1 General Principles in Pediatric Nuclear Medicine

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1.1 General Information for Referring Physician, Parents, and NM Team [1–5]

Multidisciplinary Care Team

- The care team in nuclear medicine may include the nuclear medicine technologist(s), nuclear medicine nurse, child life specialist, anesthesiologist and anesthesia team, nuclear medicine physician, nuclear medicine/ radiology trainee, and referring physician.
- Close communication with referring specialists through multidisciplinary meetings is often utilized that can improve the impact of the nuclear medicine exam findings.

Departmental Workflow—Scheduling the Study

- Studies on children take longer than adults. Clear time on the schedule when studies in pediatric patients are scheduled.
- Book studies where the child needs to be fasting for prolonged periods of time as the first study of the day.

Information to Be Requested at Booking the Study

- Age.
- Weight and height.
- Gender identity of the patient.
- Contact information of parents/caregivers.
- Specific medical, developmental, or behavioral problems the patient may have.
- In cases that may require potential contrast material injection (SPECT/CT, PET/CT, PET/MRI) request information about:
  - Allergies.
  - Renal function.
  - History of previous contrast reaction.
- Parent's/caregiver's CONSENT: requirement for consent must follow national and institutional guidelines.

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Information to Be Provided to Parent/Caregiver

- Whether the child should be fasting or can eat and or drink before the study.
- Duration of the study and whether there is a need for a hospital stay.
- How the study is done and what is required. For example, let the parent/caregiver know in advance if an intravenous (IV) line or urinary catheter will be placed.
- Explanation of radiation risk.
- Parents/caregivers should be informed about the application of topical anesthetic cream to possible injection sites prior to the procedure.
  - If this is planned, up to an hour is required for it to work so the patient should arrive an hour before the booking time of the study.
  - As an alternative, the parent/caregiver can put it on beforehand, outside of the department.
- Request a spare change of clothes for infants and small children.
- Parents/caregivers should bring the milk formula or any specific food that the child may need (more details in the respective chapters).
- Parents and referring physicians should be aware that certain studies require medical premedication preceding the scan (More details in the respective chapters).
- If the patient is close by when the study is booked it may be useful to invite the patient and caregivers into the camera room so that they know what to expect on the day of the study.

Prior to the Study

- Phone the parents on the day before the study to confirm date and time and to remind them of above-mentioned preparation.
- Arrange for an appropriate health care professional to arrive at the department for cannulation, if necessary.
- Since patient age in this category is defined as up to 18 years, when dealing with adolescents, it is important to consider pregnancy and breastfeeding.
- Depending on institutional protocols, urine or serum pregnancy tests may be required.
- Inquire if an accompanying person is pregnant. This does not preclude her visit but appropriate radiation safety instructions should be provided.

On the Day of the Study

On arrival explain to the parent/caregiver and child what is going to happen during the study. Knowing what to expect, reduces anxiety and improves cooperation. This translates to higher-quality diagnostic images

- If available and/or necessary, as discussed above, place a local topical anesthetic on possible sites for injection.
- Do not let the child wait too long before starting the procedure.
- DO NOT LIE. Lying to your patient diminishes trust and greatly reduces cooperation.
- Tell your patient “I am going to give you an injection, it will be a bit sore, this is the only painful thing that will happen today”.
- Explain every step you execute to your patient in child friendly language: “I am going to move the bed under the camera now” etc. This leads to a marked reduction in patient anxiety.

Radiation Risks [6–9]

- Radiation-induced risk of adverse health effects is greater in children than in adults.
- There is no clear evidence regarding potential adverse health effects for the levels of exposure associated with medical imaging. However, the international health physics consensus is to optimize exposure to patients receiving these studies.
- Radiation-induced cancer risk is a function of effective dose administered, age, and gender.

- Females and younger patients are more susceptible to radiation-induced cancers.
- The optimal dose is typically understood as the lowest dose that still provides the diagnostic information necessary for proper care and therefore, on occasion, exposures higher than guideline recommendations may be necessary.
- It is recommended to weigh each request for imaging procedures that expose a patient to ionizing radiation, nuclear medicine tests in particular, with respect to their risk vs. potential clinical benefit and availability of nonionizing radiation imaging tests that can provide similar diagnostic information.
- Always be sure that the patient receives the lowest acceptable radiation exposure that allows for the highest quality diagnostic study. Modern cameras are more sensitive than older models and can produce high quality images with administered activities that are lower than the published recommendations.

Communicating Radiation Risks [10, 11]

- All parties should be mindful that the use of radiation is associated with theoretical risks that are, as a rule, significantly smaller than the risk of deciding not to perform an indicated scan.
- Care should be taken to communicate risks without raising undo alarm in patients or their families.
- Fear of radiation risk is detrimental to patients, in particular children, as well as their parents/caregivers. It can induce stress and lead to less than optimal studies or to the decision to avoid imaging. This may increase the rate of misdiagnoses with subsequent harm with no associated benefits.
- Communicating the risk associated with radiation dose can be very difficult as published articles on the topic use higher reference values than what is used in many parts of the world.
- A simple way of explaining the radiation risk from a nuclear medicine procedure is to compare it to everyday activities relative risk or to the exposure individuals receive from natural background radiation in 1 year.
- The image gently website (https://www.imagegently.org/Procedures/Nuclear-Medicine) has more information on explaining radiation risk from imaging procedures.

