1 General Aspects of Pediatric Nuclear Medicine

S. Ted Treves and Frederick D. Grant

Pediatric nuclear medicine is a very interesting, dynamic, and exciting field. Nuclear medicine contributes to the diagnosis of many diseases in children. Well-established procedures reveal physiological processes *in vivo*, permit early detection of disease, help patient management and therapeutic decisions, and provide an important tool to follow the success of therapy or to assess progression of disease. One of the reasons that nuclear medicine in pediatric patients remains successful is that nuclear medicine studies provide unique information about the patient's condition that cannot be obtained easily (or sometimes at all) with other diagnostic methods. Some nuclear medicine procedures require pharmacologic interventions. Examples include the administration of furosemide, acetazolamide, phenobarbital, cholecystokinin analog, and dobutamine.

Pediatric patients, with their wide range of body size, physical and psychological developmental changes, and medical disorders, present unique challenges. Patients in pediatric nuclear medicine range in weight from premature infants to young adults reaching adult weight. It has been said that children are not small adults, and even in nuclear medicine "one size does not fit all" [1, 2].

As a consequence, nuclear medicine physicians and members of the team frequently need to adapt to these challenges and often need to customize studies and personalize care. Diagnostic nuclear medicine procedures are well suited for the evaluation of pediatric patients because they are physiological, sensitive, minimally invasive, and safe.

An important advantage of nuclear medicine procedures in the first year of life is that they are extremely safe. Radiopharmaceuticals contain only trace amounts of material and are nontoxic and nonallergenic. The total mass of material that is administered is very small and is administered in a very small volume (typically <1.0 mL). The small administered mass and volume of material means that radiopharmaceuticals do not produce a hemodynamic or osmotic effect. For example, a patient who is allergic to iodine can safely receive ^{123}I-NaI or ^{123}I-MIBG without fear of an allergic reaction because the actual mass of

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S.T. Treves (ed.), *Pediatric Nuclear Medicine and Molecular Imaging*,
DOI 10.1007/978-1-4614-9551-2_1,

Table 1.1 Comparison of mass and volumes for certain radiopharmaceuticals and contrast agents. Example in a 1-year-old

	Volume (mL)	Mass (mg)
^{99m}Tc-MDP	0.06	0.64
^{99m}Tc-DMSA	0.03	0.22
^{99m}Tc-MAG$_3$	0.10	1.1
Gd-DTPA	2.0	940
Optiray 320	20	6,400

iodine that is administered is exceedingly small and well below the threshold needed to trigger an allergic reaction. The volume and mass of a radiopharmaceutical that is administered is significantly lower than for MRI and CT contrast agents. For example, the volume of ^{99m}Tc-MDP solution administered to a 1-year-old patient weighing 10 kg is 0.06 mL, and the administered mass of material is 0.64 mg. In comparison, for the same 1-year-old, the volume of Gd-DTPA (Magnevist, Bayer) administered for an MRI scan is 2.0 mL, and the mass is 940 mg. The volume of ioversol (Optiray 320^{TM} Covidien) administered for a CT scan is 20 mL, and the mass is 6,400 mg. Thus, the administered volume for ^{99m}Tc-MDP is 20–200-fold less than for MRI or CT contrast agents, and the administered mass is more than a thousandfold less. Other radiopharmaceuticals are listed in Table 1.1.

A characteristic of pediatric nuclear medicine is that normal values in children are difficult to find, as normal patients cannot be studied easily with these techniques due to ethical and other concerns relating to the use of radioactive materials.

Also, the wide range of disorders, body sizes, and developmental stages of pediatric patients requires patient-centered care with considerations regarding individualized adjustments of imaging methodology, dosimetry, and interpretation. Physicians and technologists working in pediatric nuclear medicine should be familiar with children, their varied behavior, and the disorders that affect them. Dealing with pediatric patients adds a level of complexity compared to adult nuclear medicine patients. Pediatric nuclear medicine procedures are “people-intensive.” Many procedures that in an adult setting can be conducted adequately by a single technologist may require two technologists (or a technologist and an aide) in children. More time and patience is necessary when dealing with children than with adults. Despite the best efforts of staff, procedures in children usually take longer than in adults (sometimes as much as twice as long).

