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Radiological protection in paediatric diagnostic and interventional radiology

Text produced by Pek-Lan Khong (Co-Chairperson), Veronica Donoghue, Donald Frush, Madan Rehani, Kimberly Appelgate, Ramon Sanchez, and Hans Ringertz (Co-Chairperson).

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1. INTRODUCTION

(1) The use of radiation for medical diagnostic examinations contributes over 95% of man-made radiation exposure and is only exceeded by natural background as a source of exposure to the world's population (UNSCEAR 2008).

(2) For several developed countries, the increased use of high-dose X-ray technology, in particular computed tomography, has resulted for the first time in history, in a situation where the annual collective and per capita doses of ionizing radiation due to diagnostic radiology have exceeded those from the previously largest source (natural background radiation) (UNSCEAR 2008).

(3) UNSCEAR (2008) compared estimates of the 1991-96 and 1997-2007 periods and concluded that the worldwide collective effective dose for medical diagnostic procedures increased by 70 percent. It was also estimated that worldwide there were about 3.6 billion imaging studies per year (survey covering period of 1997-2007) using ionizing radiation compared to the previous report of 2.4 billion per year (survey covering period of 1991-1996) – an increase of approximately 50%.

(4) Diagnostic radiological examinations carry higher risk per unit of radiation dose for the development of cancer in infants and children compared to adults.

(5) The higher risk is explained by the longer life expectancy in children for any harmful effects of radiation to manifest and the fact that developing organs and tissues are more sensitive to the effects of radiation.

(6) In particular, CT examinations may involve relatively high radiation dose, and an estimated 6% to 11 % of CT examinations are performed in children (Brenner, et al. 2007). The absorbed doses to organs and tissues from CT (typically more than 10 mGy) can sometimes approach or exceed the levels known from epidemiological studies to increase the probability of tumour development.

(7) Therefore, it is important for all patients, and particularly for infants and children, that all radiological examinations must be justified and optimised with regard to radiological protection.

(8) The objective of this report is to provide guiding principles to protect children from radiation for referring clinicians and clinical staff performing diagnostic imaging and interventional procedures involving ionizing radiation, highlighting the specific issues which may be unique to imaging children.

1.1 References

Brenner, D., Hall, E., 2007. Computed Tomography - An increasing source of radiation exposure. N Engl J Med 357(22), 2277-2284.

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2. BASIC CONCEPTS OF RADIOLOGICAL PROTECTION

2.1. Quantities and units

(9) The basic physical quantity used in radiological protection for stochastic effects (cell damage) such as cancer and heritable effects, is the absorbed dose averaged over an organ or tissue (i.e. mean absorbed dose; the energy deposited in the organ divided by the mass of that organ or tissue). For deterministic effects (tissue reactions resulting from cell killing), the absorbed dose is averaged over the highly irradiated portion of the tissue, such as the volume of irradiated skin in the direct radiation field. For further details on the definitions of stochastic and deterministic effects, please refer to section 2.2. The SI unit for absorbed dose is joule per kilogram (J/kg) and its special name is gray (Gy).

(10) During medical imaging procedures using X-rays, mean absorbed doses in organs or tissues of the patient undergoing diagnostic or interventional procedures cannot usually be measured directly. Therefore, measurable quantities that characterise the external radiation field are used to assist in managing the patient dose. These include simple quantities such as absorbed dose in a tissue-equivalent material at the surface of a body or in a phantom, but also a number of other quantities of varying complexity, depending on the nature of the X-ray equipment e.g. for CT, see ICRP (2000d, 2007c). Significant progress has been achieved in recent years in providing methods to derive mean absorbed doses in organs and tissues from a number of practical measurements, and a considerable body of data is available e.g. ICRU Report 74, ‘Patient dosimetry for X-rays used in medical imaging’ (ICRU, 2005) and in the technical report of IAEA series No. 457: Diagnostic radiology: an international code of practice (IAEA, 2007).

(11) Some types of radiation are more effective at inducing cell damage leading to stochastic effects. To allow for this, a quantity equivalent dose (the mean absorbed dose in an organ or tissue multiplied by a dimensionless radiation weighting factor) has been introduced. This factor accounts for the type of radiation.

For the principal type of radiation used in imaging (photons), the radiation weighting factor is assigned a value of 1, so the mean absorbed dose and the equivalent dose are numerically

equal. The SI unit for equivalent dose is joule per kilogram (J/kg) and its special name is sievert (Sv). A detailed discussion on radiation weighting factors is provided in ICRP 92 (ICRP, 2003c) and ICRP 103 (ICRP, 2007).

(12) The same value for equivalent dose in different organs and tissues in the body results in different probabilities of harm and different severities. The Commission calls the combination of probability and severity of harm, 'detriment', meaning health detriment. To reflect the combined detriment from stochastic effects due to the equivalent doses in all the organs and tissues of the body, the equivalent dose in each organ and tissue is multiplied by a tissue weighting factor, and the results are summed over the whole body to give the effective dose. The SI unit for effective dose is also joule per kilogram (J/kg) with the special name sievert (Sv). The tissue weighting factors are those recommended in ICRP (2007b) and given in Table 1. The relationship between mean absorbed dose, equivalent dose and effective dose is shown in Figure 1.

(13) The Commission intended effective dose for use as a principal protection quantity for the establishment of radiological protection guidance. It should not be used to assess risks of stochastic effects in retrospective situations for exposures in identified individuals, nor should it be used in epidemiological evaluations of human exposure, because the Commission has made judgments on the relative severity of various components of the radiation risks in the derivation of detriment for the purpose of defining tissue weighting factors. Such risks for stochastic effects are dependent on age and sex and for medical exposure on other factors such as health status. The age and sex distributions (and health status) of workers and the general population (for which the effective dose is derived) can be quite different from the overall age and sex distribution (and health status) for the population undergoing medical procedures using ionising radiation, and will also differ from one type of medical procedure to another, depending on the prevalence of the individuals for the medical condition being evaluated. For these reasons, risk assessment for medical uses of ionising radiation is best evaluated using appropriate risk values for the individual tissues at risk, and for the age and sex distribution (and health status if known) of the individuals undergoing the medical procedures (ICRP 103, 2007).

(14) Effective dose can be of practical value for comparing the relative doses related to stochastic effects from:

- different diagnostic examinations and interventional procedures;
- the use of similar technologies and procedures in different hospitals and countries; and
- the use of different technologies for the same medical examination;

provided that the representative patients or patient populations for which the effective doses are compared are similar with regard to age and sex (and health status). However, comparisons of effective doses derived as given in Section 4.3.5 of the Commission's 2007 Recommendations (ICRP, 2007d) are inappropriate when there are significant dissimilarities between the age and sex distributions (and health status) of the representative patients or patient populations being compared (e.g., children, all females, elderly patients, seriously ill patients) and the Commission's reference distribution of both sexes and all ages. This is a consequence of the fact that the magnitudes of risk for stochastic effects are dependent on age and sex (and health status).

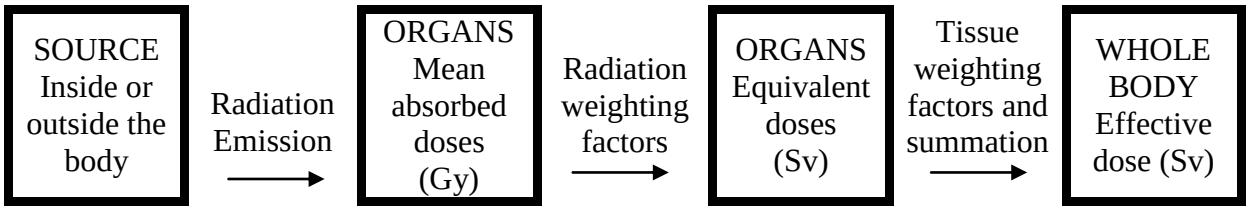

Figure 1. The relationship between absorbed dose, equivalent dose and effective dose.

	tissue weighting factor (w_T)	Σw_T
Bone-marrow (red), Colon, Lung Stomach, Breast, Remainder tissues*	**0.12**	**0.72**
Gonads	**0.08**	**0.08**
Bladder, Oesophagus, Liver, Thyroid	**0.04**	**0.16**
Bone surface, Brain, Salivary glands, Skin	**0.01**	**0.04**
	Total	**1.00**

Table 1: Tissue weighting factors recommended in ICRP publication 103 (ICRP, 2007). *Remainder tissues; Adrenals, Extrathoracic (ET) region, Gallbladder, Heart, Kidneys, Lymphatic nodes, Muscles, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus, Uterus/cervix.

2.2 Summary of biological basis for radiological protection

(15) The biological effects of radiation can be grouped into two types: deterministic effects (tissue reactions) and stochastic effects (cancer and heritable effects). These effects are noted briefly here; the biological basis for radiological protection is covered in depth in the 2007 Recommendations (ICRP, 2007d).

2.2.1 Deterministic effects

(16) If the effect only results when many cells in an organ or tissue are killed, the effect will only be clinically observable if the radiation dose is above some threshold.

The magnitude of this threshold will depend on the dose rate (i.e. dose per unit time) and linear energy transfer of the radiation, the organ or tissue irradiated the volume of the

irradiated part of the organ or tissue, and the clinical effect of interest. With increasing doses above the threshold, the probability of occurrence will rise steeply to
l00% (i.e. every exposed person will show the effect), and the severity of the effect will increase with dose. The Commission calls these effects 'deterministic' (tissue reactions), and a detailed discussion and information on deterministic effects (tissue reactions) is found in ICRP (2007a). Such effects can occur in the application of ionizing radiation in radiation therapy, and in interventional procedures, particularly when fluoroscopically guided interventional procedures are complex and require longer fluoroscopy times or acquisition of numerous images.