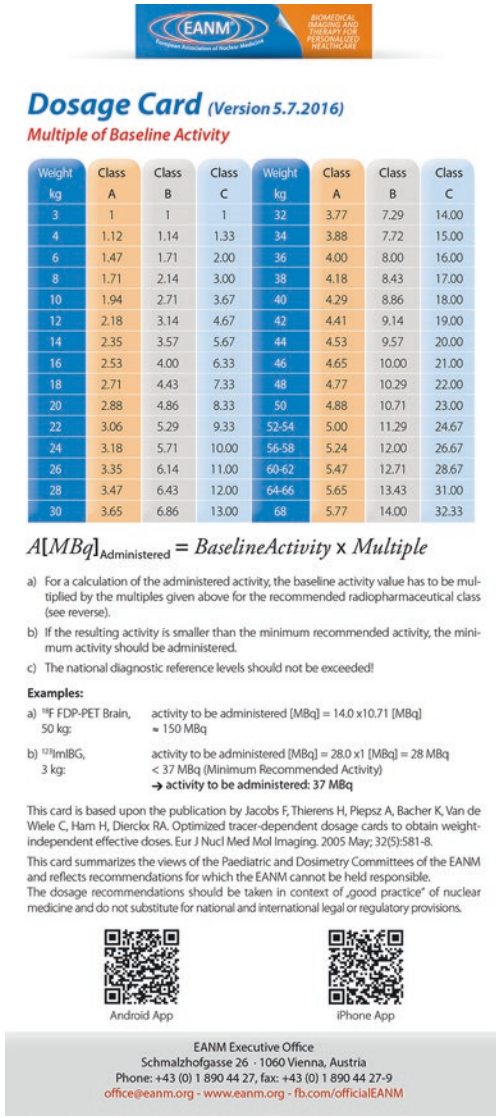
Calculating the Administered Activity

- Use the latest versions of EANM pediatric dose card (Fig. 1.1) [12], or the North American Consensus Guidelines for Administered Radiopharmaceutical Activities in Children and Adolescents (Fig. 1.2,) [13].
- Both the EANM and SNMMI have dose calculators available online (Fig. 1.3):
- http://EANM.org/publications/dosage_calculator.php
- http://www.snmmi.org/ClinicalPractice/PediatricTool.aspx
- In addition, the PedDose App provided by the EANM proves to be a useful tool.
- If a radiopharmaceutical does not appear on the dose cards it is best to consult with an expert pediatric nuclear medicine center.

Sedation [14–16]

Suggestions for Avoiding Sedation

- In small babies and infants: tracer injection should be timed as close to the next breast/milk feeding as possible. A feed may be given from 30 min after tracer injection in infants not having anesthesia or sedation.
- Encourage the parent/caregiver to bring the child's own food, a pacifier and soothing toy or story books to the department.
- Infants: wrapping them snuggly in a blanket increases the likelihood of a baby falling asleep.
- Toddlers: entertaining them reduces movement artifacts.
- School-age child, above the age of 6 years: is usually able to follow instructions.



EANM

BIOMEDICAL IMAGING AND THERAPY FOR PERSONALIZED HEALTHCARE

Dosage Card (Version 5.7.2016)

Multiple of Baseline Activity

Weight kg	Class A	Class B	Class C	Weight kg	Class A	Class B	Class C
3	1	1	1	32	3.77	7.29	14.00
4	1.12	1.14	1.33	34	3.88	7.72	15.00
6	1.47	1.71	2.00	36	4.00	8.00	16.00
8	1.71	2.14	3.00	38	4.18	8.43	17.00
10	1.94	2.71	3.67	40	4.29	8.86	18.00
12	2.18	3.14	4.67	42	4.41	9.14	19.00
14	2.35	3.57	5.67	44	4.53	9.57	20.00
16	2.53	4.00	6.33	46	4.65	10.00	21.00
18	2.71	4.43	7.33	48	4.77	10.29	22.00
20	2.88	4.86	8.33	50	4.88	10.71	23.00
22	3.06	5.29	9.33	52-54	5.00	11.29	24.67
24	3.18	5.71	10.00	56-58	5.24	12.00	26.67
26	3.35	6.14	11.00	60-62	5.47	12.71	28.67
28	3.47	6.43	12.00	64-66	5.65	13.43	31.00
30	3.65	6.86	13.00	68	5.77	14.00	32.33

$$A[MBq]_{Administered} = BaselineActivity \times Multiple$$

a) For a calculation of the administered activity, the baseline activity value has to be multiplied by the multiples given above for the recommended radiopharmaceutical class (see reverse).

b) If the resulting activity is smaller than the minimum recommended activity, the minimum activity should be administered.

c) The national diagnostic reference levels should not be exceeded!