Formal training and experience in pediatric nuclear medicine allows medical professionals to adjust the practice of nuclear medicine to meet the medical and personal needs of pediatric patients. For example, at centers experienced in the care of children, patient sedation for pediatric nuclear medicine studies is used less frequently than in less specialized centers. Also, image quality in specialized centers is frequently superior to those from nonspecialized institutions.

The nuclear medicine team should adjust the procedures in order to address the clinical problem to be investigated. The goal of every pediatric nuclear medicine study is to obtain the best diagnostic yield while employing the highest technical standards in the shortest period of time, with the lowest patient radiation exposure.

The Consultation

Pediatric nuclear medicine studies should begin with evaluation of the diagnostic question, review of prior medical history, and assessment of the needs and concerns of the patient and family. Obtaining a clear description of the clinical question being asked is of utmost importance in guiding the procedure. Although current medical information systems treat the request for a nuclear medicine study as an “order,” the patient will be better served if the requesting clinician and nuclear medicine physician treat this as a request for a consultation. As a consultant, the nuclear medicine physician can determine the most appropriate study to answer the clinical question and can optimize the nuclear medicine study to the physical and physiological development of the pediatric patient. If the nuclear medicine consultant determines that the examination requested is not appropriate to address the problem in question or that another type of examination is indicated, he or she should communicate such concern to the referring physician in order to select a more appropriate examination or to avoid an unnecessary examination. Whenever possible, questioning parents and patients about the clinical history and symptoms, or an appropriately directed physical examination, should be considered integral parts of the nuclear medicine study as sometimes important relevant information may be gathered that may not be available on the original request.

Before proceeding with a nuclear medicine study, a female adolescent or young adult should be asked if she might possibly be pregnant. If the post-menarche patient does not know if she is pregnant, it is prudent to wait until the next menstrual period or to perform a pregnancy test. If the patient is pregnant, it is advisable to consult with the referring physician about the need for the test at this time and to evaluate the potential risks and benefits of performing the test (or not). Asking a young woman if she is pregnant, however, can be a very delicate matter, and it needs to be handled with care and sensitivity. This can be difficult, and it can be worse if the parent does not know that the young woman is sexually active. Sometimes it is necessary to consult with the referring physician about the best way to handle the situation given each individual family situation. If the mother of the patient having an examination is pregnant, she should be instructed on how to avoid or reduce her radiation exposure.

Optimal results are obtained when the physician and the technologist review the case and consult in order to determine if any aspect of the examination requires special attention. It is highly desirable that previous imaging studies be readily accessible to the nuclear medicine physician. Knowledge of potentially conflicting imaging tests already scheduled is essential when planning the study. Planning several studies in the same day requires careful scheduling, so the patient experience can be streamlined. It is important to determine if the patient had been given radiographic contrast during the past few days as contrast can produce shielding artifacts on the nuclear medicine images. It is also important to determine, before the test, if the patient may require sedation and if there are any special precautions. In addition, knowledge of patient medications that may interfere with the nuclear medicine study is important for successful interpretation and results.

Optimal pediatric nuclear medicine practice requires the use of modern equipment, appropriate radiopharmaceutical administered doses, updated techniques, displays, and advanced image processing software. In the modern era, nuclear medicine results should be reported promptly to the referring physician. Results of image analysis should be available immediately after the studies are completed so results can be reported rapidly and within a clinically useful time. The report should be clear and concise, and it must address the clinical question(s) being asked. Rapid and efficient electronic access to nuclear medicine images and reports facilitates communication with referring physicians and can help improve patient care.