2.2.2. Stochastic effects

(17) There is good evidence from cellular and molecular biology that radiation damage to the DNA in a single cell can lead to a transformed cell that is still capable of reproduction. Despite the body's defences, which are normally very effective, there is a small probability that this type of damage, promoted by the influence of other agents not necessarily associated with radiation, can lead to a malignant condition (somatic effect). As the probability is low, this will only occur in a few of those exposed. If the initial damage is to the germ cells in the gonads, heritable effects may occur. These effects, both somatic and heritable, are called 'stochastic'.

(18) The probability of a stochastic effect attributable to the radiation increases with dose and is probably proportional to dose at low doses. At higher doses and dose rates, the probability often increases with dose more markedly than simple proportion.
At even higher doses, close to the thresholds of deterministic effects (tissue reactions); the probability increases more slowly, and may begin to decrease, because of the competing effect of cell killing. The probability of such effects is increased when ionising radiation is used in medical procedures.

(19) Although a single radiological examination only leads to a small increase in the probability of cancer induction in a patient, in industrialised countries each member of the population undergoes, on average, one such examination each year; therefore, the cumulative

risk increases accordingly. Calculations performed on the assumption of a linear non-threshold model of radiation action estimate that the proportion of cancer deaths in a general population that could be attributed to exposure from radiological procedures may reach a level from a fraction of one to a few percent of that cancer mortality (NAS/NRC, 2006). In addition, the risk is non-uniformly distributed in a population. Some groups of patients are examined much more frequently due to their health status. Also, some groups show higher than average sensitivity for cancer induction (e.g. embryo/foetus, infants, young children, those with genetic susceptibility). Moreover, cancers occurring early in life result in much higher lifetime loss than cancers that become manifest late in life. All these circumstances indicate that proper justification of radiation use and optimisation of radiation protection in medicine are indispensable principles of radiological protection.

(20) A detailed discussion and information on stochastic effects is found in ICRP (2007a) and the Commission's view on cancer risk at low doses is presented in Publication 99 (ICRP, 2005c). It is not feasible to determine on epidemiological grounds alone that there is, or is not, an increased risk of cancer for members of the public associated with absorbed doses of the order of 100 mGy or below. The linear non-threshold model remains a prudent basis for the practical purposes of radiological protection at low doses and low dose rates.

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3. GENERAL ASPECTS OF RADIOLOGICAL PROTECTION IN PAEDIATRIC DIAGNOSTIC IMAGING

3.1. Justification of diagnostic radiology procedures

(21) In 2007, ICRP 103 defined the general radiological protection principle that any examination requiring the use of ionizing radiation requires that the referring health care provider in consultation with the radiologist justify:

- the use of the radiological examination in question will do more good than harm to the patient
- that the specific radiological examination when required for a specific disease and age group has a specified objective and this will usually improve the diagnosis or treatment or will provide necessary information about the exposed individuals
- that the examination is required for that individual patient.

(22) It is very important for all patients, and particularly for infants and children, undergoing radiological examinations, that the examination is indicated. If doubt arises, the final decision should be taken by the radiologist in consultation with the referring clinician if necessary.

(23) A documented request for an examination including clinical information, signed by a referring clinician, should be available before an examination is performed. The type of examination to be performed should be generally justified as a procedure. Thus every examination should result in a net benefit for the individual or for the public health. The examination should be anticipated to influence the efficacy of the decisions of the referring clinician with respect to diagnosis, patient management, treatment and final outcome for the child (Dauer LT et al, 2008)

(24) Justification also implies that the necessary results cannot be achieved with other methods which would be associated with lower risk for the patient (European Commission 1996).

(25) Justification requires that the selected imaging procedure is reliable, i.e., its results are reproducible and have sufficient sensitivity, specificity, accuracy, and predictive value with respect to the particular clinical question. Thus the radiologist responsible for the examination should have sufficient knowledge and experience to make an accurate interpretation of the examination. To make this possible, the examination should be performed by a qualified clinician or by a technologist in conjunction with appropriate monitoring for quality and safety measures by medical physicists. Justification also necessitates that a single person takes the overall responsibility for the examination. This person, normally a radiologist, should be trained and experienced in radiological techniques and radiological protection as recognized by a competent authority. This person should work in close cooperation with the referring clinician in order to establish the most appropriate procedure for patient management and therapy. The responsible person can delegate the task to perform the examination to a qualified technologist, who should also be suitably trained and experienced.

(26) The feasibility of alternative techniques which do not use ionizing radiation, such as ultrasonography and magnetic resonance imaging, should always be considered. This is particularly true in children with chronic diseases. Referral guidelines on imaging for clinicians are available from, for example, the American College of Radiology (ACR Appropriateness criteria), and the Royal College of Radiologists, UK (Royal College of Radiologists, 2007). These guidelines discuss the appropriateness of the imaging modalities available to investigate many common clinical problems. Illustrative examples of such guidelines for paediatric patients from the Royal College of Radiologists are provided in Appendix A.

(27) In female patients of child-bearing age and potential, one should document last menstrual period. If there is missed period, pregnancy should be ruled out. Whenever

possible, one should conduct a pregnancy test prior to a procedure that involves higher exposure of the pelvic region through a primary beam such as interventional fluoroscopic examinations. Consideration should also be given for radiographs of the abdomen and pelvis. If the examinations are considered urgent and beneficial, the referring clinician may override this recommendation.

(28) All requests for biomedical research projects which involve the use of ionizing radiation should be individually analysed by the radiological protection committee of the institution regarding the benefits to the patients. This committee should include medical and physics expertise and it should coordinate with the medical ethics committee/ethics review board of the institution. There should be a high probability of establishing clear benefits to children in the eventual outcome.

(29) It has been shown specifically in paediatric health care that many diagnostic imaging procedures can be avoided if the above mentioned aspects of justification have been adhered to (Oikarinen et al, 2009). Thus, justification is imperative to radiological protection in paediatric patients.

3.2 Examples of paediatric examinations not justified

(30) The following radiographic examinations are not routinely justified:

- skull radiograph in an infant or child with epilepsy
- skull radiograph in an infant or child with headaches
- sinus radiograph in an infant or child under 6 years suspected of having sinusitis
- cervical spine radiograph in an infant or child with torticollis without trauma
- radiographs of the opposite side for comparison in limb injury
- scaphoid radiographs in children under 6 years
- nasal bone radiographs in children under 3 years

(31) The use of routine daily chest examination in intensive care units should be discouraged and should only be performed for specific indications (Valk, Plotz et al. 2001). These guidelines have been published by the American College of Radiology (ACR, 1996).

(32) Radiological examinations requested purely for medico-legal purposes, such as bone-age request in immigrant adolescents, are not medically justified.

3.3 Optimisation of the practice of diagnostic radiology

(33) The basic aim of the optimisation of radiological protection during an examination is to adjust imaging parameters and protection measures in such a way that the required image is obtained with least radiation dose and net benefit is maximised i.e. the ALARA (as low as reasonably achievable) principle should be adhered to for every examination.

(34) Optimisation of radiological protection involves three main aspects: radiological equipment, adjustment of radiation parameters when examining children, and diagnostic reference levels applicable to paediatric patients.

3.3.1 Radiological equipment

(35) As part of the optimisation process it is important to ensure that equipment is working properly, is delivering the appropriate exposures, and is compliant with established standards of installation and performance. This starts with the procurement process, where equipment should be purchased so that its performance is to a level set out in a written specification that requires compliance with relevant international, national, state, and regional or local as well as professional standards. Once installed, the equipment should be both acceptance tested and commissioned so that its performance to these standards is verified. In some countries this should be done by an agent (physicist or engineer) other than the supplier who acts for the end user/hospital or the national regulatory agency. Whether or not it is legally required, it is important that it is done and properly documented, even in the case of relatively simple

equipment such as intra-oral dental systems. Proper documentation will make the omission of system components such as filters or pulsed facilities easier to identify.

(36) X-ray equipment used for paediatric procedures should have the full range of settings to optimise the dose to the size of the child. Programs should be instigated and should cover a selection of the most important physical and technical parameters associated with the types of X-ray examinations being carried out. Limiting values for these technical parameters and tolerances for the accuracy of their measurement are required for meaningful application of good radiographic technique.

(37) After introduction into routine use, it is important to ensure that equipment continues to perform satisfactorily. This can be assured by relatively quick and simple constancy checks, performed and documented regularly by the hospital. Suggestions for appropriate tests and their frequency are available (IPEM 2004). An example for a general radiography unit is to check if the X-ray beam is coincident with the light beam localization system. Next in importance would be to measure the X-ray beam output and checking for the presence of filters. Other relatively easy to perform quality control (QC) tests are often provided by the manufacturers with equipment such as CT scanners. At a more demanding level, it is important to comprehensively review the performance of each machine every year, or after it undergoes a major repair or service (e.g. a tube change). All of these QC procedures should be documented properly. Finally, it is essential that this process of assessing equipment performance is integrated into the management of the department, so that the findings of tests are noted and acted on.

3.3.2 Adjustment in parameters

(38) As most imaging equipment is structured to handle adult patients, modifications of the above mentioned parameters may be necessary both at installation and later in the use of the equipment. Special consideration should be given to dose reduction measures when purchasing new radiographic or fluoroscopic equipment for paediatric use. Adding a 0.3 mm copper filter in addition to the inherent aluminium filtration should be considered if not provided. Dose reduction methods can be helpful and the availability of pulsed fluoroscopy, especially grid controlled, last image hold and capture, spectral filters and adaptive

technologies to minimize blooming (in addition to the recognized importance of minimizing fluoroscopy time) together allow for substantial dose reduction, especially in paediatric imaging. For optimisation of parameters in CT, please refer to section 6.

3.3.3 Diagnostic reference levels (DRLs) in paediatric radiology

(39) The radiological protection principle of dose limits used for exposure of workers and the general public does not apply to medical exposures for patients. To assist in the optimisation process of medical exposure to patients, the concept of **diagnostic reference level** (DRL) has been introduced. A DRL value is advisory, and in practice is set so that if the value is exceeded regularly, the practice involved should be investigated. This does not mean there is necessarily unacceptable practice; rather the practice requires explanation, review, or possibly a new approach.