Examples:

a) ^{18}F FDP-PET Brain, 50 kg: activity to be administered [MBq] = 14.0 x10.71 [MBq] ≈ 150 MBq

b) ^{123}ImIBG, 3 kg: activity to be administered [MBq] = 28.0 x1 [MBq] = 28 MBq < 37 MBq (Minimum Recommended Activity) → **activity to be administered: 37 MBq**

This card is based upon the publication by Jacobs F, Thierens H, Piepsz A, Bacher K, Van de Wiele C, Ham H, Dierckx RA. Optimized tracer-dependent dosage cards to obtain weight-independent effective doses. Eur J Nucl Med Mol Imaging. 2005 May; 32(5):581-8.

This card summarizes the views of the Paediatric and Dosimetry Committees of the EANM and reflects recommendations for which the EANM cannot be held responsible.
The dosage recommendations should be taken in context of „good practice" of nuclear medicine and do not substitute for national and international legal or regulatory provisions.

Android App

iPhone App

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Recommended Amounts in MBq

Radiopharmaceutical	Class	Baseline Activity (for calculation purposes only) MBq	Minimum Recommended Activity[1] MBq
^{123}I (Thyroid)	C	0.6	3
^{123}I Amphetamine (Brain)	B	13.0	18
^{123}I HIPPURAN (Abnormal renal function)	B	5.3	10
^{123}I HIPPURAN (Normal renal function)	A	12.8	10
^{123}I mIBG	B	28.0	37
^{131}I mIBG	B	5.6	35
^{18}F FDG-PET torso	B	25.9	26
^{18}F FDG-PET brain	B	14.0	14
^{18}F Sodium fluoride	B	10.5	14
^{67}Ga Citrate	B	5.6	10
^{68}Ga-labelled peptides	B	12.8	14
^{99m}Tc ALBUMIN (Cardiac)	B	56.0	80
^{99m}Tc COLLOID (Gastric Reflux)	B	2.8	10
^{99m}Tc COLLOID (Liver/Spleen)	B	5.6	15
^{99m}Tc COLLOID (Marrow)	B	21.0	20
^{99m}Tc DMSA	B	6.8	18.5
^{99m}Tc DTPA (Abnormal renal function)	B	14.0	20
^{99m}Tc DTPA (Normal renal function)	A	34.0	20
^{99m}Tc ECD	B	51.8	100
^{99m}Tc HMPAO (Brain)	B	51.8	100
^{99m}Tc HMPAO (WBC)	B	35.0	40
^{99m}Tc IDA (Biliary)	B	10.5	20
^{99m}Tc MAA / Microspheres	B	5.6	10
^{99m}Tc MAG3	A	11.9	15
^{99m}Tc MDP	B	35.0	40
^{99m}Tc Pertechnetate (Cystography)	B	1.4	20
^{99m}Tc Pertechnetate (Ectopic Gastric Mucosa)	B	10.5	20
^{99m}Tc Pertechnetate (Cardiac First Pass)	B	35.0	80
^{99m}Tc Pertechnetate (Thyroid)	B	5.6	10
^{99m}Tc RBC (Blood Pool)	B	56.0	80
^{99m}Tc SestaMIBI/Tetrofosmin (Cancer seeking agent)	B	63.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac rest scan 2-day protocol min)	B	42.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac rest scan 2-day protocol max)	B	63.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac stress scan 2-day protocol min)	B	42.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac stress scan 2-day protocol max)	B	63.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac rest scan 1-day protocol)	B	28.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac stress scan 1-day protocol)	B	84.0	80
^{99m}Tc Spleen (Denatured RBC)	B	2.8	20
^{99}Tc TECHNEGAS (Lung ventilation)[3]	B	49.0	100

[1] The minimum recommended activities are calculated for commonly used gamma cameras or positron emission tomographs. Lower activities could be administered when using systems with higher counting efficiency.

[2] The minimum and maximum values correspond to the recommended administered activities in the EANM/ESC procedural guidelines (Hesse B, Tagil K, Cuocolo A, et al). EANM/ESC procedural guidelines for myocardial perfusion imaging in nuclear Cardiology. Eur J Nucl Med Mol Imaging. 2005 Jul;32(7):855-97.

[3] This is the activity load needed to prepare the Technegas device. The amount of inhaled activity will be lower.

Fig. 1.1 The EANM calculator screen shot. Reproduced with permission from https://www.eanm.org/content-eanm/uploads/2017/01/EANM_Dosage_Card_040214.pdf. "This card summarises the views of the Paediatrics and Dosimetry Committees of the EANM and reflects recommendations for which the EANM cannot be held responsible. The dosage recommendations should be taken in the context of "good practice" of nuclear medicine and do not substitute for national and international legal or regulatory provisions." It is based upon work published in references [12, 30, 31]

- Patients in pain may be uncooperative. Proper pain relief given in consultation with the referring physician is beneficial and reduces movement artifacts on scans.
- If possible, have the parent/caregiver close by and let them help. For example, letting the patient sit on their lap during an esophageal transit study or milk scan is less intimidating than sitting on the technologist's lap.
- When necessary parents/caregivers can assist the technologists in preventing motion during

Follow the new North American Guidelines for Pediatric Nuclear Medicine for high-quality images at low radiation dose.

