommendation from 2019 [A-15], endorsed by some organisations or scientific societies in Australia [A-60] and Canada [A-45], patient gonadal and fetal shielding during X-ray diagnostic imaging should be discontinued as routine practice. The exception to this recommendation are patients or guardians experiencing fear and anxiety about radiation exposure, when the use of gonadal or fetal shielding may calm and comfort the patient enough to improve the exam outcome. Similarly, another recommendation from US organisations [A-28] does not encourage the use of gonadal shielding either, but states that it may be used to comply with individual desires and local regulations. In the latter case, an exception is made for mobile radiography, where it is stated that the use of shielding should not be discouraged because it is an acknowledgement to the patient, child, parents, or other carers and comforters that every attention to minimizing exposure has been addressed.

Specific findings

Conventional radiography

A total of 55 documents (including recommendations and legislative documents) from 15 countries and 3 international organisations have been analysed concerning the patient's use of out-of-field shielding when performing conventional radiographic examinations.

When discussing out-of-field shielding for conventional radiography examinations, the following projections, group of projections or protocols were found in the reviewed documents: all radiography projections, all paediatric protocols, and some specific projections such as abdomen, pelvis, hip-joint, scoliosis, chest/thorax, head, maxilla, shoulder, spine, skeleton, skull, extremities and urinary system.

Table 2

Summary of the IAEA and ICRP recommendations on use of out-of-field shielding.

Reference	Recommendation	Imaging modality	Critical organs	Patient category
ICRP 34 (1982) [A-70]	Gonadal shielding should be used when it does not interfere with diagnosis [...] if they are within the primary beam or within 5 cm of it. Shielding can also be used in follow-up studies such as those for hip disease or scoliosis. Exceptions: if the gonads are beyond 5 cm (negligible effects), when impractical or impossible (female gonads)	Diverse modalities	Gonads, thyroid, fetus	All
ICRP 117 (2010) [A-74]	Shielding [...] has a limited role for protecting patients' body parts, such as the breasts, female gonads, eyes, and thyroid, in fluoroscopy (with the exception of male gonads).	Fluoroscopy	Male's gonads	All
ICRP 121 (2013) [A-75]	Breasts, gonads and/or thyroid should be protected (whenever possible) if they lie within 5 cm of the primary beam, but not if they are within the primary beam. Exceptions: in girls, gonad protection may not be possible and shadow masks within the diaphragm of the collimator are as efficient as direct shields.	Radiography, fluoroscopy, computed tomography	Breasts, gonads, thyroid	Paediatric
IAEA HHS24 (2013) [A-14]	Critical organs [...] should be shielded in paediatric patients whenever the placement of the shield does not obscure important information in the clinical image. While shielded organs that are not directly irradiated receive little benefit from external shielding, in most cases, this shielding provides 'peace of mind' for the patient's parent.	Radiography, fluoroscopy, computed tomography	Thyroid, gonads, eye lens, breast	Paediatric
IAEA SSG46 (2018) [A-27]	Care should be taken in the anatomical placement of such shields, the impact of shielding on image quality (artefacts), and the use of AEC devices and the	Diverse modalities	Thyroid, gonads, eye lens, breast	All

Table 2 (continued)

Reference	Recommendation	Imaging modality	Critical organs	Patient category
IAEA (2019) ¹ (web)	consequences for patient dose. It has very little effect, but it can be reassuring to the patient and staff.	Diverse modalities	Fetus	Pregnant woman
IAEA (2019) ² (web)	Shielding devices should be appropriately positioned to be efficient for protecting the tissues for which they are placed and to avoid unnecessary repeat examinations.	Diverse modalities	All	Paediatric

¹ <https://www.iaea.org/resources/rpop/health-professionals/radiology/pregnant-women>.

² <https://www.iaea.org/resources/rpop/health-professionals/radiology/children>.

In conventional radiography, the imaged anatomy and the organs in or near the primary beam are highly variable, being dependent on the pathology of interest and the operator's technique (e.g. positioning and collimation). When performing imaging procedures, the radiographer needs to consider organs that are close to the primary beam and make necessary radiation protection arrangements, such as good collimation and favorable radiography projections.

Concerning the patients' categories and the considered organs, a great variety of answers have been found in the analysed documents. Systematization of recommendations, based on organs at risk and patient age, is presented in Table 3 and Figs. 2 and 3.

Most of the countries that require out-of-field shielding in national regulations do this for all patient categories, irrespective to the age. This is the case, for example, of the Brazilian legislation from 2019, previously described. Similarly, in Croatian legislation from 2018, protective tools shall ensure protection of at least 0.25 mm lead thickness equivalence for thyroid, eye lens, gonads and hematopoietic organs, without interfering with radiological procedures [A-25]. A recent legislation from Finland [A-3] requires use of shielding tools in all patients only if such tools can be used to significantly reduce the patient's radiation exposure, without further information of what "significantly" means. The Hungarian regulation from 2017 [A-9] requires use of lead-rubber shielding for breast, thyroid and gonads in all patients, when these organs are close as 5 cm to the direct beam. According to the Serbian regulation from 2012 [A-44], protective tools shall be used for all patients and all relevant organs, whereas the details on use of such tools should be available in the local rules. A Safety Guide published by the Spanish Nuclear Safety Council in 1990 recommends the use of gonadal shielding in conventional radiography whenever it is possible [A-78]. In a Swiss recommendation from 2011 [A-13]: the use of shielding of gonads is recommended during radiography of abdomen, spine, pelvis and extremities; shielding of thyroid is recommended during head examinations; and shielding of the breasts (in women) during spine radiography examinations. Other recommendations from 2018 in the same country requires shielding of gonads during radiography of thorax, shoulder, extremities, head, spine, abdomen and urinary system and shielding of thyroid during head radiography [A-12].

