5. FLUOROSCOPY, FLUOROGRAPHY AND INTERVENTIONS

Fluoroscopic procedures may be classified into two broad types. Long established investigations, for example, gastrointestinal contrast studies, are considered in Section 5.1. Newer interventional and more sophisticated diagnostic procedures are addressed in Section 5.2. These often require higher doses and frequently involve using purpose designed equipment whose operational modes are not always clear to the end user. The risk of high doses to patients and staff is much greater with these procedures, although this risk is balanced by a therapeutic benefit. Increased awareness of the doses and risks from medical irradiation of children has led to the Image Gently Campaign [10].Sections 5.3 and 5.4 deal with doses to patients and to staff.

The terms 'fluoroscopy' and 'fluorography' are not precise. 'Fluoroscopy' denotes procedures such as gastrointestinal studies involving contrast media, or other dynamic studies involving real-time visualization of macroscopic movement of anatomic and/or vascular structures using frame rates typical of those obtained in video systems. The dose rates used in fluoroscopy are categorized and regulated in many countries, with 'high' and 'low' doses allowed.

'Fluorography' denotes the capture of discrete images from an imaging chain and/or digital system, generally at lower frame rates and higher dose or dose rates than in fluoroscopy. For example, the frame rate might be 1 frame/s. The image quality is generally high and the images may be used for the final record. In cardiology, digital fluorography may replace Cine fluorography at relatively high frame rates.

5.1. CONVENTIONAL FLUOROSCOPY

Safety issues for a range of techniques, such as micturating cystograms and gastrointestinal contrast studies, are treated in conventional fluoroscopy. These are generally well established techniques that are undertaken with well tested protocols and with equipment whose design and purpose are well accepted and understood.

5.1.1. Justification in conventional fluoroscopy

As with general radiography, it is required that all fluoroscopic examinations for infants and children be justified. The general points raised in

Sections 2 and 4 are repeated and summarized in Table 16. It is important to ask the referring practitioner, the patient and/or the family about previous procedures. Where doubt arises about the procedure, the final decision needs to be taken by an experienced radiological practitioner, where possible in consultation with the referring medical practitioner. Examples of examinations that are not routinely indicated[5] are also listed in Table 16.

At a more formal evidence based level, tools with a structured evidential approach which can assist the justification process are available. These include the referral guidelines developed by the EC, which are reproduced with permission in Appendix II [28, 29]. Other guidelines with a similar intent are also available [30, 31]. While these criteria are helpful, they are advisory and they were developed for conditions that prevail in Europe. They may need to be adapted to take account of changes in appropriateness with changes in place and time. In particular, the EC guidelines are a revision of a set originally developed in 2001 and issued in 2008, pending an update which is presently being considered. Notwithstanding this, they provide helpful advice on when it is appropriate to undertake an examination and what the alternatives are. As pointed

TABLE 16. JUSTIFICATION IN FLUOROSCOPY AND EXAMPLES OF EXAMINATIONS NOT ROUTINELY INDICATED

Justification
Justification is required for fluoroscopy studies.
The referring practitioner, patient and/or family need to be asked about previous procedures.
Referral guidelines need to be used where appropriate.
Alternative approaches, such as ultrasound or MRI, need to be used where appropriate.
Information needs to be provided to the patient in accordance with the BSS or national standards.
Justification needs to be included in clinical audit.
Examples of fluoroscopy examinations not routinely indicated
Upper gastrointestinal contrast studies of pyloric stenosis.
Upper gastrointestinal contrast studies of children with recurrent vomiting.
Contrast enema in a child with rectal bleeding.

[5] Endoscopy may be preferable to diagnose polyps; endoscopy or ultrasonography to diagnose inflammatory bowel disease; and nuclear medicine studies to diagnose Meckel's diverticulum.

out in Section 2, a good approach to justification is to audit the effectiveness of the process in practice.

Once an investigation has been justified, the path to follow will depend upon the clinical indication, and on the alternatives, such as ultrasound, CT, MRI, endoscopy, etc., that are realistically available in the time scale required. With this caveat, fluoroscopy continues to play a significant role in medical imaging. Micturating cystourethrography and gastrointestinal contrast studies, among other examinations, are regularly performed.