2016 Update: North American Consensus Guidelines for Pediatric Administered Radiopharmaceutical Activities[1]

Radiopharmaceutical	Notes	Administered Activity	Minimum Administered Activity	Maximum Administered Activity
^{123}I-MIBG	[A]	5.2 MBq/kg (0.14 mCi/kg)	37 MBq (1.0 mCi)	370 MBq (10.0 mCi)
^{99m}Tc-MDP	[A]	9.3 MBq/kg (0.25 mCi/kg)	37 MBq (1.0 mCi)	
^{18}F-FDG	[A, B]	Body: 3.7-5.2 MBq/kg (0.10-0.14 mCi/kg)	26.MBq (0.7 mCi)	
		Brain: 3.7 MBq/kg (0.10 mCi/kg)	14 MBq (0.37 mCi)	
^{99m}Tc-DMSA	[A]	1.85 MBq/kg (0.05 mCi/kg)	18.5 MBq (0.5 mCi)	100 MBq (2.7 mCi)
^{99m}Tc-MAG3	[A, C]	Without flow study: 3.7 MBq/kg (0.10 mCi/kg)	37 MBq (1.0 mCi)	148 MBq (4.0 mCi)
	[A]	With flow study: 5.55 MBq/kg (0.15 mCi/kg)		
^{99m}Tc-IDA	[A, D]	1.85 MBq/kg (0.05 mCi/kg)	18.5 MBq (0.5 mCi)	
^{99m}Tc-MAA	[A]	If ^{99m}Tc used for ventilation: 2.59 MBq/kg (0.07 mCi/kg)		
	[A]	No ^{99m}Tc ventilation study: 1.11 MBq/kg (0.03 mCi/kg)	14.8 MBq (0.4 mCi)	
^{99m}Tc-pertechnetate (Meckel diverticulum imaging)	[A]	1.85 MBq/kg (0.05 mCi/kg)	9.25 MBq (0.25 mCi)	
^{18}F-sodium fluoride	[A]	2.22 MBq/kg (0.06 mCi/kg)	14 MBq (0.38 mCi)	
^{99m}Tc (for cystography)	[E]	No weight-based dose	No more than 37 MBq (1.0 mCi) for each bladder filling cycle	
^{99m}Tc-sulfur colloid (for oral liquid gastric emptying)	[F]	No weight-based dose	9.25 MBq (0.25 mCi)	37 MBq (1.0 mCi)
^{99m}Tc-sulfur colloid (for solid gastric emptying)	[F]	No weight-based dose	9.25 MBq (0.25 mCi)	18.5 MBq (0.5 mCi)
^{99m}Tc- HMPAO (Ceretec)/^{99m}Tc-ECD (Neurolite) for brain perfusion		11.1 MBq/kg (0.3 mCi/kg)	185 MBq (5 mCi)	740 MBq (20 mCi)
^{99m}Tc-sestamibi (Cardiolite)/^{99m}Tc-tetrofosmin (Myoview) for myocardial perfusion (single scan or first of 2 scans, same day)		5.55 MBq/kg (0.15 mCi/kg)	74 MBq (2 mCi)	370 MBq (10 mCi)
^{99m}Tc-sestamibi (Cardiolite)/^{99m}Tc-tetrofosmin (Myoview) for myocardial perfusion (second of 2 scans, same day)		16.7 MBq/kg (0.45 mCi/kg)	222 MBq (6 mCi)	1110 MBq (30 mCi)
Na^{123}I for thyroid imaging		0.28 MBq/kg (0.0075 mCi)	1 MBq (0.027 mCi)	11 MBq (0.3 mCi)
^{99m}Tc-pertechnetate for thyroid imaging		1.1 MBq/kg (0.03 mCi/kg)	7 MBq (0.19 mCi)	93 MBq (2.5 mCi)
^{99m}Tc-RBC for blood pool imaging		11.8 MBq/kg (0.32 mCi/kg)	74 MBq (2 mCi)	740 MBq (20 mCi)
^{99m}Tc-WBC for infection imaging		7.4 MBq/kg (0.2 mCi/kg)	74 MBq (2 mCi)	555 MBq (15 mCi)
^{68}Ga-DOTATOC or ^{68}Ga-DOTATATE	[G]	2.7 MBq/kg (0.074 mCi/kg)	14 MBq (0.38 mCi)	185 MBq (5 mCi)

NOTES: This information is intended as a guideline only. Local practice may vary depending on patient population, choice of collimator, and the specific requirements of clinical protocols. Administered activity may be adjusted when appropriate by order of the nuclear medicine practitioner.