(40) This may be illustrated by the EU DRLs for 5-year olds in paediatric radiology (European Commission 1996; EU Radiation protection 109 1999). These are established by surveying an appropriate field-related quantity for a number of the more common projections in a range of institutions. For general radiography various projections of chest, skull, abdomen, spine and pelvis are surveyed. In practice, a field-related quantity that is easy to measure is utilized (in the case of the EU approach, entrance skin dose (ESD) is used). The upper DRL is often taken as the third quartile value, i.e. the value below which the measurements for three quarters of the institutions lie; a lower DRL may also be selected. Thus there is a reasonable expectation that measurements taken in any institutions should lie below the upper DRL, and if above, it should be possible to reduce exposures below the DRL without loss of clinical information. For example, excessive use of an antiscatter grid may result in ESD values above the upper DRL. With review of technique, image quality, further education and training, the resultant ESD values will potentially be below the upper DRL. It is important to understand that it is possible the ESD values may be too low, and corrective action in this regard may also be warranted when the value is consistently below a selected lower DRL.

Table 2: Examples of Diagnostic Reference Levels in Paediatrics for standard five-year-old patients, expressed in entrance surface dose per image for single views. (European Commission 1996) .

Radiograph	5-year-old patients Entrance surface dose Per single view (mGy)*
Chest Posterior Anterior (PA)	0.1
Chest Anterior Posterior (AP for non-co-operative patients)	0.1
Chest Lateral (Lat)	0.2
Chest Anterior Posterior (AP new-born)	0.08
Skull Posterior Anterior/Anterior Posterior (PA/AP)	1.5
Skull Lateral (Lat)	1.0
Pelvis Anterior Posterior (AP)	0.9
Pelvis Anterior Posterior (AP infants)	0.2
Abdomen (AP/PA with vertical/horizontal beam)	1.0

*Upper DRL expressed as entrance surface dose to the patient. The entrance surface dose for standard-sized patients is the absorbed dose in air (mGy) at the point of intersection of the beam axis with the surface of a paediatric patient, backscatter radiation included.

(41) Diagnostic reference levels for some conventional radiographic examinations are given in Table 2. It is important to be aware that these are for 5-year olds and that different values would be obtained with other age-groups, for instance, infants or 10-year olds. Some available data for these older and younger age groups is presented in Table 3, but these have not been adopted as DRLs to date (European Commission 1996). Formally adopted EU DRLs have been limited to the 5 year old group, on the grounds that assessing results for even one group will give a marker for department performance. It is important to note that these DRLs were obtained prior to the widespread introduction of computed radiography (CR) and digital radiography (DR) in many parts of the world, and they need to be extended and re-evaluated (ICRP 93, 2004) to take account of recent developments. Somewhat more comprehensive data for UK values for fluoroscopic studies have been determined (Hart, Hillier et al. 2007) and compared with equivalent DRLs documented in Great Ormond Street Hospital, London (Hiorns, Saini et al. 2006). DRLs have also been determined for CT though not based on as wide a survey. The same comments apply with respect to the age groups involved and innovations in imaging technology.

Table 3: Variations of entrance surface dose* (converted to mGy, to the nearest 2 decimal places) observed in the three European Union paediatric trials (1989/91, 1992, 1994/95; (Kohn 1996)) median, minimum-maximum values and corresponding ratio (min:max) of frequent X-ray examinations in paediatric patients.

Examination type	Infant			5 year-old			10 year-old		
	med	min-max	min:max	med	min-max	min:max	med	min-max	min:max
Chest AP (1000 g new-born)	0.05	0.01–0.34	1:35						
Chest PA/AP	0.08	0.02-1.0	1:47	0.07	0.02-1.35	1:71	0.07	0.02-1.16	1:68
Chest AP (mobile)	0.09	0.03-0.72	1:21	0.07	0.03-0.33	1:11	0.09	0.03-0.76	1:26
Chest Lateral				0.14	0.04-0.55	1:15	0.15	0.04-1.98	1:51
Skull PA/AP	0.93	0.15-4.51	1:30	1.00	0.24-4.63	1:19	1.04	0.13-5.21	1:40
Skull Lateral				0.70	0.14-2.36	1:17	0.58	0.11-3.79	1:33
Pelvis AP	0.26	0.02-1.37	1:76	0.49	0.09-2.79	1:32	0.81	0.09-4.17	1:47
Full SpinePA/AP	0.87	0.12-0.44	1:41						
Thoracic Spine AP							0.89	0.20-4.31	1:21
Thoracic Spine Lateral							1.63	0.30-6.66	1:22
Lumbar Spine AP							1.15	0.13-5.69	1:43
Lumbar Spine Lateral							2.43	0.25-23.5	1:94
Abdomen AP/PA	0.44	0.08-3.21	1:42	0.59	0.06-2.92	1:52	0.73	0.15-3.98	1:27

- See definition for entrance surface dose in Table 2.

3.4 Quality criteria implementation and audit

(42) As a part of the radiological protection culture that is needed in any unit examining children with ionizing radiation, there is a need for follow up and regular audits after implementation of quality criteria.

(43) The following are some examples of how auditing was implemented for radiological protection in paediatric practices and the favourable outcome that resulted from auditing.

- For paediatric skull trauma, an audit of the recommended guidelines for CT examinations demonstrated that adjustments in clinical referring practices resulted in an eightfold decrease in CT utilization (McGregor and McKie, 2005). In the same

way, repeated audits resulted in marked reduction in skull radiographs and significant increase in compliance to guidelines for paediatric head trauma (Johnson and Williams, 2004).

- Audits of referral criteria, image quality and imaging technique in paediatric radiology practices revealed better results for paediatric specialist centres compared to non-specialist centres (Cook, et al. 2001; Alt, et al. 2006).
- Gonad shield placement was audited using a multidisciplinary approach after which dose reduction measures were introduced and this improved the outcome of shielding. The percentage of correct placement was increased from 32% and 22% to 78% and 94% for boys and girls respectively (McCarty, et al. 2001).

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4. RADIOLOGICAL PROTECTION IN CONVENTIONAL PAEDIATRIC RADIOGRAPHY AND FLUOROSCOPY

(44) European guidelines on quality criteria in paediatric radiology (European Commission, 1996) cover conventional examinations of chest, skull, pelvis, total and focal spine examinations, abdomen and urinary tract for different projections and in some instances specific criteria for new-borns. For each examination there is a need for diagnostic criteria specifying anatomical image criteria, criteria for radiation dose to the patient, and examples for good radiographic technique by which the diagnostic requirements and dose criteria can be achieved.

4.1 Patient positioning and immobilization

(45) Patient positioning has to be exact even if the patient does not cooperate so that the beam can be correctly centred, the proper projection and collimation can be obtained, and the non-examined part of the body is shielded.

(46) Immobilization is required in many children when performing radiographic studies. Devices, such as sponges, Plexiglas or sandbags may be used in the very small infants. It may be useful to take advantage of the period when the infant is calm or asleep after having been feed to perform the radiological examination. Immobilization devices should be easy to use and their application should not be traumatic to the patient (or caregivers). Therefore their use and benefits should be explained to the accompanying caregiver.

(47) The patient should be held by the radiological staff in exceptional circumstances only. When hospital personnel help to immobilize a child, this is regarded as an occupational exposure and care should be taken to ensure that the staff is not repeatedly exposed to radiation. When physical restraint by parents or other accompanying person is unavoidable, they should be informed about the exact procedure and what is required from them in particular the effect of distance. They should be provided with protective apron and be

outside of the primary beam of radiation. Caregiver hands holding the child should not be exposed to the radiation beam.

(48) The time allocation for an examination should include time to explain the procedure not only to the accompanying caregiver, but also to the child. Time taken is well spent in achieving an optimized examination fulfilling the necessary quality criteria (European Commission 1996). This procedure can be simplified by providing information explaining the details of the procedure to be undertaken in advance of the study. Videos, written material or web sites available for viewing by the children in the waiting area or in the examination room prior to the studies can also be helpful in making child feel comfortable and thus achieving cooperation.

4.2 Field size and X-ray beam limitation

(49) A field which is too small increases the risk of a diagnostic error or may require a second exposure. A field that is too large will impair the image contrast and resolution by increasing the scattered radiation and will result in unnecessary radiation dose to the child outside the area of interest. Some degree of flexibility is necessary to ensure that the entire field of interest is included, but repeatedly using unnecessarily large field sizes in children is inappropriate.

(50) Correct beam limitation requires knowledge of external anatomic landmarks. These landmarks change with age of the patient due to varying proportions of the body during development. The size of the field of interest is more dependent on the underlying disease in infants and younger children compared to adults due to more marked deformation of the normal anatomy with disease. Thus basic knowledge of paediatric disorders is also required from the radiographers to ensure proper beam limitation in all age groups. It is important to use collimation to expose only the area intended for examination, rather than for example, doing baby-grams (whole body, chest, abdomen, and pelvis on one image) in neonates.