5.1.2. Optimization of protection and safety in conventional fluoroscopy

Once it has been decided to perform an examination, it has to be undertaken with a protocol that includes optimization for the specific equipment and facilities available, and for the requirements of the patient involved. Modern fluoroscopy systems tend to be provided with powerful ergonomically convenient software control systems. These allow exposures and full examination protocols to be pre-programmed, for both fluoroscopy and fluorography. In clinical practice, thiscan be a great strength but from a radiation protection perspective it may be problematic.

This can be so in particular if the pre-set protocols are for adults or larger children. Thus, it is essential to 'child-size' the protocols for the equipment in use [10, 20]. Within the category 'child-size', it is further necessary to differentiate protocols for children of differing ages and sizes. This cannot be assumed to have been done even in equipment supplied for pediatric use. Thus, it is essential to adopt the team approach to protocol development identified in Table 17.

The staff operating the systems need to be comprehensively trained in the systems' characteristics. Otherwise, these systems will result in exposures that vary over several orders of magnitude without the operator being aware of it. With such units, the traditional classification of fluoroscopic exposure levels as 'high' or 'low' becomes difficult to interpret or, on occasion, meaningless in practice, even though the regulatory framework surrounding these classificationscontinues to exist in some areas.

Participants in the team approach need to include a radiologist, medical radiation technologist, medical physicist and clinical engineer; and the service engineer and application specialist from the manufacturer. The team has to ensure compliance with local regulations and, perhaps even more importantly, it also has to ensure that those operating each system understand its features and the terminology used by the suppliers.

Training of the radiologist and medical radiation technologist in the operational features of each fluoroscopy and fluorography exposure system

TABLE 17. TRAINING FOR DOSE MANAGEMENT

A team approach to dose management in fluoroscopy is essential. Participants in the team include: a radiologist, medical physicist, medical radiation technologist, clinical engineer, company service engineer and company application specialist.
Training of the radiologist and medical radiation technologist in the specific operational features of each fluoroscopy system in use is essential.
Where non-radiologists (e.g. cardiologists or orthopaedic surgeons) are directly involved with the use of these systems, certified training needs to be provided for them within the national regulatory framework.
In larger departments, consideration needs to be given to training a trainer who will be fully conversant with the equipment and with how to introduce new or rotated staff to it.

employed is essential. In larger departments, consideration needs to be given to training a trainer who will be fully conversant with the equipment and with how to introduce new or rotating staff to it [92]. In some areas, consideration is being given to credential programs that are machine specific. Such programs already exist in other areas such as medical laser safety and with the training of airline pilots [93].

The examination technique is very important in optimization, and some guidelines are provided in Table 18. Table 19 provides useful additional information on dose levels at the entrance of the image receptor in different acquisition modes.

As with general radiology, positioning, collimation and selection of exposure factors are essential in optimization in fluoroscopy [94]. Coning to a small field of view can be achieved by the operator by using a light beam diaphragm, rather than fluoroscopy, for guidance; radiation-free adjustment of the primary and semi-transparent collimators may also be used if available. A low attenuation carbon fiber table may be used where possible; these are available from most fluoroscopic equipment manufacturers.

A removable anti-scatter grid needs to be available. This would normally only be used for older children (over 8 years of age) unless a younger child is particularly large. Such a grid may also need to be used in fluoroscopy for children where very high detail is required [62, 65]. Added copper filtration (e.g. 0.3 mm) can be used and can be left permanently in place if the equipment isused solely for children.

An over couch tube may have significant advantages for general fluoroscopy in a pediatric department, provided that the operator is fully trained. This equipment configuration is less frightening for a child than that with an under couch tube. It may slightly increase radiation dose but it makes access to thechild easier for the operator and for carers and comforters, and it reduces the time required for the study. In operation, the distance between the tube and the image