Interaction with Patients and Families

Parents are naturally concerned about what is going to happen to their child. The word nuclear can be concerning to some patients and parents. It is important that the nuclear medicine physician and other members of the nuclear medicine care team be accessible to patients, parents, and referring physicians to help explain the low radiation exposures and physiological nature of nuclear medicine examinations [3].

Patients and families should be given information about what the anticipated nuclear medicine procedure will entail. If possible, the patient's family should be contacted by a member of the nuclear medicine staff a day or two in advance to confirm the appointment and to discuss the test. For example, it is important that families understand necessary patient preparation, the anticipated duration of the study, and whether it may be necessary to return later the same day or on a later day. Many parents find it helpful if information about nuclear medicine studies and departmental procedures is posted on the hospital or department website. It is useful to provide referring physicians' offices with brochures explaining common nuclear medicine tests (Appendix 1).

Fig. 1.1 Young patient with a nuclear medicine technologist after a study was completed. Establishing a good rapport with the patient can be helpful in assuring patient cooperation

The first contact, whether by phone or in person, is important and should include a clear and honest explanation of the procedure. Physicians and technologists should make a concerted effort to inform patients (whenever possible) and parents personally about the examination. Every pediatric patient must be treated as an individual with individual emotional and physical needs. Children who are prepared can be more cooperative, often facilitating the examination for everyone involved. Patients should be told what they will see, hear, feel, and, most importantly, what they will be expected to do. For example, they should be informed of an impending injection, the injection site, if there will be any pain, and any other appropriate explanations all of which tend to help reduce anxiety. Children have highly developed imaginations, and their fantasies can be anxiety provoking. It is important to keep in mind a child's developmental level when giving information and defining expectations during the procedure. Explanations and words should be chosen accordingly to ensure proper understanding of the information being given. It is sometimes helpful to explain the procedure to the child at least twice, first outside the imaging room where the child may feel less threatened and then in the imaging room. Throughout the examination, the technologist should provide reassurance and positive verbal reinforcement to enhance the child's sense of mastery (Figs. 1.1 and 1.2).

In most instances, children of all ages benefit from having a parent, relative, or a familiar staff person in the imaging room. Typically, children between the ages of 8 and 36 months may suffer separation anxiety if removed from their parents. Older children may tolerate separation, but most will prefer the presence of a familiar person. Younger children may be comforted by a favorite toy or stuffed animal that they have with them during the examination (Fig. 1.3). This should be permitted so long as it does not interfere with the test. Some children can cope better with the examination when they are alone rather than with their parents. Many adolescents may prefer privacy and independence, while other adolescents will still want a parent with them during the study. Children and teenagers with extensive medical or hospital experience may have strong feelings about whether or not parents stay in the examination room, and these desires should be respected (Fig. 1.4) [1].

Fig. 1.2 A young girl walking toward the examining room accompanied by her mother and a nuclear medicine technologist

Fig. 1.3 The patient is allowed to hold a favorite toy while undergoing a nuclear medicine scan. The toy did not interfere with the test. The technologist is supporting the child by talking to her

Fig. 1.4 Both parents and the child are watching TV while the patient is undergoing a ^{99m}Tc-DMSA SPECT. Watching TV or a favorite program while imaging is proceeding can have a calming effect

Physical Environment

Ideally, the physical environment of the nuclear medicine department should support patient comfort as well as patient, family, and personnel safety and efficient workflow. Making a department accessible and friendly for children requires extra attention to the design and workflow of the department. Space is needed for patient reception and waiting, imaging, a radiopharmaceutical administration room, an examination room, a radiopharmacy, a technologist workspace or room, and a consultation/reading room. Ideally, the radiopharmacy and administration/examination room should be in close proximity to each other, while reception and waiting areas should be located away from the examination rooms. The consultation/reading room and the technologist work area should be easily accessible to nuclear medicine personnel and referring physicians. Emergency supplies should be readily accessible.