606
607 **4.3 Protective shielding**
608
609 (51) Good radiographic technique includes standard use of lead or equivalent shielding of the
610 child's body in the immediate proximity of the diagnostic field. However, the use of
611 additional shielding should be considered for certain examinations to protect against external
612 scattered and extra-focal radiation. For exposures of 60-80 kV, a maximum gonadal dose
613 reduction of about 30-40 % can be obtained by shielding with 0.25 millimetres lead
614 equivalent material immediately at the field edge. However, this is only true when the
615 protection is placed correctly at the field edge. Lead equivalent coverings further away are
616 less effective and at a distance of more than four centimetres are likely ineffective. Doses to
617 the tissues outside of the X-ray beam occurring from internal scatter radiation cannot be
618 effectively shielded.
619
620 (52) When the breasts, gonads, and/or thyroid lie within or nearer than five centimetres to the
621 primary beam, they should be protected whenever this is possible without impairing the
622 necessary diagnostic information. It should be noted that such shielding can have serious
623 impacts on image quality, and in such cases, shielding may not be appropriate (Dauer LT,
624 2007). Lead or equivalent shields for girls and lead or equivalent capsules for boys are
625 commercially available or maybe made in-house. They should be available in many sizes.
626 Non-lead protective devices are nowadays available and might be more environmental
627 friendly and more durable. The testes should be protected by securing them within the
628 scrotum to avoid upward movement caused by the cremasteric reflex. Using properly
629 adjusted capsules, the absorbed dose in the testes can be reduced up to 95%. In girls, shadow
630 masks within the diaphragm of the collimator are as efficient as direct shields. They can be
631 more exactly positioned and do not slip as easily as contact shields. When shielding of the
632 female gonads is appropriate, the reduction of the absorbed dose using effective shielding for
633 the ovaries can be about 50 %. (Fawcett and Barter, 2009).
634
635 (53) There is typically no reason to include the male gonads within the primary radiation field
636 for radiographs of the abdomen. The same is usually valid for examinations of the pelvis and
637 micturating cystourethrographies. The testes should be protected with the protective capsule

but kept outside the direct radiation field. In abdominal or pelvic examinations gonad protection for girls is not possible. There are justifiable reasons for omitting gonad protection for pelvic films in girls, e.g. trauma, incontinence, abdominal pain, etc. as misplaced shielding may mask important pathology (Bardo et al. 2009).

(54) The eyes should be shielded, if feasible, with appropriate shielding material (e.g. bismuth shields) or lead-equivalent eyeglasses, for X-ray examinations involving high absorbed doses in the eyes, e.g. for CT of the brain and facial bones when angulation of the gantry is not sufficient to keep the orbits outside the examination volume. If the patient is co-operative, the absorbed dose can be reduced by 50-70 %. In head CT studies the use of angulation of the gantry can reduce the eye dose by 90% (Mettler et al 2008). Posterior-anterior (PA) projection in radiography of the skull rather than the anterior-posterior (AP) projection can also reduce the absorbed dose in the eyes. PA-projection therefore should be preferred as soon as patient age and co-operation permit prone or erect positioning.

(55) In girls of pubertal age, the developing breast tissue is particularly sensitive to radiation, and thus exposure should be limited as much as possible. The most effective method in radiography is by using the PA-projection, rather than the AP. This is well accepted for chest examinations, but the greatest risk is during spinal examinations where PA-examinations should replace AP projections.

(56) It is also important that thyroid tissue is protected in children when appropriate and possible. Shielding during CT of the skull or dental X-ray examinations has however been shown to have little effect on dose reduction as long as the distance to the primary field is kept more than a couple of centimetres. The dose to the thyroid consists mainly of internally scattered radiation during CT of the skull or chest, dental examinations, and chest X-ray.

4.4 Radiographic exposure conditions

(57) Knowledge and correct use of appropriate radiographic exposure factors, e.g., nominal focal spot size, filtration, focus to image plane distance, and tube voltage is necessary

because they have a considerable impact on image quality and this may have implications on dose. Permanent parameters of apparatus such as total tube filtration and antiscatter grid characteristics should also be taken into consideration.

4.4.1 Nominal focal spot size

(58) One should endeavour to achieve good image detail by maintaining a balance between the use of a small focal spot size and a short exposure time. Usually a nominal focal spot value between 0.6 and 1.3 is suitable for paediatric patients. When bifocal tubes are available, the nominal focal spot value should be that which allows for the most appropriate setting of exposure time and tube voltage at a chosen focus to image plane distance. This may not always be the smaller option.

4.4.2 Additional filtration

(59) The X-ray spectrum includes photons of different energies. The low-energy photons, i.e., the soft part of the spectrum is completely absorbed in the patient and does not contribute to radiological examinations, unnecessarily adding to the examination dose. In general, radiation dose can be reduced by using higher kVp and an additional filtration. Most tubes have a minimum filtration of 2.5 mm of aluminium which includes inherent filtration plus fixed filters. Additional filters can further reduce the unproductive radiation and thus the patient dose.

(60) Not all generators allow the short exposure times (particularly mobile radiography units) that are required for these higher kVp techniques. Consequently, low tube voltage is often used for paediatric patients. This results in comparatively higher patient doses. To overcome the limited capacity of such equipment for short exposure, adequate additional filtration will allow the use of higher tube voltage with the shortest available exposure times. This makes the use of computed radiography (CR) and digital radiography (DR), image intensifier photography and high speed screen film systems possible.

(61) Rare-earth filter materials with absorption edges at specific wavelengths have little or no advantage over simple inexpensive aluminium-copper (or aluminium-iron) filters, which can easily be homemade, provided that the appropriate high purity material is available. All tubes used for paediatric patients in stationary, mobile, or fluoroscopic equipment should have the facility for adding additional filtration, and for changing it easily when appropriate. Usually up to 1 mm aluminium plus 0.1 (or 0.2) mm copper as additional filtration is adequate. For standard tube voltages, each 0.1 mm of copper is equal to about 3 mm of aluminium.

4.4.3 Anti-scatter grid

(62) In infants and younger children the use of an antiscatter grid or other anti-scatter measures is often unnecessary; because of the relatively low scatter radiation produced in the irradiated volume (mass). Antiscatter grids increase contrast but increase the radiation dose. Not using grids can avoid excessive patient dose. When anti-scatter measures are necessary, grid ratios of eight and line numbers of 40/cm (moving grid) are usually sufficient even at higher radiographic voltage. However, in newer pulsed fluoroscopic units recommendations are to use antiscatter grid even with infants since quality improvement has been found to outweigh increase in dose.

(63) Grids incorporating low attenuation materials such as carbon fibre or other non-metallic material are preferable. Moving grids may present problems in very short exposure times (less than ten milliseconds). In these cases, stationary grids with high strip densities (density>60/cm) should be used. Quality control of moving grid devices for paediatric patients should take this into consideration. The accurate alignment of grid, patient, and X-ray beam, as well as careful attention to the correct focus-to-grid distance is of particular importance.

(64) Depending on manufacturer recommendations, most often fluoroscopic equipment with the potential for quick and easy removal of the grid should be used in children. Removable grids are desirable not only for fluoroscopic work but ideally all equipment used for paediatric should patients have this facility. This should always be supplemented with the lowest pulsed fluoroscopic setting to decrease unnecessary radiation exposures.

4.4.4 Focus to image plane distance

(65) The correct adjustment of the focus to image plane distance should be observed when using a non-grid cassette technique. When no grid is used and the cassette is placed upon the table, focus to image plane distance of about 100 cm should be chosen, ensuring that the same tube to table distance is obtained as with the grid. Special circumstances may call for a longer focus to image plane distance.

(66) In all fluoroscopic examinations, patient to image plane and patient to image intensifier distances should be kept as short as possible to reduce patient dose.

4.4.5 Automatic exposure control (AEC)

(67) Adult patients vary in size, but their variation is small compared to paediatric patients which may range between premature infants, weighing considerably less than one kilogram, to adolescents heavier than 100 kg. Those investigating paediatric patients need to be able to adapt to this wide range. However, AEC device in many of the systems commonly available are not satisfactory, because the exposure time required in the case of small children may be too short for the AEC to react and be accurate and reproducible. They have relatively large and fixed ionization chambers. Their size, shape, and position are unable to compensate for the many variations of body size and body proportions in paediatric patients. In addition, the usual ionisation chambers of AECs are built in behind an antiscatter grid. Consequently, AEC-use may be associated with the use of the grid, which is frequently unnecessary.

(68) The optimal adaptation of the radiographic technique to the clinical needs requires the use of digital plates or screen film systems of different speeds and different switch-off doses at the image receptor. Screens and AEC chambers are energy dependent, particularly in the lower range of radiographic voltage, but these dependencies do not correspond with each other. AECs lengthen the minimal exposure times. All these factors should be considered when AECs are used with paediatric patients.

765
766 (69) Specially designed paediatric AECs have a small mobile detector for use behind a lead-
767 free cassette (Dendy & Heaton 1999). Its position can be selected with respect to the most
768 important region of interest. This should be done very carefully as even minor patient
769 movements may affect image quality and patient dose. The high speed of digital plates or
770 modern screens requires a minute dose at the cassette front. Consequently, the detector
771 behind the cassette has to work in the range of a fraction of 1 mGy and this may be
772 challenging to implement.
773
774 (70) Much safer than automatic exposure control (AEC) in the case of small children, easy-
775 to-use and less expensive are exposure charts, corresponding to radiographic technique,
776 accounting for patient's weight when examining the trunk, or patient age when examining the
777 extremities. Small and simple computer programs may use the multiple parameters to
778 calculate optimal exposure data. Examples of good radiographic techniques can indicate
779 when the AEC may be used and which chamber should be selected.
780
781 **4.4.6 Automatic brightness control in fluoroscopy**
782
783 (71) Automatic brightness control has to be switched off during fluoroscopic examinations
784 where there are relatively large areas with positive contrast material to avoid excessive dose
785 rates, e.g. contrast-filled full bladders.
786
787 **4.4.7 Exposure time**
788
789 (72) In paediatric imaging, exposure times should be short because children generally do not
790 co-operate and are difficult to restrain. These short times are only possible with powerful
791 generators and tubes, as well as optimal rectification and accurate time switches. The
792 equipment should work and provide constancy in the shortest time range. For old generators,
793 exposure time settings lower than 4 milliseconds, even if desired, should not be used as the
794 pre-peak times (>2 milliseconds) interfere, to a relatively greater degree, with short pre-set
795 exposures. Therefore more recent generators such as 12-pulse and multi-pulse or high
796 frequency generators are recommended.

(73) For these short exposure times, the cable length between the transformer and the tube is important. The cable works as a capacitor and may, depending on its length, produce a significant surge of radiation after the generator has been switched off. This post-peak radiation may last for 2 milliseconds or more.