TABLE 18. OPTIMIZATION IN CONVENTIONAL AND INTERVENTIONAL FLUOROSCOPIC TECHNIQUES

General applicability
Positioning, collimation, selection of exposure factors in optimization, etc. are essential in fluoroscopy.
The protocol needs to be 'child-sized', and the lowest dose protocol possible for patient size, frame rate and length of run needs to be used.
Fields need to be tightly aligned to the area of interest using the light beam diaphragm rather than fluoroscopy. The footswitch needs to be tapped to confirm position.
The image intensifier and/or receptor needs to be positioned over the area of interest before fluoroscopy is commenced rather than positioning during fluoroscopy.
Field overlap in different runs needs to be minimized.
Eyes, thyroid, breast and gonads need to be excluded whenever possible.
Use of electronic magnification needs to be minimized; digital zoom needs to be used whenever possible.
A low attenuation carbon fiber table needs to be used where possible.
A removable grid needs to be available, but is normally only to be used with older and large children (over 8 years of age).
Added copper filtration (e.g. 0.3 mm) needs to be used and can be left permanently in place if the equipment is deployed solely for children.
Pulsed fluoroscopy needs to be available and used where possible. Many workers recommend3.5–7.5 pulses/s as adequate for guidance and/or monitoring of most procedures.
Static fluoroscopic or fluorographic images or the 'last image hold' facility need to be used to review the anatomy and/or findings.
An overcouch tube may be advantageous in pediatric radiology, provided that operators are fully trained to protect themselves from irradiation of the upper body, head and neck.
Fluoroscopy timing alerts need to be acknowledged during the procedure.
A calibrated kerma area product meter needs to be available and used effectively.
The dose needs to be recorded and reviewed.
Special emphasis on interventional fluoroscopy
The number and timing of acquisitions, contrast parameters, patient positioning and suspension of respiration need to be planned and communicated to the radiological and sedation team in advance to minimize unneeded runs. The plan needs to be communicated to the team members. Each run needs to be necessary for diagnosis or to assess progress and/or outcome.
Acquisition parameters need to be adjusted to achieve the lowest dose necessary to accomplish the procedure: the lowest dose protocol possible needs to be used, account being taken of patient size, frame rate and length of run.
The patient table needs to be kept as far from the X ray source as possible and the image intensifier and/or receptor needs to be as close to the patient as possible. The table needs to be moved away from the X ray tube in both planes. The patient needs to be moved as close as possible to the detector in both planes.
Fluoroscopy only needs to be used to evaluate a moving target or structure, and fluoroscopy time needs to be limited.

TABLE 19. ENTRANCE EXPOSURE RANGE AT THE IMAGE RECEPTOR IN TERMS OF AIR KERMA FOR VARIOUS ACQUISITION MODES

Operational mode	Air kerma range (nGy/image)
'Low' fluoroscopy	6.0–8.5
'Medium' fluoroscopy	12–17
'High' fluoroscopy	24–34
Digital angiography	450–900
Digital subtraction angiography	4500–9000
Cardiac digital	90–130

[a] For a 23 cm image receptor, normal exposure rate, 30 pulses/s, 80 kVp and a standard total filtration of 2.5 mm Al.

intensifier needs to be maximized, with the table as low and as close as possible to the image intensifier [37].

With larger children and adolescents, the well known risks of these systems for the operators come into play owing to the increase in scattered radiation. This requires awareness on the part of the operators. In addition, it needs to be borne in mind that such systems are often designed and intended for use in the remote control mode, which generally allows the operator and attending staff to be in the protected console area. Obviously, this will not always be possible with small children, and the consequent risks to staff and to carers and comforters will require careful management.

Pulsed fluoroscopy can be effective in reducing dose, and it needs to be available and used where possible. It is a standard feature of modern equipment. Most fluoroscopy units have a range of 3–7.5 to 15–30 pulses/s. The lower range is satisfactory for many procedures and can be increased if the child is very mobile or uncooperative or if better detail is required.

Static fluoroscopic or fluorographic images may be reviewed from the digital or pulsed system (e.g. using last image hold) rather than from ongoing exposure. In addition, the duration of fluoroscopy and the number of images in digital runs need to be minimized with a view to dose reduction. Finally, it is worth noting that most doses to staff arise from radiation scattered from the patient, so that measures to reduce the dose to patients usually have a corresponding benefit in reducing doses to staff.

Fluoroscopy systems generally emit audible periodic time alerts. Acknowledging the cumulative timing device alerts may help in minimizing doses in the procedure.

A KAP meter is helpful in achieving knowledge of the dose used and is required by law in many countries [5, 93]. It is of value both for the patient record and as a training tool. A record of the information provided by the KAP needs to be transferred to the RIS/PACS systems. Ideally, future generations of equipment will be more flexible in this regard [50].

The KAP in fluoroscopic studies in children has to be kept as low as reasonably achievable, consistent with the diagnostic information required. However, the doses involved can be expected to vary depending on the age, sex, body mass, body thickness and cooperation of the child. The doses will also vary with the imaging objectives. Hiorns et al. have demonstrated that, for the eight most commonly performed fluoroscopic examinations, dose values which are a factor of between 5 and 25 less than the current national DRLs can be achieved [37] (see Section 5.3). The authors attribute this to improvements in both equipment performance and operator technique.