Although there are some discrepancies between countries, or even between different organisations of the same country, shielding of the male gonads is more widely recommended. On the contrary, shielding of the female gonads is more widely not recommended. This is due to the fact that shielding is easy to perform in male gonads (the testes are easily visible and relatively far away from the clinical region of interest) and effective, whereas for females the position of the gonads is variable

Table 3

Summary of recommendations for use of out-of-field shielding in conventional radiography, for different organs and patient categories. The reference is classified as “L” if it is a legislative document and as “R” if it is a recommendation.

Organ/Age	Shielding recommended or may be considered	Shielding not recommended
All sensitive organs		
Age not specified	Croatia (L-2018) [A-25] Finland (L-2019) [A-3] IAEA (R-2018) [A-27] Serbia (L-2012) [A-44] Switzerland ¹ (R-2018) [A-12] (R-2011) [A-13] IAEA (R-2013) [A-14] (R-2019) (web) ²	Germany (R-2018) [A-8] Switzerland (R-2020) [A-77] UK (R-2020) [A-42]
Paediatric patients		
All sensitive organs within 5 cm from the primary field edge		
Age not specified	Brazil (L-2019) [A-69] Hungary (L-2017) [A-9] USA (R-2019) [A-18] ICRP (R-2013) [A-75]	
Paediatric patients		
Organs beyond 5 cm from the primary field edge		
Age not specified		ICRP (R-1982) [A-70]
Gonads – Males		
Age not specified	Denmark (L-2018) ³ [A-7] (R-2019) [A-6] Finland (R-2019) [A-6] Germany ⁴ (R-2018) [A-8] Iceland (R-2019) [A-6] ICRP ⁵ (R-1982) [A-70] Norway (R-2019) [A-6] Spain (R-1990) [A-78] Sweden (R-2019) [A-6] UK (R-2020) [A-42] EuroSafe (R-2015) [A-38] ICRP (R-2013) [A-75]	Australia (R-2019) [A-60] Canada (R-2019) [A-45] Italy (R-2020) [A-34] Netherlands (R-2017) [A-26] USA ⁶ (R-2019) [A-15] (R-2021) [A-79] UK (R-2020) [A-42] USA (R-2019) [A-28] EuroSafe ⁷ (R-2018) [A-41]
Paediatric patients		
Newborns		
Gonads – Females		
Age not specified	Denmark (L-2018) [A-7] Germany ⁶ (R-2018) [A-8] Spain (R-1990) [A-78]	Australia (R-2019) [A-60] Canada (R-2019) [A-45] Denmark (R-2019) [A-6] Finland (R-2019) [A-6] Iceland (R-2019) [A-6] ICRP (R-1982) [A-70] Italy (R-2020) [A-34] Netherlands (R-2017) [A-26] Norway (R-2019) [A-6] Sweden (R-2019) [A-6] UK (R-2020) [A-42] USA (R-2019) [A-15] (R-2021) [A-79] Spain (R-2013) [A-1] ICRP (R-2013) [A-75] USA (R-2019) [A-28] EuroSafe (R-2018) [A-41]
Paediatric patients		
Newborns		
Thyroid		
Age not specified	UK (R-2020) [A-42] USA (R-2013) [A-46]	
Fetus		
Pregnant woman	ICRP (R-1982) [A-70] IAEA (R-2019) (web) ⁸	Australia (R-2019) [A-60] Canada (R-2019) [A-45] Italy (R-2020) [A-34] USA (R-2019) [A-15]

¹ Switzerland recommendations for shielding the gonads apply for thorax, extremities, head, spine, abdomen and pelvis examinations; for shielding the thyroid, head examinations; and for shielding the breasts (in women), spine examinations.

² <https://www.iaea.org/resources/rpop/health-professionals/radiology/children>.

³ It applies to all ages below 50 years old.

⁴ Only for imaging of “pelvis and hip joint”.

⁵ In this age group, ICRP 34 applies to all individuals with reproductive potential.

⁶ In Ref. A-15 (2019), an exception is stated for patients/guardians with fear or anxiety.

⁷ EuroSafe states that, in this case, shielding is very difficult due to the small patient size, and the low dose (and risk) achievable if AEC, correct collimation and added filtration are used.

⁸ <https://www.iaea.org/resources/rpop/health-professionals/radiology/pregnant-women>.

(mainly in paediatric patients), there is less dose reduction and the technique is therefore riskier. This conclusion does not depend on the date of publication of the legislations/recommendations reviewed. In particular, the Danish legislation from 2018 requires using it in all patients under the age of 50 if these are closer than 5 cm to the primary field [A-7]. In the legislation from 2019, this requirement is modified in a way that it should be performed with dedicated shielding tools for male gonads, with special precautions if AEC is used, whereas for females its use is discouraged. The dose reduction that can be achieved in male shielding is 95%, whereas this is less efficient in female patients [A-6] (as described earlier). The same recommendations are made in Iceland, Norway and Sweden [A-6]. The Eurosafe campaign of the European Society of Radiology (ESR), among many other guidelines (see Table 3), similarly underlines more complicated positioning of shielding tools for gonads in female pelvic radiography compared to male patients [A-38].