(74) Accurately reproducible exposure times around 1 millisecond with a rectangular configuration of the dose rate and wavelength of radiation, practically without pre- or post-radiation, may be achieved with grid controlled tubes (Plewes & Vogelstein, 1984)

(75) For most equipment used for paediatric patients, however, the difficulty is in obtaining optimal short exposure times. Unless it is possible to adapt the available equipment to use the recommended range of exposure times, the equipment should not be used for paediatric patients.

4.5 Mobile radiography

(76) Where practicable, all X-ray examinations should be carried out in the radiology department because the higher image quality of stationary equipment and patient dose considerations. Thus, the use of mobile X-ray units should be limited to those patients who cannot be transported to the radiology department.

(77) In addition to the principles outlined above for general radiography, regular use should be made of portable lead shielding to protect nearby patients, unless there is sufficient distance between other patients and the radiation source.

(78) For low-birth weight and very low-birth weight premature infants who cannot be transported to the radiology department, mobile units using a very low exposure with little scattered radiation are often utilized.

(79) Where mobile examinations are frequently performed in a specific unit (i.e. an intensive care unit for older children), the adequacy of the shielding in the surrounding walls and floor should be assessed.

4.6 Digital radiographic systems

(80) In general, digital imaging has allowed a reduction in radiation dose while improving image quality and diagnostic accuracy, but only after appropriate training and careful monitoring of parameters used in the individual radiology department. Patient dose parameters should be displayed at the operator console.

(81) It is important that radiology departments optimise their exposure parameters when a new digital system is installed, and regularly thereafter to maintain QA (ICRP 93, 2004). One of the simplest methods is to monitor the exposure index of the digital system, which is an objective indicator of radiation exposure incident on the imaging plate. (Vano E et al, 2008)

(82) Appropriate image processing is crucial in producing the optimal paediatric CR or DR image. Most CR and DR manufacturers now recognise that paediatric patients are unique and have or are developing special provisions for paediatric examinations, including image processing. (Sanchez Jacob et al. 2009)

(83) The following recommendations to aid dose reduction and image optimisation include those from The Second ALARA conference organised by the Society for Paediatric Radiology held in Houston, Texas in February 2004 (Willis and Slovis 2004):

Guidelines to practitioners:

1. There should be a team approach to dose management in CR and DR. The team should include the active participation of a radiologist, medical physicist, radiographer/technologist, biomedical engineer, manufacturer service engineer, manufacturer applications engineer and manufacturer imaging scientist.
2. Training of radiographer/technologist in CR and DR technology and practice.
3. Obtain the best patient positioning that is practicable and collimate adequately.

4. Consider the indication for the study. In the intensive care setting, for example, lines and catheters etc. are inherently of high contrast and there is therefore significant scope for dose reduction when the clinical indication is solely to confirm their position.

4.7 Screen film systems

(84) Among the technical parameters, the selection of higher speed classes of screen film system has the greatest impact on dose reduction. In addition, it allows shorter exposure times that minimizes motion artefact, which is the most common cause of blurring in paediatric imaging. The reduced resolution of higher speed screens is comparatively insignificant for the majority of clinical indications. For special purposes like bony detail, speed classes of 200 to 400 are to be preferred. If different sets of cassettes are available, one for special indications with screens of lower speed and higher resolution and one set for general use, they should be clearly marked. It should also be noted that similar screen film systems may vary between manufacturers and intermediate values of speed classes are common. Therefore, the indicated nominal speed classes in this text can only give approximate guidance.

(85) Users should be encouraged to measure the real speeds of their screen film systems under standard conditions. The variation in speed which can occur with changes in X-ray beam energy, especially below 70 kV, should be recognized for individual screen film systems. Users are also encouraged to measure the resolution of their screen film systems since this varies with the speed classes.

4.8 Fluoroscopy

(86) Pulsed fluoroscopy was initially developed as an attempt to reduce fluoroscopic radiation dose by limiting the time during which the patient was exposed to the X-ray beam, by using reduction in the number of exposures per second. Current grid-controlled pulsed fluoroscopy units use a negatively charged grid interposed between the cathode and the anode

of the X-ray tube. The grid can be rapidly switched on and off, which thereby allows appropriate energy electrons generated to be intermittently passed through the grid to produce X rays. Optimisation of the fluoroscopy pulse widths and careful choice of entrance exposure per pulse during calibration of the unit can permit additional dose savings (Ward et al, 2006).

(87) Results of dose reduction versus image quality with grid-controlled pulsed fluoroscopy have demonstrated up to 10-fold reduction without significant reduction of contrast or spatial resolution in paediatric radiology (Lederman, Khademian, et al. 2002). At 15, 7.5 and 3.75 frames per second the dose reduction is about the same. In an animal model simulating infant, toddler, and child sizes, the use of pulsed fluoroscopy decreased radiation exposure by a factor of 4.6 to 7.5 compared with a conventional unit, and there was no significant loss of diagnostic quality (Ward et al, 2006).

(88) Radiation dose can be minimized by keeping the fluoroscopy table as far from the X-ray source as possible (to reduce entrance dose to the skin). The image intensifier should be as close to the patient as possible (to maximize capture of the maximum number of X-rays on the one hand and to improve image quality on the other through improvement of resolution).

(89) Scattered radiation emanating from below the table can be minimized by installing a hanging lead drape on the patient table to shield the legs of the operator. New generation sterile drapes impregnated with bismuth or other materials may be used if available. These drapes can markedly reduce doses to the operator and other staff members. They have been shown to reduce operator hand/wrist doses by up to 90% and can also be positioned to protect the radiologist from the waist down (King et al, 2002), and have been shown to reduce operator lens doses as well (Thornton RH et al, 2010, epub ahead of print). If shielding is used for patient protection it needs to be strategically placed under the patient if an undercouch tube is used, and should not be placed in the direct beam, as this will tend to increase the entrance skin doses for those units utilizing automatic exposure control features.

(90) For radiological protection during the procedure, fluoroscopy should only be used to evaluate a moving target or structure and fluoroscopy time should be limited. Still images acquired using last-image hold should be used to review findings and not live fluoroscopy.

Pulsed fluoroscopy should be used and in many instances 3 to 8 pulses per second is adequate for guidance and monitoring of a procedure (Connolly, et al. 2006). The image intensifier should be positioned over the area of interest before fluoroscopy is commenced rather than positioning during fluoroscopy. Under certain circumstances, virtual collimation helps to perform this positioning without having to use fluoroscopy for this purpose. Tight collimation to the relevant anatomical area is important. Attention should be given to angle the beam away from radiosensitive areas (breast, eyes, thyroid, and gonads) and collimating these areas out of the field if possible. Magnification should be kept to a minimum. Alarm bells for fluoroscopy beyond a certain time or live readouts in the room are useful reminders to limit fluoroscopy time. $K_{A,R}$ (total air kerma at the reference point) or P_{KA} (air kerma x X-ray beam area) for the procedure should be recorded and compared with benchmark figures, such as those published by AAPM (American Association of Physicists in Medicine 1998, Amis, et al. 2007).

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5. RADIOLOGICAL PROTECTION IN PAEDIATRIC INTERVENTIONAL RADIOLOGY

(91) The use of interventional radiology for children is increasing in frequency and also in the sophistication and length of the procedures. As a result the potential for high patient overall radiation dose is greater. Major paediatric interventional procedures, particularly in small infants, should be performed by experienced paediatric interventional operators both for clinical and radioprotective reasons.

(92) All intervention team members should be aware of radiation exposure and all should undergo training in radiological physics and radiological protection. In fact, a second, specific level of training in radiation protection, additional to that undertaken in diagnostic radiology, is desirable. Also, specific additional training should be planned when new X-ray systems or techniques are implemented in a centre (Connolly, et al. 2006, Rehani 2007). (ICRP 85, 2001)

5.1 Reducing unnecessary dose to the patient

(93) A unique feature in paediatric intervention is the large size of the image intensifiers relative to the infant size. In infants and small children the image intensifier will completely cover the patient and therefore has the potential to increase radiation exposure if collimation is not in use. There is also an increased need to use magnification in children which further increases dose (Connolly, et al. 2006).

(94) The procedure should only be performed when absolutely necessary, and when a procedure is performed, one should minimize or avoid radiation whenever possible by using ultrasound guidance rather than fluoroscopy or CT. If using fluoroscopy, use pulsed fluoroscopy with last image hold or archive fluoroscopy runs. Complex interventional procedures have been shown to impart high peak skin doses in adults and high absorbed doses to the exposed organs and tissues in children. The potential clinical effects for single-

delivery radiation doses to the skin for adults are listed in Table 4 (Balter S, et al. 2010). There are, to date, no data available for children. Each department should have a quality assurance programme in place for all equipment under the supervision of a medical physicist. (ICRP 85, 2001)

5.2 Reducing unnecessary dose to the staff

(95) Special attention should be given to staff exposure that arises from patient scattered radiation. Children are smaller but also more mobile and procedures may take a longer time. Therefore minimizing radiation exposure requires the optimisation of protection by reducing unnecessary radiation dose for the patient as well as the staff, whose dose accumulates over many procedures and years (Niklason, et al. 1993; Tsapaki 2001)

(96) Paediatric interventional radiology has unique features which relate to patient size. Patient sizes vary from as small as 0.450 kilograms to in excess of 100 kilograms. To gain access to the small child, it is frequently necessary for the interventional radiologist to come close to or on occasion enter the beam. The operator's hands may be directly in or immediately adjacent to the beam during a procedure such as a central line or abscess drainage, or they might enter the beam urgently when an unexpected event or a complication occurs. Attention should be paid to the following points:

- Protective lead apron and protection for the eyes (ceiling suspended screen or lead glasses) should be used by the team members operating close to the X-ray tube and the patient, if the level of scatter dose is significant. The appropriate protection of the anaesthetist shall also be considered.
- Ceiling mounted leaded glass or plastic shields or lead glass eyewear with side shields reduce radiation exposure to the eyes of the operator by 90% (Thornton RH et al, 2010)
- Prescription and non-prescription lead glasses are available.
- Protective aprons should be well fitted, with arm wings to protect the axillary tail of the breasts for female workers, and a full front and back apron for those moving around in the room.