It is, therefore, recommended that pediatric fluoroscopy be conducted in specialist units whenever possible. When not possible, for example in non-specialist radiology departments with responsibility for pediatric imaging, the task may be assigned to a group of specially trained and experienced radiologists and medical radiation technologists (and other suitably trained professionals where appropriate, e.g. cardiologists).

5.2. DIAGNOSTIC AND THERAPEUTIC INTERVENTIONAL PROCEDURES

Interventional and more sophisticated diagnostic fluoroscopic procedures are generally conducted using purpose designed equipment that meets additional requirements, particularly in respect of real time monitoring of skin dose and/or dose rate [95]. The risk of high doses to patients and staff is much greater with these procedures. With care, however, both can be controlled, so that bothoperator and patient are not at unnecessary and/or undue risk. These procedures often provide a therapeutic benefit to the patient, and this needs to be included inthe justification process.

Many of the measures that reduce doses to patients and staff in conventional fluoroscopy (described in Section 5.1.2) and the requirements set out in Tables 16–18 are also essential here. However, additional risk arises, such as the possibility of deterministic injury to the patient; thus, some points need extra emphasis, and additional precautions are required.

5.2.1. Justification in diagnostic and therapeutic interventional procedures

Interventional procedures in children are now more in demand, more sophisticated and take longer. Pediatric interventional procedures require individual justification and planning. This has to include a balancing of the risk against the therapeutic benefit. Such procedures, particularly for small infants, need to be undertaken by experienced pediatric interventional operators, both for clinical and for radiation protection reasons.

The procedure is to be performed only when absolutely necessary. As already mentioned (see Table 16), it is important to ask the referring practitioner, the patient and/or the family about previous procedures. Determination that the procedure is necessary relies on the judgement of the radiological practitioner and on its complexity. Referral guidelines for therapeutic interventions (even for adults) are not yet widely agreed upon [96–98].

With adults, there are wide variations in the numbers of therapeutic interventional procedures performed from country to country; even within one country, interregional variations in both numbers and complexity can be substantial. This partly reflects the general levels of socioeconomic provision but also reflects the level of staff training and the range of skills the individual practitioner has cultivated to a high level.

The provisions of Table 16 need to be followed, as far as possible, except for the recommendation about referral guidelines. The recommendations on audit and information provided to the patient need to be considered. In particular, it is now common to recommend that the patient be explicitly and fully informed in the case of interventions.

An IAEA study with the purpose of investigating the level of radiation protection of patients and staff during interventional procedures in 20 countries in Africa, Asia and Europe also included an analysis of the workload of pediatric interventional procedures [99]. Nearly 40% of the interventional rooms had an annual workload of more than 2000 patients in total. About 30% of participating countries have shown a 100% increase in workload in 3 years.

Analysis of the workload in participating centers indicated that most participating general hospitals perform pediatric procedures as well. The percentage of children in the total annual workload varies enormously between participating hospitals (0.2–35.4%). The number of pediatric patients compared with adults shows that in 2 countries the pediatric workload is in the range of 40–50% of adult procedures, 7 countries have 5–17%, and in the remaining11 countries it is less than 5%.

The annual workload in dedicated pediatric hospitals in three countries was also variable, ranging from 240 to almost 4000 procedures per year. Of the procedures in pediatric hospitals, 2–36% are therapeutic procedures. However, it

is remarkable that the workload of pediatric interventional procedures can reach the levels of adult procedures even in developing countries. Special attention to dose is, therefore, required. It is essential to thoroughly investigate the level of radiation protection and the level of training in as many countries as possible, and in as many hospitals within each country as possible. This is necessary to evaluate the potential for improving the protection of children, given that for pediatric patients, risk of stochastic effects is the main issue [99].

5.2.2. Optimization of protection and safety in diagnostic and/or therapeutic interventional procedures

Complex interventional procedures can give rise to large doses to patients and staff, and have been shown to cause high peak skin doses in adults and high effective doses in children. The measures already specified in Table 18 will also contribute to reducing doses to patients in interventional work. Some additional considerations are listed in Table 19. The training and team issues already mentioned in Section 5.1 (see Table 17) are also essential here. It is well recognized that operator training improves performance with interventional procedures conducted on adults [96].

Likewise, in pediatric interventions, it has been demonstrated, in a study involving over 1000 procedures, that specific training improves the use of safety measures. This included use of hanging lead shields and lead eye glasses. Training reduced imaging time and KAP significantly for relatively uncomplicated procedures but was not as effective in bringing about change for complicated ones [92].