In recent years, several countries have discontinued the practice of shielding gonads and the fetus, following the AAPM recommendation [A-15, A-45]. For instance, the National Council on Radiation Protection and Measurements (NCRP) recommends ending routine use of gonadal shielding during abdominal and pelvic radiography [A-79], although suggests that it may be permissible if consent for the examination cannot be obtained from the patient without use of gonadal shielding, as long as it does not interfere with the purpose of the examination. As already mentioned, a recent UK recommendation from 2020 states that: “*The use of patient contact shielding is not recommended for general radiography for the majority of imaging situations [...] Shielding of organs at risk more than 5 cm from the primary beam is likely to have a negligible effect on the radiation dose received*”, although it may be considered with caution for male gonads when < 5 cm from the primary beam, for breast tissue in anterior-posterior examinations of the spine, and for the thyroid, if < 5 cm from the primary beam, provided that projection is AP and will not obscure anatomy of interest or interfere with AEC device [A-42]. It may be worth noting that in USA there are conflicting recommendations coming from different scientific organisations (see, for example, references [A-15] and [A-18] in Table 3).

Fluoroscopy guided procedures

A total of 51 documents containing recommendations and legislation from 14 countries and 3 organisations have been analysed with respect to the use of out-of-field shielding when performing fluoroscopic guided examinations.

Fluoroscopy is associated with relatively high radiation doses. In fluoroscopy-guided imaging procedures, the imaged anatomy and the organs in or near the primary beam are highly variable. Patient shielding may be used for protection of the patient’s radio-sensitive organs close to the primary beam, such as the breast, eyes and thyroid, provided it does not interfere with the equipment. However, this can be a difficult task due to the dynamic nature of fluoroscopy, in which the anatomical region in the primary beam is not fixed. When the X-ray system moves, the protection tool used might appear in the primary beam. Moreover, scattered radiation arising and propagating inside the patient’s body constitutes the main source of radiation dose to organs and this internal scatter can only be managed by good radiography technique [3]. A summary of recommendations for use of out-of-field shielding in fluoroscopy for different organs and patient categories is presented in

Table 4 and Figs. 2 and 3.

Use of shielding in fluoroscopy is recommended in several documents from different countries and international organisations. In the Australian regulation from 2008 [A-35], use of shielding to protect gonads, eye lens, thyroid and breast is recommended for all patients undergoing fluoroscopy procedures, stating that in some instances the use of lead shielding is more aimed at patient reassurance than at any real physical benefit, as the major source of exposure to the abdominal organs is internal scatter.

EuroSafe (ESR) [A-37] recommends shielding of breasts, gonads and/or thyroid in paediatric patients whenever possible and if they lie within 5 cm of the primary beam. IAEA and ICRP in a range of documents also recommend use of shielding in fluoroscopy guided procedures (see Table 1).

As presented in Table 1, ICRP Publication 177 [A-74] claims that shielding has a limited role for protecting body parts such as the breasts, female gonads, eyes and thyroid in fluoroscopy (with the exception of male gonads). Furthermore, in girls, shadow masks within the diaphragm of the collimator are as efficient as direct shields. Therefore, in abdominal or pelvic examinations for girls gonad protection may not be possible and misplaced shielding may mask important pathology [A-75].

Similarly to conventional radiography, USA [A-15], Australia [A-60], Canada [A-45] and Italy [A-34] recently recommended discontinuation of use of gonadal and fetal shielding for all patient categories. However, it is important to note that apart from the Canadian Organisation of Medical Physicists position statement, different provinces and territories in Canada follow different rules¹. Scandinavian countries in the joint recommendation from 2019 [A-6] concluded that shielding of the female gonads is less beneficial, especially for younger females. A dose reduction up to about 50% may be achieved if the shielding is applied correctly. However, the location of the female gonads can vary significantly, so the dose reduction in many cases will be much smaller than 50%. In addition, the risk associated with the potential loss of diagnostic information, resulting in retakes, often outweighs the benefit of gonad shielding. Therefore, the use of the other described dose reduction techniques is potentially more efficient. Finally, the British Institute of Radiology in 2020 recommended cessation of the widespread practice of applying patient contact shielding for all patient categories. Great care should also be taken if protective material, intended to reduce staff radiation dose, is applied to patients [A-42].

Computed tomography

A total of 49 documents, including recommendations and legislative documents from 14 countries and 2 organisations were analysed in the context of use of out-of-field shielding in CT. The documents analysed were published in the period 1984–2020. A summary of recommendations is presented in Table 5 and Figs. 2 and 3.

In the context of use of out-of-field shielding for CT examinations, the following protocols were considered: head, chest, High Resolution (HR) lungs, abdomen, pelvis, and abdomen/pelvis.

There are several recent documents recommending use of shielding in CT or addressing use of shielding in general, as presented in the section “General findings”. For example, an Australian recommendation published in 2008 [A-35] requires use of shielding for gonads, eye lens, thyroid and breast in all patients, even if it is only for patient reassurance, as well as covering of the female abdomen during a chest CT scan. The German recommendation from 2018 specifies use of shielding in CT in all patients (except paediatric patients in the case of thyroid protection during chest CT) [A-8]. This implies that thyroid protection is recommended during head and chest CT, testicle protection during abdomen/pelvis CT, breast shielding during head CT and abdominal shielding during chest CT. According to the Swiss recommendation from

Table 4

Summary of recommendation for use of out-of-field shielding in fluoroscopy for different organs and patient categories. The reference is classified as “L” if it is a legislative document and as “R” if it is a recommendation.