- Radio-protective gloves can reduce the hand dose from scattered radiation by 40-50%. On the other hand, it is noteworthy that the use of such gloves can reduced dexterity and may prolong the procedure.
- Foot and leg doses for the operator are increasingly receiving attention as procedures become more complex and longer. Lead table flaps or newer compound material drapes that reduce the dose from scattered radiation to the legs and ankles may be considered.
- Staff dose should be determined with one badge under the lead apron and one over the apron at the collar if being used. (ICRP 85, 2001) The use of radiation ring badges is also important if the procedures performed have the probability of the hands falling in the primary beam or on the edge of the primary beam.
- Slight angulation of the beam off the hands, strict collimation and careful attention to finger positioning will help reduce operator exposure.
- The operator should stand to the side of the image intensifier and team members should step back and take advantage of the reduction in radiation levels due to the greater distance from the source (i.e., the inverse square law).
- In an adult study, the use of a power injector instead of hand injecting contrast material has been shown to be the single most effective way to reduce operator dose during angiography (Hayashi, Sakai et al. 1998). It should be used where possible and the operator should step away from the patient and/or behind a mobile lead screen during contrast injections. When manual injection is necessary, maximizing the distance from the patient as much as catheter length will permit is important to minimize radiation dose.

5.3 Image acquisition using digital angiography or digital subtraction angiography

(97) Each run should be necessary for diagnosis or to assess outcome after a procedure. The fewest number of frames per second should be used, and images should be obtained using the

lowest magnification (post processing magnification is possible). Tight collimation should always be used to include only the area of interest. Furthermore, last image hold, image capture, video-recording and digital archiving of fluoroscopy runs that can be also archived in the PACS system, all offer opportunities to further reduce dose during paediatric fluoroscopy.

(98) When C-arm equipment is used, it is important to be aware of the proximity of the skin to the X-ray source in the lateral and oblique views, as it might be closer than permitted in the PA view and result in an increase in patient skin dose. The patient's arms should be raised whenever possible when in the lateral and oblique positions. After the C-arm is put in the lateral position, the patient should be distanced from the source to the same degree as permitted in the PA view. Field overlap in different runs should be minimized.

Table 4: Tissue Reactions from Single-Delivery Radiation Dose to Skin of the Neck, Torso, Pelvis, Buttocks, or Arms (Balter S et al, 2010)

Band	Single-Site Acute Skin-Dose Range (Gy)*	NCI Skin Reaction Grade†	Prompt	Early	Midterm	Long Term
A1	0-2	NA	No observable effects expected	No observable effects expected	No observable effects expected	No observable effects expected
A2	2-5	1	Transient erythema	Epilation	Recovery from hair loss	No observable results expected
B	5-10	1-2	Transient erythema	Erythema, epilation	Recovery; at higher doses, prolonged erythema, permanent partial epilation	Recovery; at higher doses, dermal atrophy or induration
C	10-15	2-3	Transient erythema	Erythema, epilation; possible dry or moist desquamation; recovery from desquamation	Prolonged erythema; permanent epilation	Telangiectasia‡; dermal atrophy or induration; skin likely to be weak
D	>15	3-4	Transient erythema; after very high doses, oedema and acute ulceration; long-term surgical intervention likely to be required	Erythema, epilation; moist desquamation	Dermal atrophy; secondary ulceration due to failure of moist desquamation to heal; surgical intervention likely to be required; at higher doses, dermal necrosis, surgical intervention likely to be required	Telangiectasia‡; dermal atrophy or induration; possible late skin breakdown; wound might be persistent and progress into a deeper lesion; surgical intervention likely to be required

Note – Applicable to normal range of patient radiosensitivities in absence of mitigating or aggravating physical or clinical factors. Data do not apply to the skin of the scalp. Dose and time bands are not rigid boundaries. Signs and symptoms are expected to appear earlier as skin dose increases. Prompt is <2 weeks; early, 2-8 weeks; midterm, 6-52 weeks; long term >40 weeks.

* Skin dose refers to actual skin dose (including backscatter). This quantity is not the reference point air kerma described by Food and Drug Administration (21 CFR § 1020.32 [2008]) or International Electrotechnical Commission (57). Skin dosimetry is unlikely to be more accurate than ± 50%. NA=not applicable.

† NCI=National Cancer Institute

‡ Refers to radiation-induced telangiectasia. Telangiectasia associated with area of initial moist desquamation or healing of ulceration may be present earlier.

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6. RADIOLOGICAL PROTECTION IN PAEDIATRIC COMPUTED TOMOGRAPHY

6.1 Justification/Indications

(99) Paediatric CT examinations are dominated by about 50 % examinations of the brain and about 35 % of the chest, abdomen, and pelvis. Thus, the justification of CT of the brain is of considerable importance. CT is not indicated after minor trauma to the head as the prevalence of injuries requiring neurosurgery is low, 0.02 % (Teasdale, et al. 1990). Furthermore, it was found in a recent study that CT brain may be omitted in children after head trauma if they fulfilled the following criterion of normal mental status, no scalp haematoma except frontal, no loss of consciousness or loss of consciousness for less than 5 secs, non-severe injury mechanism, no palpable skull fracture, and acting normally according to the parents (for children younger than 2 years) and normal mental status, no loss of consciousness, no vomiting, non-severe injury mechanism, no signs of basilar skull fracture, and no severe headache (for children aged 2 years and older) (Kuppermann, et al. Lancet 2009). Although the frequency of positive CT findings was found to be higher in children with daily headache or migraine, and children with new onset of seizures, there was no influence on therapy or outcome for the patients (Lewis and Dorbad, 2000, Maytal, Krauss et al. 2000).

(100) Especially in children, ultrasonography should be the first-line imaging consideration for the abdomen since their slim body habitus allows visualization of even deeper abdominal structures. In experienced hands, ultrasonography can provide a great deal of information and may obviate CT. For example, ultrasonography should be the examination first considered in children suspected of acute appendicitis. When ultrasonography (and/or radiography) is unlikely to provide the answer the choice of examination is often between CT and MRI. However, for out-of-hours examinations, MRI may be limited or not available in many hospitals.

(101) While there is no absolute consensus, a problem requiring detailed information of the soft tissues, nervous system, or bone marrow is often best evaluated with MRI. Malignant disease with a poor prognosis may alter considerations of risk for CT radiation exposure. However, with an increasing chance of curative treatment, the added risk of many follow-up studies under and after treatment, as well as dose from CT examinations for image guided therapy (IGRT) if performed, should be considered.

(102) Follow-up CT scans should not be performed too early when, according to the known biology of the disease, one cannot yet expect any response to treatment Justification has to be as rigorous as for the first examination, and alternative modalities may suffice. For follow-up CT studies, the scan volume can also be restricted depending on the clinical indication in order to reduce radiation dose. For example Jimenez et al (2006) have reported substantial dose reduction (55%) by limiting the scan coverage to just 6 images per examination for follow-up CT of patients with cystic fibrosis.

6.2 Optimisation of image quality and study quality

(103) Attention should be paid to both image quality and study quality. As with other imaging modalities, patient preparation should be optimized. For example, selective use of sedation reduces or eliminates patient movement and degradation of image quality. Images may be of excellent quality as regards detail but do not provide the necessary information to make a diagnosis without some manipulation such as planar reformations. Objective contributions to quality include image noise and image contrast. Artefacts are also related to study quality. Adjustable factors such as scan time and pitch may affect the presence or absence of motion artefacts. With faster table speed and gantry rotation breathing artefacts in children may be reduced.

(104) Quality also depends on the structure or the region being examined (Frush 2006). More image noise may be acceptable in skeletal or lung parenchymal examination than in brain and abdominal examinations. This is due, in part, to the higher contrast differences in the former. Therefore, a chest examination with higher noise may have the same study quality as a lower noise abdominal study. Abdominal organs such as the liver, kidney and pancreas may show

only minimal density differences between normal tissues and pathological lesions and may require a higher patient dose to obtain diagnostic quality. In addition, 3D reconstruction to determine bony outlines for surgical planning may also be done at low-dose levels (Vock 2005).

(105) The acceptable scan quality may also be determined by the clinical indication for the study. Smaller low-contrast lesions require higher contrast resolution. For example, more image noise may be tolerated in a follow-up study to assess a fracture of the liver than in a study to assess the presence of small liver metastases.

(106) The perception of a study's quality (ICRP 87, 2001) is also related to the display of the data. A study viewed on the CT console may look inferior when viewed on a monitor which is not optimized for viewing a particular examination. An ambient environment for image review also affects study quality.

6.3 Measurements of CT Dose

(107) The CT Dose Index (CTDI) is the primary dose measurement concept in CT. It represents the average absorbed dose, along the z axis, from a series of contiguous exposures. It is measured from one axial CT scan (one rotation of the X-ray tube), and is calculated by dividing the integrated absorbed dose by the total beam width. CTDI theoretically estimates the average dose within the central region of a scan volume, which is referred to as the Multiple Scan Average Dose (MSAD) (Shope, et al. 1981), the direct measurement of which requires multiple exposures. The CTDI offers a more convenient, yet nominally equivalent method of estimating this value, and requires only a single scan acquisition, which in the early days of CT, saved a considerable amount of time.

(108) To make the MSAD and the CTDI comparable requires that all contributions from the tails of the radiation dose profile be included in the CTDI dose measurement. The exact integration limits required to meet this criterion depend upon the total beam width and the length of the scattering medium. The scattering media for CTDI measurements were standardized by the FDA (United States FDA Code of Federal Regulations 1984). These

consist of two plastic cylinders of 14-cm length. To estimate dose values for head examinations, a diameter of 16 cm is used, and to estimate dose values for body examination, a diameter of 32 cm is used. These are typically referred to, respectively, as the head and body CTDI or CT phantoms.