Complex procedures need to be pre-planned, and what is expected to be involved needs to be communicated to the team. For example, the number and timing of acquisitions, contrast parameters, patient positioning, suspension of respiration and sedation needs to be planned in advance, to the extent possible, to minimize improper or unneeded runs. The acquisition parameters need to be selected to achieve the lowest dose necessary to accomplish the procedure, with account taken of the dose protocol, patient size, frame rate, magnification and length of run. During the procedure, the operator has to ‘step lightly’ on the fluoroscopy pedal [10].

The table needs to be moved away from the X ray tube in both planes to maximize the distance between the source and the patient. The distance will generally be greater than 37.5 cm [10]. The image intensifier (or flat panel detector) needs to be as close to the patient as possible, to minimize patient to detector distance, while allowing room for manipulation of needles, wires and catheters. These considerations apply to all projections: vertical, lateral and oblique.

Image acquisition using fluorography or during digital subtraction angiography accounts for the largest radiation doses during many interventional procedures [100, 101]. Exposure factors for fluorographic image acquisitions and quasi-cine runs are much higher than those for fluoroscopy. The acquisition mode needs to be carefully selected as dose rates involved can be up to a couple of orders of magnitude higher than for fluoroscopy [102, 103].

When C-arm RIS equipment is used, the proximity of the skin to the X ray source in lateral and oblique views might be closer than during the PA view, and may result in an increase in skin dose. After the tube is placed in the lateral position, the patient needs to be distanced from the source to the maximum extent allowed by the equipment. In attending to this, the dose readout systems that are a feature of interventional equipment need to be consistently employed by the operator as part of their active monitoring of the procedure [50, 95]. The cumulative readouts from these systems need to communicate readily with the PACS and RIS systems.

Pediatric interventional procedures have unique features related to patient size. Patient sizes vary in practice, from as small as 450 g to in excess of 100 kg. To gain access to the small child, it is often necessary for the interventionist 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 placement or abscess drainage. They might also enter the beam urgently when an unexpected event or a complication occurs.

It is well known that with heavier children the indicators for patient dose increase [104]. However, it is further recognized that children are not small adults [105]. As mentioned above, imaging equipment needs to be specifically designed for use with children and the operators need to be trained accordingly. The generator needs to provide a large dynamic range of current (mA) and tube output index for defined kV (the product of tube current and time (mAs)) to minimize the range of kVp and the exposure time needed to compensate for differences in thickness. It is also desirable for there to be three focal spots, a lateral imaging plane, spatial and spectral beam profiling, and a well functioning system of entrance exposure regulation. Strauss recommends the entrance exposure values at the image receptor listed in Table 19 [105]. He also provides suggestions with regard to how these values can be adapted to other operating conditions.

Another unique feature in pediatric intervention is the large size of image intensifiers or digital image receptors relative to an infant's size. With infants and small children, the image intensifier will completely cover the patient. In such situations, the accuracy of collimation is more important than for adults, where the field of view is often allowed to fill the image receptor field. This is unacceptable in pediatric cases. Thus, ensuring that the collimation is precisely

aligned becomes a key design, performance and quality assurance issue. There is also an increased need to use magnification in children. This can further increase dose when analogue magnification is unnecessarily used [100].

After the procedure, the dose records may be noted and reviewed. A dose record may be included in the medical record [50, 95]. The 'step lightly' campaign recommends audit of radiation doses for all operators [10]. Specific feedback and additional training need to be provided where necessary [20, 21].

Implementing the above measures needs to be balanced against safe, accurate and effective completion of the procedure. Not all of the steps mentioned may be possible in each case, depending on patient size, the technical challenge and the critical nature of the procedure. The goal is to minimize the dose to the patient while providing important and necessary medical care.

5.3. DOSES TO PAEDIATRIC PATIENTS AND REFERENCE LEVELS FOR FLUOROSCOPY AND INTERVENTIONAL PROCEDURES

Only limited data are available for reference dose levels for both fluoroscopic and interventional pediatric procedures. The available data are not completely satisfactory as they are dependent on the generation of the technology on which they were measured.

Three sets of data available for fluoroscopy from the United Kingdom are illustrated in Table 20. The third column from the left provides the current national reference doses for pediatric fluoroscopy (2005 review) [89]. The column to its right provides the set of national reference doses that prevailed in the 2000 United Kingdom review [106]. Clearly, the reference doses were reduced in 2005 in all cases except one, the barium swallow at 10 years of age. This demonstrates the value of an ongoing national program of monitoring andof hospital involvement and/or collaboration in this area.

