7. NUCLEAR MEDICINE

Nuclear medicine investigations are an important component of the overall imaging armamentarium used in pediatric imaging. The general provisions for patient and staff safety in nuclear medicine are not addressed in this section as these are beyond the scope of this publication, and are widely available from many sources [4, 143, 144]. This section is limited to aspects of safety in nuclear medicine that have specific pediatric applications. Some additional practical information is provided in Appendix VI.

7.1. JUSTIFICATION IN NUCLEAR MEDICINE

As with other imaging modalities, nuclear medicine studies are required to be rigorously justified. Large individual and population doses arising from nuclear medicine activity in some countries are, at least in part, attributable to some overutilization and to questionable referral patterns. Alternative modalities,such as ultrasonography (e.g. in the assessment and follow-up of renal abnormalities) and MRI, have to be considered (e.g. in assessing bone lesions which involve the bone marrow and surrounding soft tissues). However, nuclear medicine studies, including renography and bone scans, continue to be useful and are regularly performed in children.

Some advice on nuclear medicine referrals is available in Ref. [28]. The advice of earlier sections needs to be followed in relation to information provided to the patient, development of local protocols for referral, clinical audit of justification, and communication with the patient, their carers and comforters, their parents and the referring physician.

7.2. OPTIMIZATION AND DOSE REDUCTION IN NUCLEAR MEDICINE

The radiopharmaceutical activity given to pediatric patients has to be the minimum amount necessary to ensure a satisfactory examination. High activity (which does not result in improved diagnostic accuracy or sensitivity) or low activity (which does not permit an adequate scan) are both unacceptable, as they are both likely to give rise to unnecessary radiation exposure.

A work group composed of pediatric nuclear medicine physicians, medical radiation technologists and medical physicists, representing the Society of Nuclear Medicine, the Society for Pediatric Radiology and the American College of Radiology, recently issued consensus guidelines for administered

radiopharmaceutical activities in children and adolescents [10]. The guidelines were based on a survey conducted at 13 pediatric hospitals in North America indicating that administered radiopharmaceutical activities in children varied widely. The purpose of the work was to fulfil the above mentioned goals of diagnostic nuclear medicine procedures.

In practice, pediatric activity is estimated based on commonly used adult activities, corrected for body weight or body surface area. These activities are generally a good guide for children over 1 year of age [145–148]. Effective dose for a pediatric patient will depend upon the method used for adjustment of radionuclide activity (body surface area or body weight). If the body weight approach is used, the effective dose for children will be comparable to that for an adult [1]. Effective doses from diagnostic nuclear medicine procedures are given in Table 34.

The DRL in nuclear medicine is specified as the activity administered to the child. Table 35 illustrates a set of DRLs used in Ireland for seven radiopharmaceuticals for children of various ages, and for adults. These are consistent with practice elsewhere in Europe. These activities can be compared with the often higher median activity per kilogram used in the USA (Table 36), based on a survey of a number of hospitals in the USA. No DRLs focused on the nuclear medicine component of positron emission tomography (PET) examinations have yet been developed. In the case of PET/CT, the guidelines for CT also have to be followed [149].

Care needs to be taken with the scanning protocol in optimization for pediatric studies. Where appropriate, use needs to be made of electronic magnification, converging collimators for small organs, high sensitivity collimators when there is an advantage in using them, and appropriate choice of radiopharmaceuticals (e.g. MAG3 instead of DTPA for dynamic renal scans).

From a practical standpoint, there are important considerations particular to infants and small children. The infant or child needs to be well hydrated, and frequent diaper changes are necessary for babies and/or toddlers. Those dealing with infants, and carers and comforters of infants need to have a good knowledge of the radionuclide involved, its half-life, the biodistribution of the radiopharmaceutical form used in the infant and any other pertinent physiological factors.

Positioning of the patient is important during nuclear medicine imaging. Immobilization devices, such as sandbags, pillows, etc., are commonly used. Viewing television or a video during the examination often helps to distract children. In some cases, sedation is required. This may be the case when lengthy procedures, such as single photon emission CT (SPECT), are performed. The type and level of sedation as well as the activity used need to be determined in consultation with the referring clinician.

TABLE 34. EFFECTIVE DOSES FROM TYPICAL NUCLEAR MEDICINE PROCEDURES FOR PAEDIATRIC PATIENTS [1]

Procedure utilizing:	Effective dose (mSv/MBq)			
	15 year old	10 year old	5 year old	1 year old
F-18 FDG	0.025	0.036	0.050	0.095
Ga-67 citrate	0.130	0.200	0.330	0.640
I-123 sodium iodide (0% uptake)	0.016	0.024	0.037	0.037
I-123 sodium iodide (5% uptake)	0.053	0.080	0.150	0.290
I-123 sodium iodide (15% uptake)	0.110	0.170	0.350	0.650
I-123 sodium iodide (25% uptake)	0.170	0.260	0.540	1.000
I-123 sodium iodide (35% uptake)	0.230	0.350	0.740	1.400
I-123 sodium iodide (45% uptake)	0.290	0.440	0.940	1.800
I-123 sodium iodide (55% uptake)	0.350	0.530	1.100	2.100
In-111 pentatreotide	0.071	0.100	0.160	0.280
In-111 white blood cells	0.836	1.240	1.910	3.380
Tc-99m HIDA	0.021	0.029	0.045	0.100
Tc-99m DMSA	0.011	0.015	0.021	0.037
Tc-99m HMPAO	0.011	0.017	0.027	0.049
Tc-99m MAA	0.016	0.023	0.034	0.063
Tc-99m MDP	0.007	0.011	0.014	0.027
Tc-99m MAG3	0.009	0.012	0.012	0.022
Tc-99m ECD	0.014	0.021	0.032	0.060
Tc-99m DTPA	0.006	0.008	0.009	0.016
Tc-99m pyrophosphate	0.007	0.011	0.014	0.027
Tc-99m red blood cells	0.009	0.014	0.021	0.039
Tc-99m sestamibi (rest)	0.012	0.018	0.028	0.053
Tc-99m sestamibi (stress)	0.010	0.016	0.023	0.045
Tc-99m sodium pertechnetate	0.017	0.026	0.042	0.079
Tc-99m sulphur colloid	0.012	0.018	0.028	0.050
Tc-99m tetrofosmin (rest)	0.010	0.013	0.022	0.043
Tc-99m tetrofosmin (stress)	0.008	0.012	0.018	0.035
Tc-99m thallous chloride	0.293	1.160	1.500	2.280