Waiting Room

Most children undergoing nuclear medicine examinations are outpatients, and careful scheduling can reduce waiting time for patients and parents. However, in practice, parents and families almost always experience some waiting before, during, and after an examination. Some studies may require extended waiting in the department after administration of the radiopharmaceutical (e.g., examinations using FDG). Other studies require the patient to return one or more times after initial imaging. Parents and other family members may wait for a few minutes to several hours while the patient is undergoing an examination. The waiting room should be spacious, friendly, comfortable, attractively decorated, and well lit, and seating should be sufficient to accommodate family members. The waiting room should be supplied with plenty of appropriate reading materials and toys as well

Fig. 1.5 A waiting room in nuclear medicine. There is abundant space for the family to wait for the patient, and there are plenty of toys, a blackboard, a TV, and other materials to help entertain the family and the siblings. There are plenty of reading materials including information about nuclear medicine and its tests. The reception desk is low to allow children to view what is behind it

as information about parking, nuclear medicine, and other subjects appropriate for patients and their families. The reception desk should be at a writing height, so children can see the receptionist and are not intimidated by a tall counter (Fig. 1.5).

Radiopharmacy

The radiopharmacy should be well equipped with lead-shielded cabinets (for SPECT and PET radiopharmaceuticals), a hood, a sufficient counter space, an appropriate safety equipment, an exhaust for volatile or gaseous materials, and a laminar flow hood. The room itself should be under negative air pressure. In departments that prepare radiopharmaceuticals, the radiopharmacy should be compliant with the requirements of section 767 of the US Pharmacopeia. Some institutions do not have a radiopharmacy, and, in this case, radiopharmaceuticals are provided by commercial vendors. Therefore, these centers do not need an elaborate in-house radiopharmacy. Radioactive storage and calibration equipment should be provided however. Data entry tools for radiopharmaceuticals and other pharmaceuticals should be provided in the nuclear medicine facility. The radiopharmacy should have sufficient space for supplies as well as for storage and disposal of radioactive materials. In addition, storage space is needed for nonradioactive supplies.

Radiopharmaceutical Administration: Examination Room

Busy pediatric nuclear medicine departments should have at least one room for administration of radiopharmaceuticals so that imaging rooms are free for performing studies. This room, which should allow for privacy, is also used to talk to patients and parents and to conduct directed physical examinations. The administration/examination room ideally should be adjacent to the radiopharmacy. This room also can be used for the administration of ^{131}I for the treatment of hyperthyroidism or thyroid cancer. Patients undergoing FDG-PET studies require special planning as they will need an area for waiting during the 1-h uptake period after FDG administration. Keeping this room at 24° centigrade has been shown to markedly reduce FDG uptake in brown adipose tissue, and it may be helpful for the patient to acclimate in this room for at least 30 min prior to FDG administration [4]. With the increased use of CT with PET, there is a need for

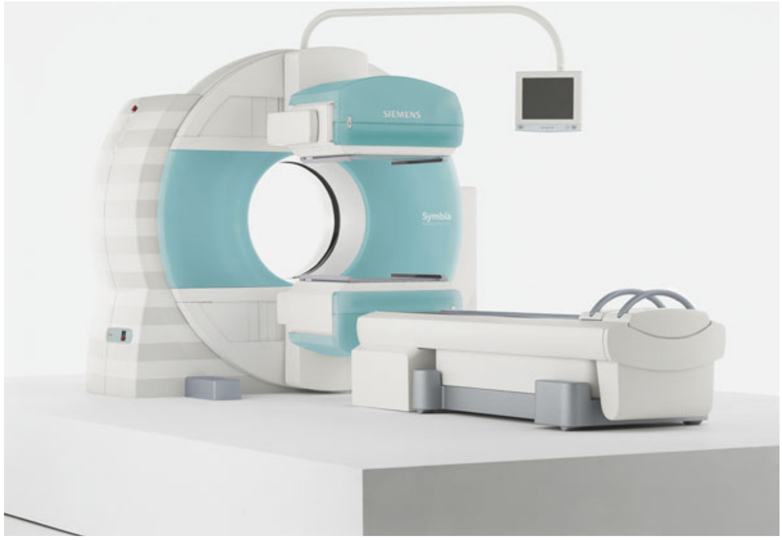


Fig. 1.6 An example of a modern gamma camera/SPECT/CT system (© COPYRIGHT Siemens Healthcare 2013)

space for the administration of oral contrast agents.