The reduction observed is consistent with the pattern reported by the Health Protection Agency for other examinations in adults. It may also be noted that the reference doses are set at the third quartile level, which means that 75% of those involved achieve lower values. Additional data to this effect are provided in the United Kingdom reports [89, 106].

The right hand column of Table 20 lists local DRLs established at Great Ormond Street Hospital, London [37]. Hiorns et al. have also demonstrated that, with the eight most commonly performed examinations (2215 cases), the KAPs (75th percentile) for upper gastrointestinal studies and micturating cystograms are substantially lower (by a factor of between 5 and 25) than the current national doses. Some of the median values are 50 times lower. Their small KAP values in all examinations demonstrate the substantial reduction in dose and, consequently,

TABLE 20. COMPARISON OF THE UNITED KINGDOM'S REFERENCE DOSES (2005 AND 2000) FOR PAEDIATRICS AND DIAGNOSTIC REFERENCE LEVELS AT GREAT ORMOND STREET HOSPITAL [37, 89, 106]

Examination	Age (a)	2005 national reference doses ($cGy \cdot cm^2$)	2000 review kerma area product per exam ($cGy \cdot cm^2$)	Great Ormond Street Hospital diagnostic reference level ($cGy \cdot cm^2$)
Micturating cystourethrogram	0	30	40	5
	1	70	100	5
	5	80	100	10
	10	150	210	42
	15	250	470	42
Barium meal	0	40	70	8
	1	110	200	8
	5	130	200	12
	10	240	450	32
	15	640	720	32
Barium swallow	0	40	80	8
	1	120	150	8
	5	130	150	12
	10	290	270	32
	15	350	460	32

in risk that can be achieved when both equipment performance and operator technique are optimized.

While different institutions will have differing practices, it is important that practitioners be aware of the range of KAPs achievable and of the fact that national or international DRLs do not necessarily represent best practice, and may in fact be falsely reassuring. The Great Ormond Street Hospital values are a compelling example of what can be achieved with a dedicated approach [34]. The figures in the table also illustrate the spread in values that arises, and are a reminder of the need for much more work in the area. Other studies confirm that large dose savings can be achieved with relatively straightforward technical strategies [107]. The results of a limited European survey are available and have been published [71]. Some details are provided in Appendix III.

With regard to interventional radiology and cardiology, there has been a significant growth in the literature available worldwide in the past decade.Studies are now available for adults in respect of reference values, the mean dose per procedure and local DRLs [31]. While these techniques are now commonly used in pediatric radiology, few studies are available detailing the doses or frequencies involved.

However, Onnash et al. report mean effective doses and KAP normalized to body weight in interventional cardiac procedures as illustrated in Table 21 [1, 108]. This may prove to be a useful approach from the point of view of pediatric radiology. It may, with some care, be used to draw on adult studies pending a larger range of pediatric data becoming available [108].

Deterministic injuries following interventional procedures that have been reported in adults, and their time course and/or dose relationship, are presented in Table 22 [109]. They include serious injury to skin and underlying tissues, although these are less likely in children than in adults. Many of these injuries may be missed as they become manifest after the patient has left hospital and/or the team caring for the patient may not be aware of the risk of radiation injury [100].

To help avoid these injuries, modern interventional equipment generally provides a dose estimate at the interventional reference point. The IEC defines the interventional reference point as 15 cm from the isocenter towards the X ray tube [50, 95]. The interventional reference point is related to the dose to the skin.Where it is suspected that a patient has received a high skin dose (2 Gy or more),a follow-up visit 30 days after the procedure has to be planned. The parents and/or the patient have to be informed that if symptoms of skin injury (i.e. skin

TABLE 21. EFFECTIVE DOSE AND MEAN KERMA AREA PRODUCT PER KILOGRAM FOR A SELECTION OF PAEDIATRIC CARDIAC INTERVENTIONS *(based on Ref. [108])*

Procedure	Number	Mean kerma area product ($Gy \cdot cm^2 \cdot kg^{-1}$)	Effective dose (mSv)
Atrial septal defect occlusion	259	0.42	3.9
Patent ductus arteriosus occlusion	165	0.35	3.2
Balloon dilatation	122	0.48	4.4
Coil embolization	33	0.50	4.6
Ventricular septal defect occlusion	32	1.3	12
Atrial septostomy	25	0.39	3.6
Patent foramen ovale occlusion	21	0.23	2.2