For patients who weigh more than 70 kg, it is recommended that the maximum administered activity not exceed the product of the patient's weight (kg) and the recommended weight-based administered activity. Some practitioners may choose to set a fixed maximum administered activity equal to 70 times the recommended weight-based administered activity, expressed as MBq/kg or mCi/kg. For example, approximately 10 mCi (370 MBq) for ^{18}F-FDG body imaging. The administered activities assume use of a low energy high-resolution collimator for ^{99m}Tc-radiopharmaceutical and a medium energy collimator for ^{123}I-MIBG.

Individual practitioners may use lower administered activities if their equipment or software permits them to do so. Higher administered activities may be required in selected patients. No recommended dose is given for intravenous ^{67}Ga-citrate; Intravenous ^{67}Ga-citrate should be used very infrequently and only in low doses.

(A) The EANM Dosage Card 2014 version 2 administered activity may also be used.

(B) The low end of the dose range should be considered for smaller patients. Administered activity may take into account patient mass and time available on the PET scanner. The EANM Dosage Card 2014 version 2 administered activity may also be used.

(C) The administered activities assume that image data are reformed at 1 min/image. The administered activity may be reduced if image data are reformed at a longer time per image.

(D) A higher administered activity of 1 mCi may be considered for neonatal jaundice.

(E) ^{99m}Tc-sulfur colloid, ^{99m}Tc-pertechnetate, ^{99m}Tc-DTPA or possibly other ^{99m}Tc radiopharmaceuticals may be used. There is a wide variety of acceptable administration and imaging techniques for ^{99m}Tc cystography, many of which will work well with lower administered activities. An example of appropriate lower administered activities is found in the 2014 revision of the EANM Paediatric Dose Card[2].

(F) The administered activity may be based on patient weight or on the age of the child.

(G) The administered activity is based on the EANM Dosage Card 2014 version 22 dosage for a 60 kg patient, using the minimum and maximum doses from the EANM Dosage Card. There was little experience with this radiopharmaceutical in children in North America at the time of preparation of this dosage table.

[1] Gelfand MJ, Parisi MT, Treves ST. Pediatric Radiopharmaceutical Administered Doses: 2010 North American Consensus Guidelines. J Nucl Med 2011; 52(2):318-322.
[2] Lassmann M, Treves, ST. Pediatric Radiopharmaceutical Administration: Harmonization of the 2007 EANM Paediatric Dosage Card (Version 1.5.2008) and the 2010 North America Consensus guideline. Eur J Nucl Med Mol Imaging 2014; 41(8):1636 Epub Mar 6 2014.

SNMMI SOCIETY OF NUCLEAR MEDICINE AND MOLECULAR IMAGING

image gently®

Fig. 1.2 North American Consensus Guidelines for Pediatric Administered Radiopharmaceutical Activities 2016. Reproduced with permission of imagegently.org