Organ/Age	Shielding recommended or may be considered	Shielding not recommended
All sensitive organs Age not specified	Australia ¹ (R-2008) [A-35] Croatia (L-2018) [A-25] Finland (L-2109) [A-3] Germany (R-2018) [A-8] IAEA (R-2020) [www] ² Serbia (L-2012) [A-44] Switzerland (R-2018) [A-12] Switzerland (R-2011) [A-13] IAEA (R-2013) [A-14]	ICRP 117 (2013) [A-74] Switzerland (R-2020) [A-77] UK (R-2020) [A-42]
Paediatric patients		
All sensitive organs Age not specified	within 5 cm from the primary field edge Brazil (L-2019) [A-69] USA (R-2019) [A-18] (near primary field, not specifically 5 cm stated) EUROSAFE (ECR) (R-2019) [A-37]	
Paediatric patients		
Gonads – Males Age not specified	Denmark (R-2019) [A-6] (if gonads < 5 cm) Finland (R-2019) [A-6] (if gonads < 5 cm) Hungary (L-2017) [A-9] IAEA (R-2018) [A-27] ³ ICRP 117 (2013) [A-74] Iceland (R-2019) [A-6] (if gonads < 5 cm) Norway(R-2019) [A-6] (if gonads < 5 cm) Sweden (R-2019) [A-6] (if gonads < 5 cm) ICRP 121 (R-2013) [A-75] (if gonads < 5 cm)	Australia (R-2019) [A-60] ⁴ Canada (R-2019) [A-45] ⁴ Italy (R-2020) [A-34] Netherlands (L-2018) [A-26a&b] USA (R-2019) [A-15]
Paediatric patients For patients with age < 50 y	Denmark (L-2018) [A-7] (if gonads < 5 cm)	
Gonads – Females Age not specified	Hungary (L-2017) [A-9] IAEA (R-2018) [A-27]	Australia (R-2019) [A-60] ⁴ Canada (R-2019) [A-45] ⁴ Denmark (R-2019) [A-6] Finland (R-2019) [A-6] Iceland (R-2019) [A-6] ICRP-121 (R-2013) [A-75] Italy (R-2020) [A-34] Netherlands (L-2018) [A-26a&b] Norway (R-2019) [A-6] Sweden (R-2019) [A-6] USA (R-2019) [A-15]
Paediatric patients	Hungary (L-2017) [A-9] ICRP 121 (R-2013) [A-75] (if gonads < 5 cm)	
Fetus Pregnant woman		Australia (R-2019) [A-60] Canada (R-2019) [A-45] Italy (R-2020) [A-34] USA (R-2019) [A-15]
Thyroid Age not specified		

¹ Personal communication.

(continued on next page)

Table 4 (continued)

Organ/Age	Shielding recommended or may be considered	Shielding not recommended
Paediatric patients	Hungary (L-2017) [A-9] IAEA (R-2018) [A-27] ICRP 121 (R-2013) [A-75] (if thyroid < 5 cm)	
Woman's breast		
Age not specified	Hungary (L-2017) [A-9] IAEA (R-2018) [A-27]	
Paediatric patients	ICRP 121 (R-2013) [A-75] (if breast < 5 cm)	
Eye lens		
Age not specified	IAEA (R-2018) [A-27]	

¹ In some instances the use of lead shielding is more for patient reassurance than for any real physical benefit as the major source of exposure to the abdominal organs is by far of internal scatter.

² Can be effective, but internal scattered radiation is the main source of patient dose.

³ While shielded organs that are not directly irradiated receive little benefit from external shielding, in most cases, this shielding provides 'peace of mind' to the patient's parent.

⁴ Endorses AAPM position statement on the use of patient gonadal and fetal shielding.

2018 [A-12], protection shall be used in three types of CT examinations: all-around protection (apron 360 degrees around the body) of the chest during chest CT; all-around and additional protection of the testicles during abdomen/pelvis CT; all-around and additional protection of the thyroid during head CT.

In the USA, several recommendations address the issue of organ shielding. In particular:

- Thyroid shielding shall be used if CT scans may involve clinically relevant radiation doses to the thyroid, with the goal to reduce thyroid exposure as much as feasible [A-46];
- Gonad shielding shall be used in paediatric patients, if justified and feasible [A-28-1];
- Shielding shall be used to protect uterus in pregnant patients, having in mind that shielding may also reassure and support the emotional well-being of the pregnant patient [A-28-2];
- Eye lens and thyroid shielding shall be used during paediatric chest CT [A-28-7].

According to the IAEA publication Human Health Series No 24, the use of shielding on paediatric patients can be generally considered [A-14]. Protection of organs, as thyroid, is also recommended by EuroSafe [A-39], owing that thyroid shielding is proven to reduce radiation doses by 45% during head CT examinations. The use of shielding is strongly recommended, especially in younger age groups, provided that protective tools are positioned out of the acquisition plane, around the patient body in 360 degrees.

Several organisations suggested changing this practice with respect to the use of out-of-field shielding. For example, the recent British guideline [A-42] discourages the use of shielding to protect radiosensitive organs during paediatric and adult CT examinations due to ineffectiveness in protection from the internal scatter, effect on the tube current modulation or potential misplacement. For similar reasons, out-of-field contact shielding is not recommended to protect fetus in pregnancy, as actual dose savings will be low. There is also little evidence that shielding is effective in protecting the gonads, as it is not possible to limit internal scatter (especially for ovaries) [A-42].

Mammography

A total of 42 documents from 12 countries and 2 organisations have

Table 5

Summary of recommendation for use of out-of-field shielding in CT, for different organs and patient categories. The reference is classified as "L" if it is a legislative document and as "R" if it is a recommendation.