TABLE 22. DOSE, TIME AND DETERMINISTIC INJURIES [109]

Peak skin dose band	Range (Gy)	Prompt: <14 d	Early: 14–40 d	Mid-term: 40–400 d	Late: >400 d
A1	<2	No effects expected			
A2	2–5	Transient erythema	Transient hair thinning	Hair recovery	None expected
B	5–10	Transient erythema	Erythema, epilation	Recovery; at higher doses, prolonged erythema, permanent epilation	Recovery; skin changes at higher doses
C	10–15	Transient erythema	Erythema, epilation, possible dry or moist desquamation	Prolonged erythema, permanent total epilation	Telangiectasia, induration; skin likely to be weak
D	>15	Transient erythema with possible pain; oedema and acute ulceration at very high dose	Erythema, epilation, moist desquamation	Dermal atrophy, secondary ulceration, dermal necrosis	Dermal atrophy, induration, late skin breakdown; persistent wound; surgical intervention likely

irritation or reddening) occur, these have to be reported to the department in which the procedure was performed.

5.4. DOSES TO STAFF IN FLUOROSCOPY, INCLUDING INTERVENTIONAL FLUOROSCOPY

The team approach already mentioned needs to be adopted for management of staff doses. All team members need to be aware of the radiation exposure issues with fluoroscopy and interventional procedures, and the means of controlling them. In practice, those operationally involved need to be recognized radiological medical practitioners and medical radiation technologists — i.e. they have the requisite specialist education and training, including in radiation protection. This may mean, as is required in many countries, that they need to undergo special training in the techniques involved and in radiation protection [47, 100].

The requirements for good practice have much in common with the practice for adults but are adapted for pediatric radiology. The main features are presented here for ease of reference. Exposure of staff can arise from the direct beam or from scatter from the patient. For a well designed set up with good protocols, there will be little risk of exposure to the direct beam, with theexception of those circumstances where the operator's hands may, for exceptionalreasons, be in the beam for short periods (see below). This apart, most exposure of staff, in practice, arises from scattered radiation.

It is widely recognized that for a given set-up, doses to both patients and staff are dependent on the total amount of X ray energy emitted from the tube. The connection between doses to staff and doses to patients also arises from the fact that most exposure of staff is due to scattering of radiation from the patient. Vano et al. have demonstrated a linear relationship between KAP to the patient and staff doses in cardiac simulations [110, 111].

Thus, minimizing exposure of staff will be facilitated by optimization for the patient. Many researchers have demonstrated that the exposure regime and/or protocol employed is very important in determining doses to staff. For example, in digital fluoroscopy, cine, digital 'cine-like' or digital subtraction angiography runs, the dose to staff due to scattering of radiation from the patient can be several orders of magnitude higher than during fluoroscopy [110–113].

Doses to staff are also dependent on the size of the patient, which influences the amount of scatter. The amount of scatter is also influenced by the complexity of the procedure and by the adequacy of the training and experience of the operating staff [92, 95]. Simulation studies by Vano et al. have demonstrated that the dose to staff due to scattering of radiation from larger children is likely to be higher by a factor of up to 20–30 than that due to scattering from infants [110].

To reduce exposure to scattered radiation, staff need to position themselves strategically with respect to the configuration of the image receptor and the X ray source assembly (Table 23). The operator generally needs to be on the image receptor side and, where possible, to step back during injections. The dominant direction for scatter tends to be from the patient backwards towards the X ray tube. This is well illustrated in Balter's diagrams [111], which are reproduced in Appendix IV.

Operators need to become familiar with the profile of scattered radiation in the room when the tube is oriented in the main directions used in practice. Where equipment has been designed and sold for interventional use, the suppliers, in compliance with international technical standards [114], have to provide isodose curves such as those shown in Appendix IV [47, 92]. The room floor could be color coded to help staff position themselves in such a way as to minimize exposure. While Balter's data are based on adults, they provide some guidance

for pediatric interventionists, pending the availability of more complete pediatric data [110, 111].

During interventional procedures, the staff member most at risk is the operator. Others need be in the room only if their presence is required. All need to have adequate personal protection, such as good, well designed lead aprons, thyroid collars and lead glasses, as required. Where pediatric interventionists performing these procedures spend much of their working life wearing lead aprons, the risk of back or joint injury needs to be considered.