Note: DMSA: dimercaptosuccinic acid; DTPA: diethylenetriaminepentaacetic acid; ECD: ethyl cysteinate dimer; FDG: fluorodeoxyglucose; HIDA: hepatobiliary iminodiacetic acid; HMPAO: hexamethylpropyleneamine oxime; MAA: macroaggregate of albumin; MAG3: mercaptoacetyltriglycine; MDP: methylene diphosphonate.

TABLE 35. PAEDIATRIC DIAGNOSTIC REFERENCE LEVELS (MBq) FOR COMMONLY PERFORMED DIAGNOSTIC PROCEDURES [145]

Radiopharmaceutical	Pediatric diagnostic reference level (MBq)					
	Newborn (5 kg)	1 year old (10.5 kg)	5 year old (19.5 kg)	10 year old (33 kg)	15 year old (64.5 kg)	Adult (70 kg)
Tc-99m phosphonates (bone)	43	90	167	283	549	600
Tc-99m DMSA	15	15	28	47	91	100
Tc-99m DTPA	20	33	61	104	201	220
Tc-99m MAG3	15	15	28	47	91	100
Tc-99m pertechnetate thyroid	10	12	22	38	73	80
Tc-99m pertechnetate Meckel's	28	58	107	182	352	385

Note: DMSA: dimercaptosuccinic acid; DTPA: diethylenetriaminepentaacetic acid; MAG3: mercaptoacetyltriglycine.

Stabin et al. present effective and absorbed dose estimates for children of different ages, for different nuclear medicine procedures, using standard medical internal radiation dose methodology [150]. Effective doses per unit of administered radiopharmaceutical (mSv/MBq) have also been calculated using five pediatric phantoms for a number of radiopharmaceuticals commonly used in children.

Values of effective dose resulting from the application of the weight/surface area schedules of administered radiopharmaceutical proposed by the pediatric task group of the European Association of Nuclear Medicine are also available. Although some values of effective dose exceed 10 mSv for the surface area schedule, the majority are less than 5 mSv [151].

As mentioned in Section 2.5, arrangements to deal with the unintended administration of activity to patients are required. This may be more sensitive in pediatric nuclear medicine than in radiology, even when the dose is lower. Good, well conceived and well tested systems to provide fail-safe protection against misadministration need to be part of the operational policy of every department.

When a pediatric patient receives the incorrect amount of radiopharmaceutical or when the incorrect radiopharmaceutical is administered, this needs to be reported within the hospital and investigated, as discussed in Section 2.5, with a view to implementing corrective actions to reduce the likelihood of recurrence of such an incident. The patient and/or the parent and/or guardian and/or carers and comforters have to be informed. In some countries, it is also mandatory to report incidents of this type to the regulatory authorities or medical authorities (Section 2.5).

TABLE 35. PAEDIATRIC DIAGNOSTIC REFERENCE LEVELS (MBq) FOR COMMONLY PERFORMED DIAGNOSTIC PROCEDURES [145]

	Pediatric diagnostic reference level (MBq)					
Radiopharmaceutical	Newborn	1 year old	5 year old	10 year old	15 year old	Adult

TABLE 36. MEDIAN ACTIVITY PER KILOGRAM OF BODY WEIGHT INJECTED INTO PAEDIATRIC PATIENTS (*adapted from Ref. [146]*)

Radionuclide and marker	Median activity (MBq/kg)
Tc-99m DMSA	2.22
Tc-99m MAG3	5.55
Tc-99m MDP	11.10
Tc-99m DISIDA	2.78
I-123 MIBG	5.55
Tc-99m $NaTcO_4$ for Meckel's	5.18
I-123 NaI for thyroid	0.10
Tc-99m ECD or HMPAO	10.55
Tc-99m MIBI	12.95
Tc-99m MAA	1.85
Tc-99m ultratag for gastrointestinal	8.33
Tc-99m ultratag for multiple gated acquisition	8.14
Tc-99m denatured red blood cells	2.22
Ga-67 inflammatory disease	1.85
Ga-67 tumour imaging	4.07
F-18 FDG	5.37

Note: DISIDA: di-isopropyliminodiacetic acid; DMSA: dimercaptosuccinic acid; ECD: ethyl cysteinate dimer; FDG: fluorodeoxyglucose; HMPAO: hexamethylpropyleneamine oxime; MAA: macroaggregate of albumin; MAG3: mercaptoacetyltriglycine; MDP: methylene diphosphonate; MIBG: metaiodobenzylguanidine; MIBI: methoxyisobutylisonitrile.