Organ/Age	Shielding recommended or may be considered	Shielding not recommended
All sensitive organs		
Age not specified	Croatia (L-2018) [A-25] Finland (L-2109) [A-3] Serbia (L-2012) [A-44] Switzerland (R-2018) [A-12] EUROSAFE (R-2016) [A-39] IAEA (R-2013) [A-14]	Switzerland (R-2020) [A-77] UK (R-2020) [A-42]
Paediatric patients		
All sensitive organs within 5 cm from the primary field edge		
Age not specified	Brazil (L-2019) [A-69] Hungary ¹ (L-2017) [A-9]	
Gonads – Males		
Age not specified	Australia (R-2008) [A-35] Denmark ² (L-2018) [A-7] Germany (R-2018) [A-8] (Abdomen/pelvis CT)	Australia (R-2019) [A-60] Canada (R-2019) [A-45] Italy (R-2020) [A-34] Netherlands (L-2018) [A-26a&b] USA (R-2019) [A-15]
Paediatric patients	USA (R – 2017) [A-28–1]	
Gonads – Females		
Age not specified	Australia (R-2008) [A-35] Denmark ² (L-2018) [A-7]	Australia (R-2019) [A-60] Canada (R-2019) [A-45] Italy (R-2020) [A-34] Netherlands (L-2018) [A-26a&b] USA (R-2019) [A-15]
Paediatric patients	USA (R – 2017) [A-28–1]	
Eye lens		
Age not specified	Australia (R-2008) [A-35]	
Paediatric patients	USA (R – 2019) [A-28–7]	
Thyroid		
Age not specified	Australia (R-2008) [A-35] Germany ³ (R-2018) [A-8] (Head and Chest CT) USA (R – 2013) [A-46] (Chest CT) EUROSAFE (R-2016) [A-39] (Head CT) USA (R – 2019) [A-28–7] (Chest CT)	
Paediatric patients		
Woman's Breast		
Age not specified	Australia (R-2008) [A-35] Germany (R-2018) [A-8] (Head CT)	
Fetus		
Pregnant woman	Australia ⁴ (R-2008) [A-35] Germany (R-2018) [A-8] (Chest CT) USA ⁵ (R – 2018) [A-28–2]	Australia (R-2019) [A-60] Canada (R-2019) [A-45] Italy (R-2020) [A-34] USA (R-2019) [A-15]

¹ It applies for breast, gonads and thyroid.

² It applies for patients below 50 years old if the primary field is closer than 5 cm.

³ With the exception of thyroid protection for paediatric chest CT.

⁴ In some instances (e.g., the covering of the female abdomen during a chest CT scan or general radiographic procedure), the use of lead shielding is more for patient reassurance than for any real physical benefit as the major source of exposure to the abdominal organs is by way of internal scatter.

⁵ Shielding may reassure and support the emotional well-being of the pregnant patient, but the dose to the uterus (primarily from internal scatter radiation) is not materially altered.

been analysed in the context of use of out-of-field shielding in mammography. The recommendations, published from 1984 to 2020, are related to the clinical and screening mammography in adult patients. A summary of recommendations is presented in Table 6 and Figs. 2 and 3. Whenever a reviewed reference has not explicitly stated that the recommendations apply just to women, in Figs. 2 and 3 the position statement has been applied to both genders.

It is important to note that in mammography there are no sensitive organs within 5 cm of the primary beam (thyroid is typically 10–15 cm far from primary beam). The radiation dose to all other organs at risk (e. g. eye lenses or thyroid) is negligible [3]. In addition, it is mainly due to internal scatter, hence minimizing the benefit of using patient contact-shielding. Moreover, due to the specific equipment geometry employed, applying protection to organs such as the thyroid may interfere with imaging or cause artifacts that would necessitate repeat imaging of the breast [3]. This is why the use of shielding in mammography is more widely not recommended (see Table 6 and Figs. 2 and 3).

In general, none of the legislative documents or recommendations explicitly require out-of-field shielding in mammography. However, one may assume that requirements and recommendations related to the use of medical imaging which are presented in the section “general findings” may apply to mammography.

Except for patient reassurance, use of shielding is not recommended in the Australian recommendations from 2008 [A-35]. This was further modified in 2019, when Australia and Canada adopted the AAPM recommendation, according to which patient gonadal and fetal shielding during X-ray based diagnostic imaging should be discontinued as routine practice [A-15].

Some countries, however, specifically address the use of shielding in mammography, such as:

- German recommendation [A-8], according to which no protection is necessary as the dose reduction for the thyroid is negligible;
- Mammography specific recommendations from the USA [A-46] do not support the use of thyroid shields due to a lack of data to substantiate their use and the extremely low amount of radiation that reaches the thyroid (up to 0.005 mGy in a mammogram with two views);
- Spanish recommendation [A-24], stating that it is not necessary to use the leaded thyroid protection, owing that its use may be detrimental to the patient from the point of view of correct diagnosis and optimisation of radiological protection, and owing to the fact that extremely low amount of radiation reaches the thyroid.

The use of a shield to cover the abdomen of women undergoing mammography is neither necessary nor recommended according to the UK recommendation [A-42]. However, since patient contact shields covering the abdomen would not generally interfere with the imaging, they may be given to a pregnant patient at their request, but not routinely as part of the imaging protocol. Furthermore, the radiation dose to all other organs at risk (e.g. the lens of the eye, thyroid and salivary glands, bone marrow) is extremely low or negligible and is mainly due to X-rays that scatter in the breast tissue and enter the trunk through the breast, minimizing the benefit of using any form of patient contact shield.