Two-piece aprons are available which redistribute the weight so that it is not all carried on the shoulders. Wrap-around aprons are also now available in which the shielding is biased towards the front, where the risk of exposure is higher for most of those involved. Leaded thyroid collars and/or lead glasses (prescription and non-prescription are available) with side shielding need to be worn in view of increasing concerns about occupational exposure [115].

Radioprotective gloves can attenuate scatter by about 50% but can be counterproductive if inadvertently placed in the beam, as they may interfere with the AEC and increase exposure. They also reduce dexterity and speed, hinder the work and can give a false sense of security. If, exceptionally, hands need to be placed in the beam, they ought, if possible, not to be placed between the X ray tube and the patient. Foot and leg doses to the operator can be significant and are receiving increasing attention as procedures become more complex and longer. Lead skirts for the table or drapes of newer compound material can reduce the scatter of radiation to the legs and ankles by as much as 10- to 20-fold [111, 116]. It is now possible to obtain single use drapes for scatter reduction.

In a study of adults, use of a power injector instead of hand injecting contrast material has been shown to be a highly effective way of reducing operator dose during angiography [117]. While the reductions may not be quite as dramatic in pediatric radiology, injectors need to be used where possible. In addition, the operator needs to step away from the image intensifier and/or behind a mobile lead screen during contrast injections. When manual injection is necessary, the distance from the patient needs to be maximized by using a long catheter.

Occupational dose measurements have to include readings from at least one dosimeter under the lead apron to assess whole body dose. Additional dosimeters over the apron to evaluate thyroid, hand and arm, and eye doses are advisable in some situations. For example, the ICRP recommends two dosimeter badges for interventional work, one under the apron and one on the shoulder over the apron. The second dosimeter is sometimes taken as being indicative of doses to areas such as the eyes, head, neck and even thyroid, and both are used in estimating effective dose [118]. Slight angulation of the beam away from the hands, strict collimation and careful attention to finger positioning will help to reduce exposure of the operator.

TABLE 23. REDUCING DOSES TO STAFF IN INTERVENTIONAL FLUOROSCOPY

Only those necessary for conduct of the procedure are to be in the room.
Personnel needs to be moved away from the table, preferably behind protective shields during acquisitions.
The operator needs to stand to the side of the image intensifier.
The operator (and other team members) may step back during injections.
The operator needs to use a power injector and to step back from the image intensifier and/or behind a mobile lead screen during contrast injections.
If manual injection is necessary, the distance needs to be maximized using a long catheter.
Doses in the room and from undercouch tubes can be greatly reduced by well configured and properly used tableside drapes.
Movable overhead shields need to be used for face and neck protection. These need to be positioned prior to the procedure.
Well designed suspended shielding and/or viewing systems are helpful to operators who learn to become skillful in their use.
Suitable, well fitted radioprotective aprons of appropriate weight need to be worn.
Aprons need to be well fitted, with arm wings to protect the axillary tail for females.
A thyroid collar and/or lead glasses with side shielding need to be worn.
The operator and personnel need to keep their hands out of the beam.
When, exceptionally, hands need to be placed in the beam, they ought, if possible, not to be placed between the X ray tube and the patient.
Radioprotective gloves may be worn where appropriate, but they can be counterproductive, reduce flexibility and dexterity, and interfere with the automatic exposure control.
Slight angulation of the beam off the hands, strict collimation and careful attention to finger positioning will help to reduce exposure of the operator.
Occupational dose measurements need to include at least one dosimeter badge under the lead apron to assess whole body dose.
Additional dosimeter badges over the apron to evaluate thyroid, hand and arm, and eye doses are advisable in some situations.

With large KAPs and work in which the operator, for effectiveness, needs to remain close to the patient, the risk of high doses to the head and neck of the operator from scattered radiation will arise. In this context, any gain from the small size of the patient may be offset by the closeness of the operator and/or the complexity of and the dexterity necessary for the manipulation involved in the procedure. This can often be the case in pediatric interventional cardiology.

In studies [110, 115], Vano et al. have drawn attention to the risk of damage to the eyes of the operator and estimate that the eye dose will be about7 $\mu Sv \cdot Gy^{-1} \cdot cm^{-2}$ of KAP to the patient. Table 23 provides a summary of many of the key points discussed above. For maximum impact, it is essential that the advice of the medical physicist and/or RPO be obtained to allow local protocols and the physical environment to be considered in the optimization of protection and safety for staff.