Imaging Rooms

Examining rooms should be designed so that they are friendly, attractive, and sufficiently spacious to contain the equipment, permit proper examination, allow sufficient privacy, and allow for the presence of the patient's parents in the room. Examining rooms should be flexible in design and adaptable to the changing technology in nuclear medicine (Figs. 1.6 and 1.7). Some useful attributes of a nuclear medicine exam room include:

1. Sufficient general ambient light as well as dimmers in order to be able to provide a soothing effect (some children fall asleep during the examination).
2. Ceiling-mounted spotlight for illuminating the injection site or catheterization fields.
3. Ceiling-mounted hangers to hold bottles or bags for intravenous infusion.
4. Ceiling-mounted heating lamps.
5. Telephone with a cancelable bell; emergency numbers must be posted clearly on the telephone.
6. Oxygen and vacuum outlets, preferably wall-mounted and within easy reach from the patient's head on the examination table.
7. Exhaust for safe disposal of radioactive gases (xenon-133 for ventilation studies).
8. Small TV mounted over the examining table within easy view of the patient; a video player to play appropriate programming for the patient.
9. Sufficient space to house associated electronic equipment, such as electrocardiographs, electroencephalograph, anesthesia monitoring equipment, and external physiological detectors.
10. Doors wide enough to permit safe access to regular and special patient beds.
11. Room designed to permit safe maneuvering of the patient's bed in relation to all the equipment around the patient.

Performing the Study

The technologist should examine patients for metallic objects that can shield gamma radiation (e.g., keys, belt buckles, coins, jewelry). Once the first images are obtained, any diapers, clothing, or gauze contaminated with radionuclides should be removed and the area reimaged. Contaminated skin should be thoroughly washed, monitored, and reimaged. Once the examination is completed, the physician and the technologist should review and evaluate the quality and adequacy of

Fig. 1.7 A modern PET/CT system (© COPYRIGHT Siemens Healthcare 2013)

the study and determine if additional imaging is necessary. Depending on the initial result, the physician may need to reexamine the patient and the clinical data before the patient is discharged. When appropriate, the physician may recommend additional anatomic imaging to clarify an abnormal finding or to try to increase the specificity of a scintigraphic finding.

Proper patient positioning to avoid motion artifacts is essential for a good examination. Because most nuclear medicine imaging requires the patient to remain still for a relatively long period, immobilization techniques to help patients remain still during imaging are commonly used. Sandbags, adhesive tape, a papoose wrap with blanket, Velcro straps, and contoured pillows may be employed, depending on the size, age, condition, and activity of the patient. Newborns usually find swaddling comforting. In addition to these immobilization techniques, it is sometimes necessary for a technologist or an aide to hold a patient in position during imaging. Imaging artifacts resulting from holding patients by hand should be anticipated, recognized on the image, and, if possible, avoided. In some cases, the nuclear medicine physician needs to mark the patient's skin over a lesion to help guide biopsy or surgery as in the case of a thyroid nodule, an osteoid osteoma, a sentinel node, etc. Technologists often need to talk, support, encourage, and distract the child while ensuring that the gamma camera is set up and functioning correctly. With a quiet environment, dim lights, and care, some children fall asleep during long examinations. Watching television or a DVD can be an effective "sedative" and can help distract and relax some patients (and parents) during the examination. In some cases, immobilization alone is not successful, and sedation is required in order to avoid multiple sedations during the day of the patient's visit (see Chap. 2).