Dental imaging

Recommendations and legislations from 16 countries and 4 organisations, consisting of 53 documents, have been analysed concerning the use of out-of-field shielding when performing dental imaging. The analysis included intraoral, cephalometric, panoramic and cone beam CT (CBCT) imaging procedures. The analysed documents were published in the period 1984–2020. A summary of recommendation is presented in Table 7 and Figs. 2 and 3.

The organs at risk in dental imaging are those in or near the primary beam, these being the thyroid, lens of the eye, brain and salivary glands. The abdomen of a pregnant patient could potentially be included in the primary beam for the vertex occlusal intraoral radiograph, but is unlikely to be included for any of the other projections [A-42].

Regulations and recommendations in many countries do not explicitly specify how protective tools shall be used, so one can assume that results presented in the section “General findings” also apply to dental imaging. Nevertheless, quite often there is a requirement concerning the availability of the protective tools, including patient shielding [A-76, A-63, A-65], or even specifications of the protective tool. For example, according to Swiss regulations [A-65], protective aprons in dentistry need to have a minimum of 0.25 mm lead equivalent.

A total of 17 out of 45 (i.e. 38%) position statements require or recommend use of shielding (see Fig. 2). A Spanish Safety Guide from 1990 recommends having a leaded apron to protect the patient whenever it is considered necessary [A-78]. Belgium guidelines from 2009 advise use of shielding for thyroid or abdomen for all patient categories undergoing dental imaging [A-29, A-30]. However, it is also advised not to use lead apron in patient categories other than pregnant women. Use of a collarless lead apron is advised for pregnant women, children or accompanying persons who have visual contact with the patient and who are in the immediate vicinity of the device. It is important to note that the more recent Belgian regulation from 2020 does not contain any recommendation on use of patient shielding in dental imaging [A-11].

According to USA guidelines from 2018 [A-18], radiation exposure to tissues adjacent to the collimated field can be significantly reduced by properly positioned shielding. In some countries, such as Finland, protective devices should be used if they do not interfere with the imaging procedures, according to the working instructions that have to be available in the X-ray room [A-3]. Shielding shall be used in all patients in Hungary [A-9], more precisely a 0.25 mm lead equivalent apron that

Table 6

Summary of recommendation for use of out-of-field shielding in mammography, for different organs and patient categories. The reference is classified as “L” if it is a legislative document and as “R” if it is a recommendation.

Organ/Age	Shielding recommended or may be considered	Shielding not recommended
All sensitive organs		
Age not specified	Croatia (L-2018) [A-25] Finland (L-2019) [A-3] IAEA (R-2018) [A-27] IAEA (R-2020) [www] Serbia (L-2012) [A-44]	Germany (R-2018) [A-8] Switzerland (R-2020) [A-77] UK (R-2020) [A-42]
Organs beyond 5 cm from the primary field edge		
Age not specified		ICRP (R-1982) [A-70]
Gonads		
Age not specified	Denmark (L-2018) [A-7] Switzerland (R-2018) [A-12]	Australia (R-2019) [A-60] Canada (R-2019) [A-45] ICRP (R-1982) [A-70] Italy (R-2020) [A-34] UK (R-2020) [A-42] USA (R-2019) [A-15]
Thyroid		
Age not specified		Spain (R-2018) [A-24] UK (R-2020) [A-42] USA (R-2013) [A-46]
Fetus		
Pregnant woman		Australia (R-2019) [A-60] Canada (R-2019) [A-45] Italy (R-2020) [A-34] UK (L-2020) [A-42] USA (R-2019) [A-15]

Table 7

Summary of recommendation for use of out-of-field shielding in dental applications (intra-oral, cephalometric, panoramic and CBCT), for different organs and patient categories. The reference is classified as “L” if it is a legislative document and as “R” if it is a recommendation.

Organ/Age	Shielding recommended or may be considered	Shielding not recommended
All sensitive organs		
Age not specified	Bulgaria (L-2016) [A-20] Croatia (L-2018) [A-25] Finland (L-2019) [A-3] Serbia (L-2012) [A-44] Spain (R-1990) [A-78] Switzerland (R-2018) [A-12] World Dental Federation (R-2014) [A-16]	Germany (R-2018) [A-8] Switzerland (R-2020) [A-77] UK (R-2010) [A-31] (R-2020) [A-42]
All except paediatric		Australia (R-2005) [A-66]
Abdomen		
Age not specified		EC (R-2004) [A-33] and EC (R-2012) [A-32] for CBCT
Gonads		
Age not specified	Denmark (L-2018) [A-7]	Australia (R-2019) [A-60] Canada (R-2019) [A-45] EC (R-2004) [A-33] and EC (R-2012) [A-32] for CBCT Italy (R-2020) [A-34] USA (R-2019) [A-15] (R-2013) [A-46] ¹
Fetus		
Age not specified		Australia (R-2019) [A-60] Canada (R-2019) [A-45] Ireland (L-2011) [A-5] Italy (R-2020) [A-34] USA (R-2019) [A-15] (R-2013) [A-46]
Thyroid		
Age not specified	Belgium for intra-oral and panoramic (R-2009) [A-29], [A-30] Brazil (L-2019) [A-69] ICRP 34 (R-1982) [A-70] Image Gently in Dentistry (R-2014) [A-17] Ireland (L-2011) [A-5] Sweden (L-2018) [A-64]	Italy (R-2020) [A-34] USA (R-2019) [A-15] (R-2013) [A-46]
Under 30 years of age	Ireland (R-2011) [A-5]	
Paediatric		ICRP 121 (R-2013) [A-75]