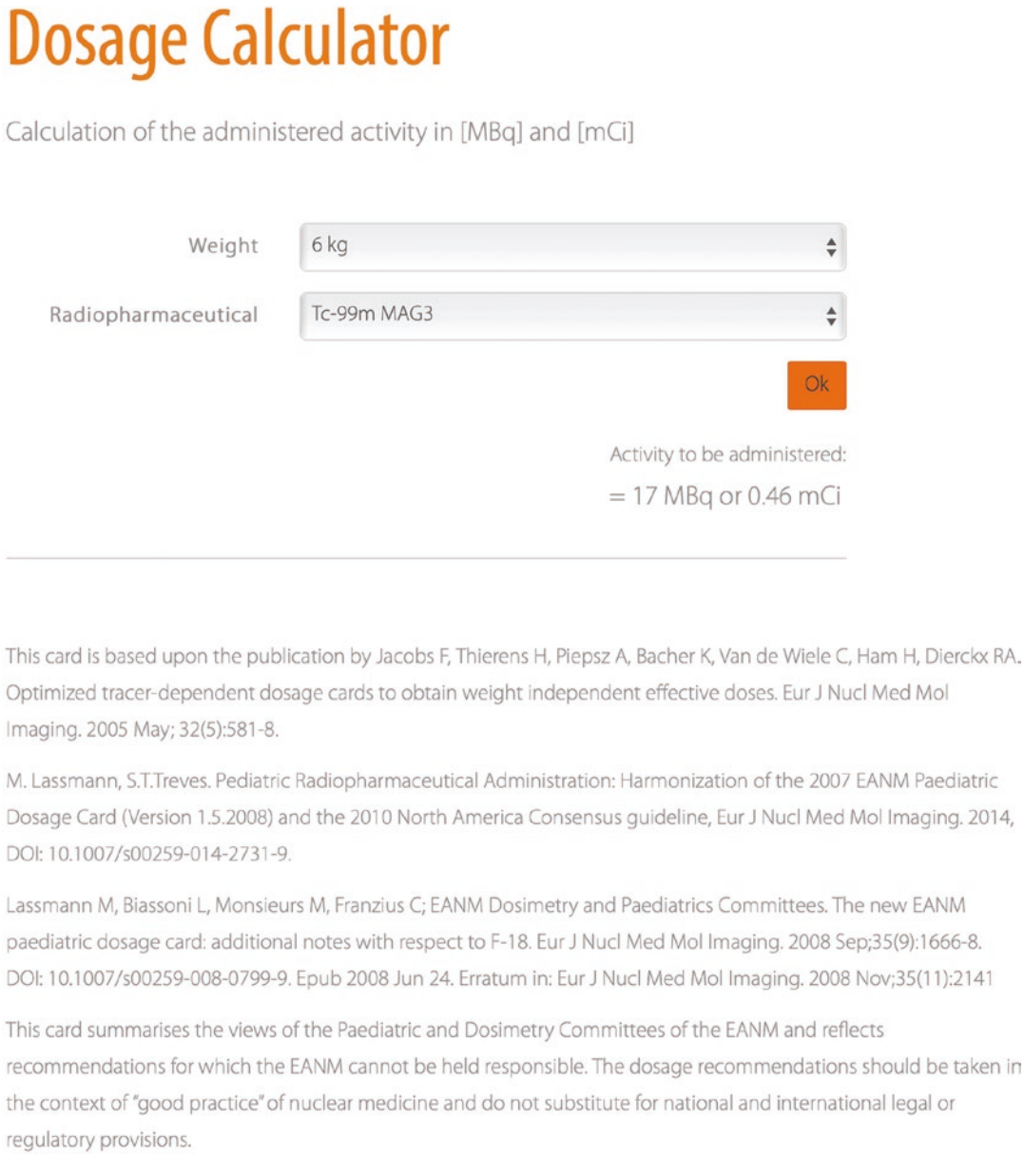

Fig. 1.3 Dose calculator snapshot. (based Reproduced with permission from https://www.eanm.org/initiatives/dosage-calculator/)

acquisition, for example, by gently securing the child's head when under the camera.
- Encourage the parent to hold the child's hand and talk to the patient during the study.
- Ensure that the accompanying caregiver is clear from the rotating camera heads.

Options for Distracting and Entertaining the Patient

- A TV screen mounted on one of the walls or ceiling above the gantry.
- A portable DVD player or one incorporated into the gamma camera.

- Stickers of popular cartoon characters or animals on the collimators.
- Smart phone to take pictures of the patient/play games /play music on.
- Read a storybook.
- Crayons and paper to entertain the child during the waiting period.
- The toys in your department should be easy to clean, preferably plastic.
- Avoid soft and plush toys as they pose a significant infection and contamination risk.

Assessing the Need for Sedation

- Sedation and anesthesia carry risk, impose a logistical challenge requiring several hours of fasting prior to the procedure and need to be considered at the time of booking study.
- If conscious sedation is to be performed, the same preparation applies.
- For short studies sedation may not be necessary.
- Consult with institutional guidelines for recommended drugs to administer for sedation.

Principles and Protocols for Sedation/General Anesthesia

- Sedation should be performed by qualified, authorized personnel including your pediatric anesthesia service applying the standard sedation used in your institution.
- Sedation or general anesthesia should be used judiciously.
  - It can be indicated in young children beyond swaddling age and under 5 years of age or non-cooperative older children.
  - The need for sedation also depends on the study type, and should be considered in particular when performing SPECT/CT and PET/CT or PET/MRI.
- Do not sedate the patient if adequate resuscitation facilities are not available, including a correct size endotracheal tube.
- Document type, dose, and time of sedation.
- A qualified nurse or physician must be present with the child during the entire sedation Monitor continuously using a pulse oximeter (document pulse rate and oxygen saturation).
- The patient is only allowed to leave the department once fully awake as determined by the nurse or physician in your department.
- Tell the parent/caregiver what to expect after sedation, and which warning signs to watch for.

1.2 Performing and Reporting the Study

Preparing and Administration of Radiopharmaceutical

- If tracers are prepared in the Nuclear Medicine department, follow national regulations for radiopharmaceutical in-house preparation.
- If small amounts of activity have to be administered they may be difficult to draw up and the activity used to prepare the kit should be diluted.
- Use the smallest syringe available to draw up the dose. For pediatric doses a 1-ml syringe is ideal.
- A butterfly needle or venous cannula is recommended to administer the radiopharmaceutical. Direct large bore venipuncture needle should not be used.
- Post-injection saline flush is very important.

Setting up the Imaging Device

- Cover the collimator with absorbent material if the patient is positioned directly on the collimator. This protects your camera from contamination.
- Contamination can easily occur with studies such as milk scans or diuretic renography.

Positioning the Patient

- Wrap small babies tightly in a blanket (swaddle).
- To prevent patient motion, use restraining devices including papoose boards, sandbags, large saline bags, rolled towels, or vacuum immobilization bags, around the patient.