In our experience, children less than 1 year of age only need sedation in less than 3 % of cases, mainly for brain or whole body SPECT or PET [2]. Sedation should only be used when absolutely necessary. The type and dose of sedative used must be individualized and should be decided in consultation with the referring physician or pediatric anesthesiologist. Some large institutions have specialized pediatric imaging sedation guidelines and dedicated teams of nurses and anesthesiologists that manage all sedation and anesthesia for imaging. When administering sedatives to patients, potential side effects such as aspiration and respiratory arrest should be anticipated and appropriate means of treatment made available. Sedation or general anesthesia can affect many physiological processes, including cerebral metabolism, myocardial function, renal blood flow, and specific functions such as cerebrospinal fluid flow and cardiovascular shunt flow.

With the increased use of single photon emission computed tomography (SPECT) and positron emission tomography (PET), the use of sedation has increased. Sedation or general anesthesia should be planned in advance of the patient's visit to nuclear medicine. It is important to assess the appropriateness of the patient for sedation or general anesthesia before the study. Proper advance instructions about eating, diet, and any other preparation should be communicated clearly to the patient or family. Similarly, outpatients need to be informed about their need to meet discharge criteria after sedation or general anesthesia and the time commitment that may be needed. Importantly, if the patient needs more than one imaging procedure in the same day, sedation scheduling should be appropriately coordinated (see Chap. 2).

Imaging Infants and Young Children

Pediatric nuclear medicine plays an important role in the evaluation of the majority of organs and systems in the body in children less than 1 year of life. Imaging patients in this age group is one of the most interesting and challenging aspects of this medical specialty, as the clinical problems encountered in patients during the first year of life are rather unique in terms of the disorders involved, extra care needed, and special imaging requirements. Successful imaging of neonates and infants requires special care and patience. Although imaging protocols should be standardized as much as possible, studying this population often requires that the nuclear medicine specialist diverge from routine protocols by altering radiopharmaceutical doses, imaging technique, or type and number of images needed in order to optimize the imaging approach and the specific diagnostic task at hand.

During growth and development in the neonate and infant, radiopharmaceutical kinetics can be different from those in the older child or the adult. These characteristics must be kept in mind during interpretation of nuclear medicine studies. Newborns and infants have relatively slower renal radiopharmaceutical kinetics, lower renal function, lower glomerular filtration rate (see Chap. 14), faster washout of radioactive gases from the lungs, faster circulation times, and faster lymphatic flow than adult patients. Another example of differences in radiopharmaceutical biodistribution occurs in the developing brain. Similarly, in children the concentration of ^{99m}Tc-methylene diphosphonate (MDP) in growth centers is relatively high.

Babies and infants experience rapid growth and development that are reflected on nuclear medicine studies. The pulmonary capillary bed in the very young child has a smaller number of arterioles than the older child. Gradually, with growth and maturation, physiological processes and radiopharmaceutical kinetics and biodistribution reach adult levels (Figs. 1.8, 1.9, 1.10, and 1.11) [2, 5].

Instrumentation and Equipment

Collimators

Collimator selection for individual types of examinations is important, and awareness of the characteristics of various collimators helps optimize imaging. Collimation in pediatric nuclear medicine should favor high- and ultrahigh-resolution-type collimators. Magnification scintigraphy with the pinhole collimator provides the highest spatial resolution images routinely