¹ The ATA [...] urges a reconsideration of the less stringent requirement put forth for thyroid shielding in adults as compared to children.

covers the shoulders and torso and has a collar for the protection of the thyroid. For use with CBCT, the apron must be wrap-around, but without collar, in order to avoid artefacts on the image. In Ireland, thyroid protection should be used where the thyroid is in the primary beam and the protection does not interfere with the image e.g. cephalometric radiography. In addition, it should be considered for intra-oral exams when circular collimation is used in patients under the age of 30 years [A-5]. Shielding of minimum 0.25 mm lead equivalent, aimed to protect thyroid, sternum and gonads, shall be used in all patients according to Serbian regulation [A-44]. Swedish regulation [A-64] requires only thyroid shield for intraoral dental examinations, whereas dental protection screen or adapted radiation protection apron shall be available in Switzerland [A-12].

Due to very low doses in properly conducted dental practice, use of shielding is not routinely recommended in Australia [A-66], Canada [A-

45, A-15], UK [A-31, A-42] and USA [A-15, A-46]. In particular, in the UK the use of shielding to protect the thyroid and torso is not recommended with the exception of large FOV units in CBCT, where there may be some benefit. In this case a Medical Physics Expert should be consulted [A-42]. In the USA, patient gonadal and foetal shielding during X-ray based diagnostic imaging should be discontinued as routine practice [A-15], whereas the more recent recommendation urges a reconsideration of the less stringent requirement put forth for thyroid shielding in adults as compared to children [A-46].

Following evidence according to which wearing a patient apron during panoramic imaging and dental CBCT showed no significant dose reduction [25,26,27], the German SSK-recommendation states that no protection is necessary in this case [A-8]. Despite that, a patient apron must be available for dental CBCT according to a recent document of the German derived legislation [A-76].

A number of relevant international organisations and campaigns have published documents containing recommendation on use of shielding in dental imaging, as presented in Table 8.

Discussion and conclusions

The concerns related to the use of out-of-field shielding have led to

Table 8

Summary of the recommendations on use of out-of-field shielding in dental imaging from relevant international originations and professional bodies.

Reference	Recommendation	Critical organs	Category of patients
EC (2012) [A-32]	Shielding devices could be used to reduce doses to the thyroid gland where it lies close to the primary beam in CBCT.	Thyroid	All
EUROSAFE (2017) [A-40]	Shield the thyroid of patients in CBCT: the thyroid gland seemed to receive four times more radiation in a 10-year-old than in an adolescent because of the anatomy of the patient. Reported dose reduction of approximately 50% to the thyroid when collar was used. Do not use thyroid shielding if region of interest is at the vertical level of the shielding (use scout image to verify)	Thyroid	Paediatric
ICRP 34 (1982) [A-70]	Use thyroid collars whenever possible, national/local regulations may apply. If the organ is further than 5 cm from the primary beam, use of shielding is not necessary.	Thyroid	All
ICRP 121 (2013) [A-75]	Shielding of thyroid tissue during dental x-ray examinations has been shown to have little effect on dose reduction provided that the distance to the primary field is kept at more than 2 cm	Thyroid	Paediatric
Image Gently in Dentistry (2014) [A-17]	Thyroid collars and lead aprons with collars should be used.	Thyroid	All
World Dental Federation (2014) [A-16]	Use of lead aprons and thyroid collars whenever possible.	All	All
EC (2004) [A-33] EC (2012) [A-32]	There is no evidence for the routine use of abdominal shielding (“lead aprons”) during dental CBCT examinations, in line with recommendations for conventional dental radiography. It is probable that rectangular collimation for intraoral radiography offers similar level of thyroid protection to lead shielding	Gonads	All

various recommendations, while its benefits are currently under debate. While the ICRP and IAEA endorse this practice in several documents (see Table 1), other documents no longer recommend it (see Tables 3–7). The solution for this debate should be constructive and based on a realistic risk and benefit analysis.

The primary goal of any imaging procedure is to achieve an appropriate image quality for the particular clinical indication with a minimal necessary radiation dose. It is assumed that shielding always improves patient safety, but this is not necessarily the case [3]. Indeed external patient shielding is ineffective in reducing internal scatter, it can obscure anatomy, resulting in a repeated exam or compromised diagnostic information, and it can negatively affect the AEC. These are some of the arguments stated by some of the reviewed documents arguing against the use of out-of-field shielding.

One of the most important aspects is the need for a clear understanding of the sources of ionising radiation that a patient is exposed to while undergoing medical imaging procedures. The sources of exposure include the primary beam and secondary radiation from several sources as tube leakage, extra focal radiation and several sources of scattered radiation. Knowledge of the relative intensity of each of these sources should guide the radiation protection practice. The primary beam provides a few orders of magnitude higher doses than all sources of secondary radiation and is controlled by means of a collimation system. Therefore, optimisation techniques which limit the primary beam size and position will have far greater impact upon patient dose than any efforts spent reducing the exposure from secondary radiation sources [3].

In some places, a lead shield is routinely placed between the X-ray table and the patient's gonads during fluoroscopy. A study performed for different levels of collimation concluded that collimation reduced 87% of the out-of-field radiation absorbed dose [28]. The remaining measurable dose originates from internal scatter, which cannot be reduced by shielding; therefore the clinical utility of routinely shielding out-of-field body parts is questionable.