- Ensure the patient is firmly secured to the bed using Velcro straps (Fig. 1.4).
- When performing extremity imaging in a small child it is useful to bind the legs together (Fig. 1.5) and improve the position of the arms using splints.
- In older children, immobilize the feet together with the toes pointing inward, this improves the position of the hips and separates the tibia and fibula (Fig. 1.5).
- If the desired position cannot be obtained (due to pain or discomfort), care should be taken to place both limbs in similar positions.
- Patient should empty the bladder before starting the scan to be comfortable during the procedure.
- If SPECT/CT or PET/CT are performed, arms should be placed above the head if possible, to avoid beam-hardening artifacts on CT when the arms are in the field-of-view (FOV).
- For PET/MRI and other studies with longer sedation times arms should be placed down, by the side of the body.
- When the site of disease is in the head and neck, an additional image of head and neck is recommended with arms by the side of the body (Fig. 1.4).

Fig. 1.4 Firmly secured child using Velcro straps

Fig. 1.5 Immobilized legs to reduce motion and better visualization of pelvic and shin bones

Performing the Study

- Determine if all organs of interest are in the FOV, use a marker if needed.
- Zoom your images according to the patient size.
- A single FOV spot image of an infant is not acceptable for whole-body visualization.
- Long acquisition times increase the likelihood of motion artifacts degrading image quality.
- While it is important to follow pediatric imaging protocols, occasionally adjustments in the imaging sequence and duration are needed in order to tailor to the specific question at hand and to the degree of the child's cooperation.
- When the infant is asleep, start with imaging the region of concern rather than sequential images from head to toe.
- For some study types, e.g., bone scans, it is recommended to first image the pelvis while the urinary bladder is relatively empty.
- The technologist should note when there is possible radioactive urine contamination, clean the area and repeat the examination without contaminated clothing.

Reporting the Study

- Check the tracer biodistribution and quality of images before reporting the study.

The report should include:

- The indication for the study with pertinent medical history.
- Premedication and pharmacologic intervention, type, and duration.
- Any usage of sedation or general anesthesia.
- CT imaging dose report to include the CT dose index (CTDI) and dose length product (DLP) when required by national or local regulations.
- Presence of a urinary catheter.
- The radiopharmaceutical type, activity, route of administration and site.
- The imaging protocol: dynamic, planar, pinhole, SPECT, SPECT/CT, PET/CT, or PET/MRI.
- A detailed study report of all findings.
- Comparison to a previous study (if performed and available) and/or, if indicated, with results of other imaging tests.

- Final impression.
- Suggestion for further evaluation as clinically indicated.
- Urgent or critical findings should be directly communicated by phone to the referring physician and this communication should be documented in the printed report, including the name of the physician, date and time of the communication.

1.3 Hybrid Imaging [17, 18]

- Hybrid imaging is now an important part of nuclear medicine, including pediatric patients.
- The power of the co-registered, cross-sectional capabilities of SPECT/CT, PET/CT, and PET/MRI provides more information than the sum of the parts standalone.
- With new techniques comes the added responsibility of optimizing the investigation.
- CT scan options for hybrid imaging studies (both PET/CT and SPECT/CT) include:
  - Attenuation correction and image optimization.
  - Study for anatomical localization.
  - Diagnostic CT with or without oral and/or IV contrast administration.
- CT settings for SPECT/CT or PET/CT should follow pediatric protocols for low-dose or diagnostic CT including:
  - Low-dose CT for anatomical localization, mainly if the patient had a diagnostic standalone CT within a short time interval prior to the hybrid imaging study.
  - Optimized study for diagnostic evaluation.
- Dose modulation should be applied for pediatric CT hybrid studies.
- CT images should be examined using bone, lung, and soft tissue windows.
- The choice of technique depends on local hospital protocols, team and clinician's preferences, and MRI availability.

SPECT/CT [19]

- Gamma camera imaging with single photon emitting radiotracers represents the majority of procedures in a routine pediatric nuclear medicine practice.
- The optimization of technology for image acquisition, display, and analysis, as well as the emergence of new ^{99m}Tc-labelled agents are enhancing the value of SPECT/CT in terms of both clinical impact on patient care.
- In general, and specifically for non-oncological indications, the decision to perform the CT is made if clinically indicated or after the SPECT images are completed and reviewed and with the patient not having moved position [20].
- SPECT/CT has proven to be especially valuable by:
  - Precise localization of areas of abnormal and/or physiological SPECT tracer uptake.
  - Improving the sensitivity and specificity of nuclear medicine procedures.
  - Allowing for quantitation.
  - Optimized guide for interventional diagnostic procedures.
- When CT is acquired only to clarify SPECT findings, its FOV can be reduced to only cover the suspicious findings. This can significantly reduce the patient's dose.

PET/CT [21–24]

- True whole-body imaging from vertex to feet has been recommended to be performed in PET/CT studies of children as pediatric diseases may occur distal to elbows and knees.
- In general, pediatric CT scanning for PET/CT, even with optimized diagnostic techniques including IV contrast administration can be adequately performed with lower kVp and with dose modulation to lower mAs.
- By utilizing an optimized post-contrast CT examination with sufficient attenuation-correction, while staging a child presumed to have malignancy, one may possibly eliminate the 1–2 additional CT scan examinations that may have been performed.
- PET/CT can be also utilized for better delineation of target volumes for external beam radiation therapy.