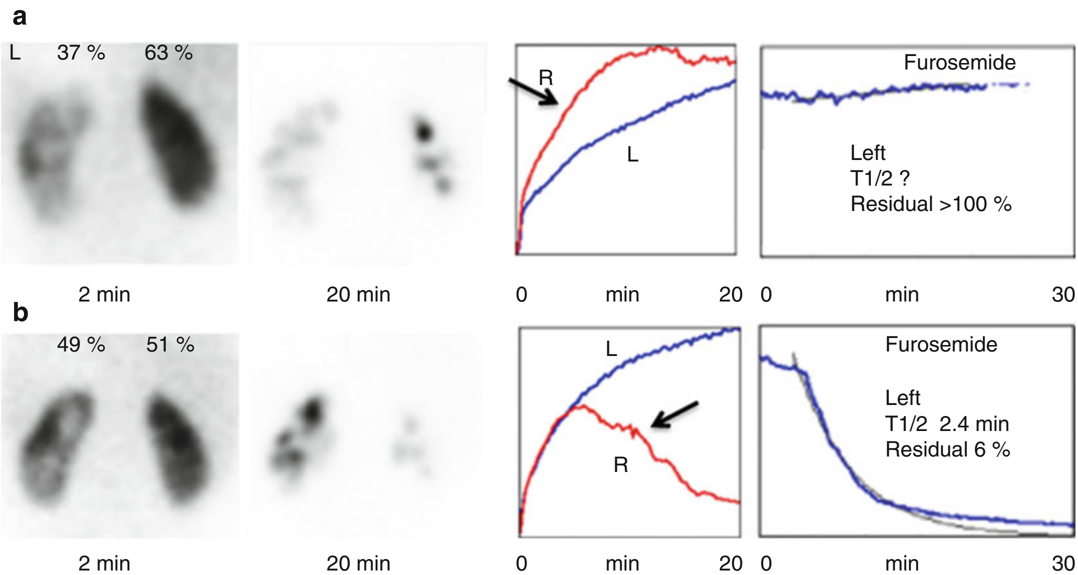


Fig. 1.8 MAG3 studies from a 3-month-old boy. (**a**) Early study reveals 63 % of the total renal function in the right kidney which is normal. Note the prolonged time-to-peak from the right renal time-activity curve and a very high residual at 20 min post-tracer administration (*red curve* and *arrow*). (**b**) Study done 2 months after left pyeloplasty without any intervention in the right kidney shows a normal right kidney time-activity curve and normal drainage (*red curve*=R). The right kidney shows maturation with a normal time-activity curve (*red curve* and *arrow*). *The blue curve* is form the left kidney as the *red curve* is from the right kidney

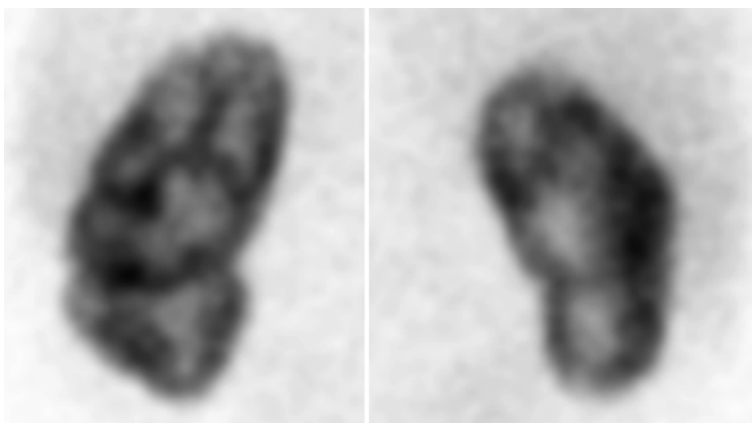


Fig. 1.9 ^{99m}Tc-DMSA pinhole images of the kidneys from a 6-week-old male showing normal fetal lobations that should not be confused with cortical defects

available with gamma cameras, and in selected applications it is an indispensable technique for imaging small body parts in children (see Chap. 28). Pinhole images using an insert of a small aperture (3–4 mm) in infants undergoing ^{99m}Tc-DMSA renal scans or ^{99m}Tc-MDP bone scans are of excellent quality even in the smallest patients. However, the pinhole collimator has the lowest sensitivity of any of the routinely used collimators used with the gamma camera, particularly with the smaller apertures, and the images can take several minutes to acquire which can be