When performing CT examinations on pregnant patients, some radiology departments use high-Z garments wrapped around the patient's lower abdomen to protect the fetus situated out-of-plane. In particular, this practice is adopted for CT imaging exams performed for exclusion of pulmonary embolism. According to the available references, uterus doses range between 0.06 and 0.66 mGy per examination, which is similar to annual doses due to background radiation. The relative dose reduction to the uterus due to high-Z garments is between 20% and 56% [29]. This is similar to the potential dose reduction achieved if scan length is reduced by one to three centimeters, which has been reported to be up to 24% for chest imaging and even 47% for upper abdominal imaging. In this case, several authors suggested that efforts should be concentrated on optimisation of imaging protocols rather than using high-Z garments for out-of-plane uterus shielding.

Other studies investigated the use of out-of field shielding for other organs of interest, such as thyroid shields in dental cone-beam CT examinations in paediatric and adult patients [30,31]. These studies recommended use of shielding when undertaking large FOV CBCT examinations. It is important to note that many of these studies were performed on phantoms, in static conditions, and as such, do not consider the inconsistent or poor use of shielding tools. In recent references, a routine use of thyroid shielding for children undergoing CBCT scanning is recommended, as well as for adults up to the age of 50 [30,32]. However, if the system uses AEC, extreme caution is needed in order to avoid an inadvertent increase of exposure.

Over several decades, imaging technology has developed, thus contributing to the significant reduction of patient exposure arising from a single procedure. For example, in 2018, the absorbed dose during pelvic radiography was 0.5% of its value from 1905 for the testes and 2% for the ovaries [33]. In spite of the evident risk reduction, optimisation has not been entirely exploited. A recent large study revealed that nearly 30 years after the introduction of the Dose Reference Levels (DRL), the

ratio of the 25th and 75th percentiles for “pelvis AP/PA” (and most other conventional X-ray projections) still exceeded a factor 2, signaling a broad distribution of doses [34] and scope for further optimisation of practice.

Therefore, modern equipment and optimisation are key aspects of organ dose reduction in medical imaging. When their full potential is exploited, the benefit of use of out-of-field shielding is small, as stated by some of the reviewed recommendations. In the light of negative side effects, discontinuation of the shielding practice seems justifiable in most cases [33,35]. However, one may also consider using shielding of radiosensitive organs, such as the gonads, the lens of the eye, the breasts and the thyroid, if appropriate and if adequate local expertise to support such practice is available, as concluded by some other reviewed documents. In this case, care should be taken in the anatomical placement of such shields, the impact of shielding on image quality and on patient dose if AEC is used.

The use of shielding has become an integral part of radiology and this practice contributed to the development of a certain psychological benefit. Many patients have a sense that routine shielding contributes to their safety and as such, provides psychological comfort even without measurable radiation protection benefit. Moreover, it is the only visual confirmation for the patient that its radiation safety is considered. This phenomenon should not be neglected. Although shielding reassures patients, it may also add confusion and cause unnecessary repetition of a procedure. Therefore, it is necessary to critically review the existing recommendations related to the use of out-of-field shielding and integrate new information related to the effectiveness of patient shielding, based on the local practice and available resources.

With this situation, it is crucial that healthcare professionals understand and are able to inform patients and those who care for them, based upon evidence-based practice and guidelines, about the benefits and risks associated with use of out-of-field shielding, in order to reach agreement on the appropriate use of such shielding.

In general, there is a wide distribution of countries and organisations among those that recommend out-of-field shielding, those that do not recommend it, and those that do not state anything about it or are not specific. Therefore, the clearest conclusion from this work is that there is no common standing on this topic.

Furthermore, the extensive documents' review reveals the following:

- The analysed documents were published over three decades, indicating that some of them might not be in line with recent scientific evidence;
- There is an evident variation of adoption of recommendations even in different provinces or regions of a single country;
- In spite of certain discrepancies between countries, or even between different organisations of the same country, shielding of the male gonads is most widely recommended when it is near the primary beam (<5 cm). On the contrary, shielding of the female gonads is most widely not recommended due to variability in position and higher probability of wrong use of shielding tools;
- For other sensitive organs that are located within 5 cm from the primary beam, the use of shielding may be considered in general with several exceptions contemplated in recent documents. Nevertheless, using shielding requires caution and careful positioning to avoid artifacts on the image or impact on the AEC system, which may lead to an increased radiation exposure;
- For those organs that are further from the primary beam (>5 cm), no particular conclusion can be derived. Often, it is acknowledged that the effect of shielding in such cases is negligible and that it may be used only to reassure patients, carers and comforters;
- With a few exceptions, in most cases the recommendations are not modality specific but rather general. Examples of modality specific recommendations are those discouraging use of shielding in mammography, in particular use of thyroid shielding due to

potential negative impact in image quality and use of gonadal shielding even in pregnant patients due to negligible dose to uterus; - In many countries, use of patient shielding in dental imaging is not recommended, except for thyroid shields in CBCT for paediatric patients, which is in some cases recommended and, in some cases, allowed.

In line with the above findings, it is evident that a common and international accepted statement regarding use of out-of-field shielding is urgently needed. Furthermore, health professionals must be adequately trained, following a standardised training programme, and have the sufficient knowledge, education and skills to know when and how to use patient shielding. It is also important that patients receive adequate information and opportunity to discuss and consent to the examination, including the decision to include or omit patient out-of-field shielding prior to the exposure. This could contribute to patient reassurance. Written procedures based on regulations, available guidance and scientific evidence are of great help to ensure consistent practice. All these points should be considered by all associations and professionals with a role in radiation protection of patients in medical imaging.

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Appendix A. Supplementary data

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