PET/MRI [25, 26]

- This technology combines PET and MRI imaging with simultaneous acquisition.
- Potentially, any study that could be done with PET/CT could be performed with PET/MRI provided there are no contraindications for the child to have an MRI.
- As with CT, renal function should be known before study.
- Strengths of MRI as compared with CT:
  - Superior soft tissue contrast resolution.
  - It provides functional data, mainly for neurological cases.
  - Lack of ionizing radiation is highly appealing, particularly in pediatric, young adult, or pregnant patients.
  - With the development of full digital and total-body PET/CT and PET/MRI scanners, the administered activity can be significantly reduced.
- Limitations of PET/MRI:
  - Most children under 8 years of age will require sedation or general anesthesia for PET/MRI.
  - Non-sedated children may experience claustrophobia.
  - The technique and its evaluation are complex, the equipment is very costly and has limited availability in some countries.
  - PET/MRI has inferior performance (compared to CT) in detecting lung and cortical bone pathology.
  - There are more frequent artifacts on the attenuation correction maps.
  - A PET/MRI procedure can be of longer duration as compared to PET/CT, due to the prolonged MRI acquisition in cases of multiparametric sequences.

Adverse Reactions to Contrast Media [27]

- Various forms of contrast media have been used to improve medical imaging.
- Like any pharmaceutical, these agents are not completely devoid of risk. When used, it is important to recognize and manage the small but real risks inherent in the use of contrast media.
- Adverse side effects from the administration of contrast media vary from minor physiological disturbances to rare but severe life-threatening situations.
- It is important to evaluate the likelihood of a patient to experience a subsequent reaction.
- The previous use of contrast media, and also presence of allergy and asthma are important parameters to evaluate prior to the scan.
- Renal insufficiency, cardiac status, and anxiety should also be evaluated.
- In some cases, premedication strategies such as steroid and antihistamine administration might be used.
- Being prepared for prompt treatment of the entire spectrum of contrast media reactions and potential adverse events includes prearranged response planning with the availability of appropriately trained personnel, equipment, and medications.
- The ACR manual's information on contrast reactions is a comprehensive resource for this topic. https://www.acr.org/Clinical-Resources/Contrast-Manual.

1.4 Correlative Imaging [27–29]

- Most radiologic correlative imaging modalities provide focused evaluation and not whole-body screening.
- Nuclear Medicine examinations in children often provide the capability for whole-body diagnostic imaging, occasionally revealing sites of disease that are outside the FOV of focused radiological investigations.
- Whole-body imaging is important because of the multifocal nature of certain oncologic and non-oncologic pediatric conditions.
- Referred pain, non-verbalization of infants, and difficulties in performing physical examination in non-cooperative children can result in directing focused radiologic examinations to the wrong sites.

- Nuclear Medicine examinations, however, must be correlated with history, physical, and correlative imaging.
- Correlative imaging can include radiographs, ultrasound (US), CT, and MRI.
- Plain radiographs are often utilized as initial imaging for children presenting with respiratory or gastrointestinal symptoms and may provide evidence of infectious, inflammatory, neoplastic, or traumatic diagnoses.
- Correlation with radiographs is particularly important for assessment of the musculoskeletal system.
- Conventional radiographs usually are followed by more specific imaging.
- In recent decades, radiation-free techniques such as US have unequivocally become the first choice modality for assessing pediatric patients.
- US is a readily available tool and is required for correlation when performing various nuclear medicine studies in children, such as renal studies.
- US should be the first study in a child with a palpable abdominal mass. It can detect the site of origin of the mass as well as involvement of solid organs. However, this is usually not the final diagnostic and/or staging test.
- Cross-sectional imaging with CT or MRI may be performed in a child presenting with a mass or with systemic symptoms.
- CT is more often utilized to assess lesions in the chest such as for pulmonary nodules that may not show activity on nuclear medicine studies either because of their size or lack of avidity.
- Because hybrid nuclear medicine studies are not able to be done as breath-hold studies, the sensitivity with a stand-alone breath-hold non-contrast CT of the lungs is often needed for correlation.
- CT studies may be performed as the first imaging test in particular in a child with trauma. Results of this CT may then be used to correlate with additionally performed functional nuclear medicine studies.
- MRI, where available, has become the procedure of choice in a variety, if not all, pediatric clinical scenarios, in particular, in suspected oncologic diseases and cancer predisposition syndromes, acute osteomyelitis, and infection and inflammation in the brain and spine.
- The majority of MRI examinations are focused exams.
- One pitfall with MRI, as well as with CT or US, is the fact that these studies are most often primarily focused on the clinical site of concern and can therefore miss the site of disease in cases of referred pain or remote sites in the presence of multifocal disease, both common situations in children.

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