(109) The CTDI requires integration of the radiation dose profile from a single axial scan over specific integration limits. In the case of $CTDI_{100}$, the integration limits are ± 50 mm, which corresponds to the 100 mm length of the commercially available "pencil" ionization chamber (Jucius and Kambic 1977; Pavlicek, Horton et al. 1979; European Commission 2000). $CTDI_{100}$ is acquired using a 100-mm long, 3-cm^3 active volume CT "pencil" ionization chamber and the two standard CTDI acrylic phantoms. The measurement should be performed with a *stationary* patient table.

(110) The CTDI can vary across the field-of-view. For body imaging, the CTDI is typically a factor or two higher at the surface than at the centre of rotation. The average CTDI across the field-of-view is given by the weighted CTDI ($CTDI_w$) (Leitz, Axelsson et al. 1995; European Commission 2000; International Electrotechnical Commission 2002), where:

$$CTDI_W = 1/3\ CTDI_{100,center} + 2/3\ CTDI_{100,edge}. \qquad \text{(Eqn. 1)}$$

The values of 1/3 and 2/3 approximate the relative volumes represented by the centre and edge values (Leitz, Axelsson et al. 1995). $CTDI_w$ is a useful indicator of scanner radiation output for a specific kVp and mAs.

(111) With single-detector CT equipment, the radiation dose[1] is approximately equal to the conventional contiguous transverse CT. There was a substantial increase in dose with four-slice CT in part because of the task of beam tracking (Frush 2006). This problem has been corrected with 8, 16 and 64-slice equipment and as a result radiation dose has become progressively lower, to levels at or below doses for single-slice CT scanners (ICRP 102, 2007; Greess, et al. 2000; Greess, et al. 2002; Kalra, et al. 2004). However the issue is more

[1] For decades, results of measurements in air of radiation fields in the diagnostic radiology energy range have been expressed in terms of absorbed dose to air, the most common being computed tomography dose index, dose-length product and entrance surface dose. Recently, ICRU 74 (ICRU 2005) and IAEA code of practice (IAEA 2007), have recommended the use of air kerma instead of absorbed dose to air. Nevertheless in order to use the terminology which readers of this report are familiar with, the term "dose" instead of "air kerma" has been kept.

complicated than the numbers of detector rows as there have been other associated changes in technology such as improved detector efficiency, changes in the distance between the X-ray tube and the isocentre and image reconstruction technology which includes new filters and these vary with the different equipment manufacturers. It is therefore very important for radiologists and radiographers/technologists to be familiar with the nuances of dose costs and benefits of the detector configuration of their particular CT equipment.

(112) In helical CT, the ratio of the table travel per rotation to the total beam width is referred to as pitch; hence $CTDI_{vol}$ is equal to $CTDI_w$ divided by the pitch. Thus, whereas $CTDI_w$ represents the average absorbed radiation dose over the x and y directions, $CTDI_{vol}$ represents the average absorbed radiation dose over the x, y and z directions where z-direction is parallel to the table feed. It is similar to the MSAD, and $CTDI_{vol}$ is the parameter that best represents the average dose at a point within the scan *volume* for a particular scan protocol. The SI unit is milligray (mGy) and the value is required to be displayed prospectively on the console of newer CT scanners (by WHO, IEC, FDA, EU). The problem when measuring $CTDI_{vol}$ in MDCT, especially high larger effective beam widths, is that the length of irradiation (tail of the beam) goes beyond the 100 mm length of the pencil ion chamber. There are proposed chambers that are designed to overcome this problem (Dixon and Ballard, 2007).

(113) While $CTDI_{vol}$ estimates the average radiation dose within the irradiated volume of a CT acquisition for an object of similar attenuation to the CTDI phantom, it does not represent the average dose differences for objects of substantially different size, shape, or attenuation. Additionally, it does not indicate the total energy deposited into the scan volume because this measurement is independent of the length of the scan.

6.4 Adjustment in scan parameters and optimising dose reduction

(114) Radiation dose can be reduced without affecting diagnostic information obtained from the study. Image noise is proportional to the X-ray beam attenuation, which in turn is affected by the distance that X-rays traverse through the patient body region being scanned. Scanning parameters (mA, kVp) can be adjusted to adapt dose to patient weight or age (Frush, et al.

2002; Moss and McLean 2006). Alternatively, automatic exposure control techniques, a form of automatic exposure control available in newer multidetector CT scanners have been used to reduce the CT radiation dose to children (Greess, et al. 2002; Greess, et al. 2004).

6.4.1. Tube current-exposure time product (mAs):

(115) Tube current-exposure time product, also called tube loading (IAEA 2007), affects image noise. It has a linear relationship to radiation dose, i.e. doubling it, in general, doubles the radiation dose. However the relationship between tube current-time product and noise is more complicated, i.e. increasing it reduces image noise proportional to the square root of the magnitude. For example, a fourfold increase in current-time product (and dose) results in half the image noise. Several authors have shown that to reach the same photon flow at the detector, the tube current-time product (mAs) can be significantly reduced in children compared to adults. At 120 kVp, Huda et al reduced the 1300 mAs for 120 kg body weight to 200 mAs for 70 kg and 17 mAs for 10 kg (Huda, et al. 2000). Boone et al (2003) reached a constant contrast-to-noise ratio for abdominal protocols when they decreased the current from 100% at 28 cm (adult phantom) to 56 % at 25 cm, 20 % at 20 cm and 5 % at 15cm respectively (different paediatric phantoms).

(116) Relatively low tube currents have been recommended for CT of the chest. Lucaya et al (2000) found that low dose, high resolution CT provided a significant reduction in radiation dose (72% for 50 mAs and 80 % for 34 mAs) and also good quality images of the lung with 50mAs in noncooperative, and 34mAs in cooperative paediatric and young adult patients. Rogalla et al (1999) recommended a range of tube currents from 25-75 mA (for a 1-second rotation time), for spiral CT, depending on the age of the patient. It is important to realize that one of the risks of low-dose scanning in addition to the possibility of missing an important abnormality is a false-positive finding that would not have occurred with a higher tube current-exposure time and a lower noise level.

(117) The use of weight-adapted paediatric CT protocols have been suggested (Frush, Soden et al. 2002; Cody, Moxley et al. 2004; Verdun, Lepori et al. 2004; Vock 2005). Some

examples of suggested paediatric CT protocols are included in Table 5 (Pages, et al. 2003; Verdun, et al. 2004; Vock 2005).

Table 5: Examples of suggested paediatric CT protocols: (Pages, et al. 2003; Verdun, et al. 2004; Vock 2005). CDTI: CT dose index, DLP: dose-length product.

Weight (kg)	CTDI	kV	mAs
Abdomen pitch 0.75			
2.5 – 5	7.1	80	90
5 – 15	9.4	100	70
15 – 30	14.0	120	80
30 – 50	18.5	120	120

Age (years)	CTDI	DLP
Brain/Chest		
Under 1	25/ 20	180/150
5	25/ 25	200/200
10	50/ 30	750/600
Upper/Lower abdomen		
Under 1	20/20	330 /170
5	25/25	360/250
10	30/30	800/500

6.4.2 Tube voltage (kVp):

(118) The kVp needed to penetrate the body of a child is lower than that of an adult as the physical size of the child is smaller compared to adult. So, 120 kVp is used in adult CT studies whereas 100 kVp and sometimes 80 kVp are adequate for children. The lower kVp without increased mAs causes an increase of noise, but, with having a higher contrast a higher noise can be tolerated, thus resulting in a dose reduction. In addition the lack of visceral fat in children also contributes to distinguish between low-contrast tissues (Cody, et al. 2004). This lower kVp may also improve the effect of iodinated contrast agents and is suggested for CT angiography. Excessive lowering of the kVp may cause beam hardening artefacts (Verdun, et al. 2004). Use of 80 kVp is suggested for infants under 5 kg by Vock et al. (2005).

6.4.3 Slice thickness:

(119) While the small dimension of a child requires relatively thinner slices than with adults to improve geometric resolution, using identical exposure with thinner slices compared with thicker slices will automatically increase noise. Keeping the noise level constant requires an increase in mAs, and in consequence in radiation exposure, that is inversely proportional to the square of the slice thickness and, in thus radiation exposure, i.e., a reduction of the thickness to one half requires an increase of the exposure-time product, mAs, by a factor of 4 . Scanners with four detector rows are less dose-efficient than single-row detectors and need relatively high dose levels for thin slices. With 8-64 detector rows this phenomenon is less important due to new detector technology and changes in scanner geometry (Thomton, et al. 2003).

6.5 Protective shielding

(120) Local superficial protective devices using bismuth may be considered in girls to protect the breast tissue where possible (Chapple, Willis et al. 2002, Coursey, Frush et al. 2008). However, it is important to note that bismuth protection should only be placed after the scannogram (or automatic exposure control pre-scanning) is performed so that the system does not inappropriately increase tube current in the area of the shield. Other devices to protect the lens, thyroid and gonads from direct or scatter radiation have been suggested. However, the protocols set should be tested specifically for the scanner as one approach is not appropriate for all scanners and if not used properly, shielding may even increase radiation dose. Some have suggested that in many situations, proper field size limitation and appropriate tube current modification can result in significant overall reductions in doses even without shielding apparatus which could have a negative effect on image quality depending upon placement and orientation of the shielding pads (Kalra MK et al, 2009, Colombo P et al, 2004, Geleijns, J et al, 2006)

6.6 Summary of principles for dose reduction in paediatric CT (Vock 2005)

(121) The following strategies have been recommended to accomplish the objective of dose reduction in paediatric CT, including rigorous justification of CT examinations, acceptance of images with greater noise if diagnostic information can be obtained, optimisation of scan protocols, scanning of minimum length as needed, and reduction of repeated scanning of identical area (appendix A).

a. Rigorous justification of CT studies.
   - In childhood, alternative imaging modalities such as ultrasonography and MRI should be considered.
   - However the risks of anaesthesia sometimes required for children undergoing MRI examinations should also be considered.

b. Prepare the patient.
   - In young children in particular, interaction is not just with the patient but also with the parents, who may ease the child's discomfort by staying with the child throughout the procedure.
   - Child friendly environments can also reduce anxiety in children.
   - Specially trained staff experienced in dealing with children is very helpful in improving the quality of the study and in preventing repeat scanning with additional exposure.
   - If an intravenous line is required it should be placed well before the examination.
   - Placement of necessary protective shielding

c. Accept image noise as long as the scan is diagnostic:
   - It is the task of the radiologist to go to the limits, i.e. to accept as much noise as the medical question allows (Donnelly, Emery et al. 2001).
   - The use of post-processing can help reduce the dose while maintaining the signal-to-noise ratio (reconstruct thicker slices of 4 – 6 mm for interpretation). The thicker images have reduced noise compared to thinner slices, while the

thinner images can be used to look at critical details and to obtain 2D and 3D reformatted images.

d. Optimize scan parameters:

- Different scanners have different geometry making direct comparison of kVp and mA problematic. The shortest rotation time is generally appropriate in paediatric CT and this will minimize motion artefacts.
- Tube current and kVp should be adjusted for the size of the patient.
- xy-plane (angular) dose modulation: This was introduced to overcome the fact that the human body is usually not round. To achieve the same signal-to-noise ratio, less radiation is generally required in the y-axis (antero-posterior) than in the direction of the x-axis (left to right). xy-plane modulation reduces the mAs by 20-40 % depending on the area examined and it should be used if available.
- z-axis (longitudinal) modulation: In the longitudinal axis of the body (z-axis) the radiation needed for an adequate signal-to-noise ratio will vary with the density of structures at various locations of the patient. The z-axis modulation is steered either from the CT localizer view or interactively and should be used where possible.

e. Limit scan coverage:

This applies both for the scout view and the rotational study.

f. Avoid non-justified multiple scans of the same area:

- If repeat scans are necessary, consideration should be given to limiting these to a smaller volume or performing them at a lower dose that will not obscure the additional information expected. Multiphase CT examinations in children should be justified in each case.
- A number of medical reasons may require repeat scans of the same area:
  - pre and post contrast enhanced scan after intravenous bolus injection
  - correct timing of scans (e.g. bolus tracking), using a test bolus or repetitive scanning of one plane at low dose for bolus triggering of the proper diagnostic scan. In this case the sequential scans can be very low dose, e.g. 5 mAs.
  - dynamic enhanced studies, including arterial, venous and/or excretion phases of organs such as the kidneys.

- supine and prone scans to demonstrate positional gravitational effects in the lungs.
- lung scans in inspiration and expiration to detect air trapping
- CT guided intervention with fluoroscopy
- screening with thick slices and subsequent detailed scanning with thin slices.

(122) Further improvements in CT technology could help the technologist to reduce unnecessary patient dose substantially. The most important of these features will be anatomically based on-line adjustment of exposure factors, including partial arc tube modulation, adaptive collimation to reduce over ranging dose, and new image reconstruction approaches such as iterative reconstruction associated with multislice-, dual-energy, and dual-source CT, more efficient detectors

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7. SUMMARY AND RECOMMENDATIONS

- Justification of every examination involving ionising radiation, followed by optimisation of radiological protection is important especially in the young due to the higher risk of adverse effects per unit of radiation dose compared to adults.

- According to the justification principle, if a diagnostic imaging examination is indicated and justified, this implies that the risk to the child of not doing the examination is greater than the risk of potential radiation induced harm to the child.

- Quality criteria implementation and regular audits should be instituted as part of the radiological protection culture in the institution.

- Imaging techniques that do not employ the use of ionising radiation should always be considered as a possible alternative, particularly in children, and especially those with chronic illness who require repeated imaging evaluation.

- For the purpose of minimising radiation dose exposure, the criteria for the image quality necessary to achieve the diagnostic task in paediatric radiology may differ from adults, and noisier images, if sufficient for radiological diagnosis, should be accepted.

- Apart from image quality, attention should also be paid to optimising study quality. Study quality for CT may be improved by image post-processing to facilitate radiological diagnoses and interpretation. Acceptable quality also depends on the structure and organ being examined and the clinical indication for the study.

- As most imaging equipment and vendor specified protocols are often structured for adults, modifications of exposure parameters maybe necessary.

- Exposure parameters that control radiation dose should be carefully tailored for children and every examination should be optimized with regard to radiological protection. For CT, dose reduction should be optimised by adjustment of scan parameters (mA, kVp and slice thickness) according to patient weight or age, and weight-adapted CT protocols have been suggested and published.

- When using fluoroscopy for diagnostic and interventional purposes, grid-controlled pulsed fluoroscopy with last image hold or archiving fluoroscopy runs will lead to considerable dose reduction without significant reduction of contrast or spatial resolution.

- Additional training in radiation protection is recommended for paediatric interventional procedures which should be performed by experienced paediatric interventional operators due to the potential for high patient radiation dose exposure.

Appendix A: Guidelines for paediatric radiological procedures

The following examples are based on the guidelines for referring doctors and radiologists published by the Royal College of Radiologists (2007). For each organ system the most frequent clinical questions leading to diagnostic imaging are given. The alternative non ionizing modalities, e.g. ultrasound and MRI are preferred and the recommendations are given as not indicated, indicated, or specialized investigation with the evidence level of the recommendation added.

1. Central nervous system

- After head injury in a child, radiography imaging is not indicated except in suspected non-accidental injury (child abuse). Depending on a number of clinical trauma features of the child, CT can be indicated. For congenital disorders of the head or spine MRI is indicated but the need for general anaesthesia or need to delineate bone detail may make CT the preferred modality. In cases of abnormal head appearance e.g. hydrocephalus with open fontanel, ultrasound is indicated with the exception of need for 3-D reconstruction prior to cranial surgery which necessitates a CT examination. For possible shunt malfunction in operated hydrocephalus, radiography of the whole valve system is indicated.

- In patients with epilepsy, skull radiography is not indicated. These recommendations are the same for deafness, developmental delay, or possible cerebral palsy. Headache or suspected sinusitis (the sinuses are poorly or not developed below 5 years of age) is not normally accepted indications for radiography. CT or preferably MRI are specialised investigations.

2. Neck and spine

- In a child with torticollis without trauma, ultrasound is indicated while radiography or CT are indicated only under specific circumstances when the clinical findings are atypical or longstanding. Spina bifida occulta is not an indication for any imaging as it is a common variation. Ultrasound or MRI are indicated if neurological symptoms or signs are present.

3. Musculoskeletal system

- Suspicion of non-accidental injury (child abuse) is an indication for skeletal survey and CT of the head below 2 years of age. However, it is recommended that skeletal survey is undertaken by a radiographer trained in paediatric practice, and that a radiologist supervises the examination and advises about additional views as necessary. Routine X-ray of the opposite site after limb injury for comparison is not indicated. X-ray of the hand for bone age determination is indicated with short stature or growth failure. In children with irritable hip or limping ultrasound is indicated while X-rays or nuclear medicine examinations are not initially indicated. MRI in these cases is a specialized investigation. Radiography of focal bone pain is indicated, ultrasound can be helpful and there is increasing use of MRI in these cases. Clicking hip should be assessed with ultrasound. Radiography in Osgood-Schlatter's disease is not indicated and the soft tissue swelling should be assessed clinically.

4. Cardiothoracic system

- Chest X-rays are not indicated initially for acute chest infections or recurrent productive cough but only if symptoms persist despite treatment, or in severely ill children, or in cases of fever of unknown origin. Radiography can also be indicated for suspected inhaled foreign body. In the latter case there is wide variation in local policy about expiratory films, fluoroscopy and CT. Chest X-rays are not routinely indicated for wheezing or acute stridor. Epiglottitis is a clinical diagnosis but lateral neck XR may be of value specifically in children with a stable airway in whom an obstructing foreign body or retropharyngeal abscess is suspected.

- Chest X-rays are not routinely indicated for a heart murmur. Specialist referral or echocardiography should be considered.

5. Gastrointestinal system

- US has a high sensitivity in the diagnosis of intussusception but it is operator dependent; it should be used as far as possible for suspected intussusception. For swallowed foreign bodies CXR, including neck is indicated, but AXR is indicated only if the foreign body is sharp or potentially poisonous.

- Minor trauma to the abdomen is not routinely an indication for abdominal radiography, unless there are positive physical signs suggestive of intra-abdominal pathology or injury to the spine or bony pelvis. CT remains the primary imaging investigation of choice for blunt abdominal trauma, but ultrasound may be useful in follow-up of known organs injuries. Major abdominal trauma should be handled according to the same local policy as for adults. The only indicated examination for projectile vomiting is ultrasound. Upper gastrointestinal contrast examinations are not normally indicated for recurrent vomiting or simple gastro-oesophageal reflux.

- Abdominal radiography in constipation is not routinely indicated and if Hirschsprung's disease is suspected, specialist referral plus biopsy is preferred. When an abdominal mass can be palpated initial ultrasound is indicated. Further imaging should be in a specialist centre.

6. Genitourinary system

- Continuous wetting should be evaluated with ultrasound, and intravenous urography only specifically for confirmation of ectopic infrasphincteric ureters in girls with duplex systems. MRI urography, if available, is an alternative to IVU. X-ray of the lumbosacral spine is indicated in children with abnormal neurology or skeletal examination, in addition to those with bladder wall thickening/trabeculation shown on

US or neuropathic vesicourethral dysfunction on video-urodynamics. Ultrasound is indicated in case of impalpable testis but MRI might be helpful in cases of intra-abdominal testis. Laparoscopic evaluation is increasingly utilized. Antenatal diagnosis of urinary tract dilatation should be evaluated with ultrasound but a low threshold for specialist referral is recommended.

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