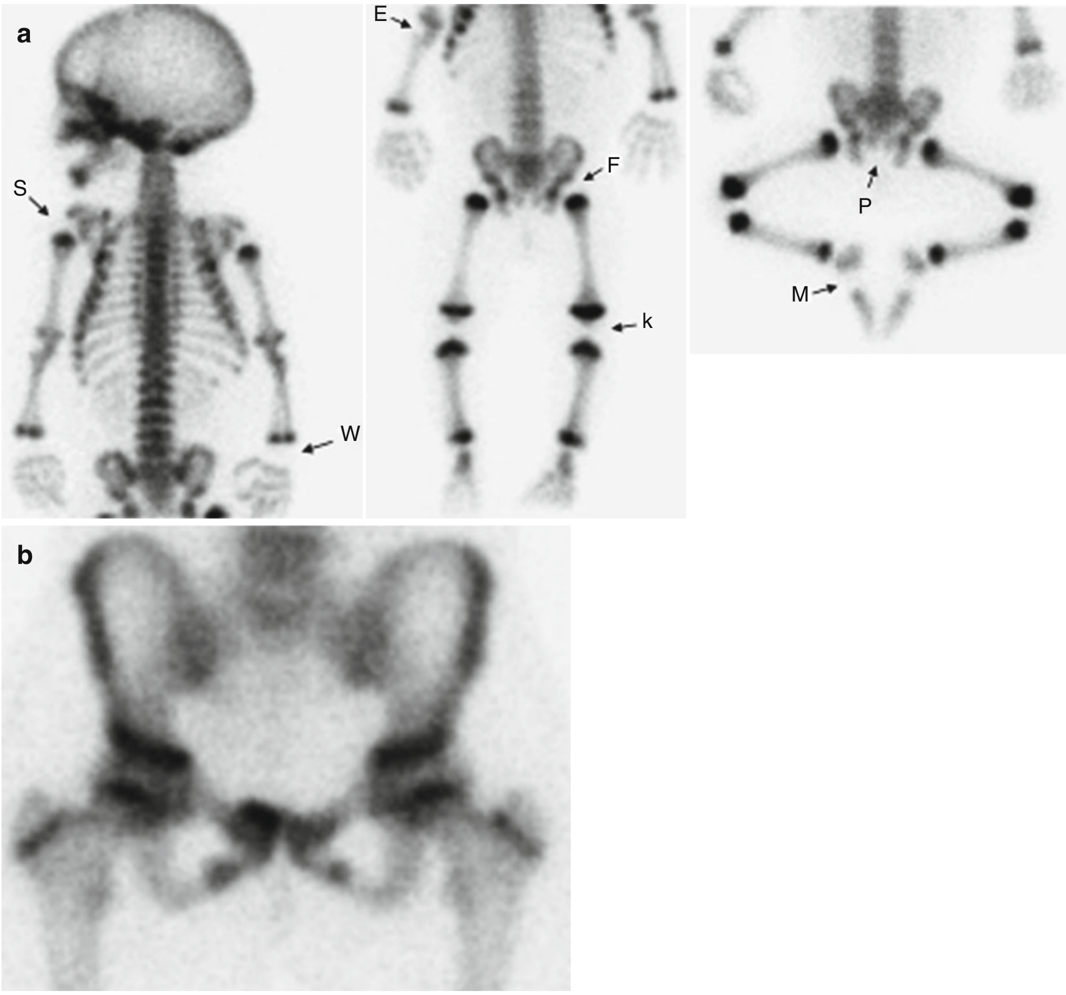


Fig. 1.10 ^{99m}Tc-MDP skeletal scans. (**a**) One-month-old baby. Absent tracer uptake in non-ossified centers. *S* shoulder, *W* wrist, *E* elbow, *F* femoral head, *K* knee, *P* pubis, *M* mid foot. (**b**) A 10-year-old patient showing open ischiopubic synchondroses

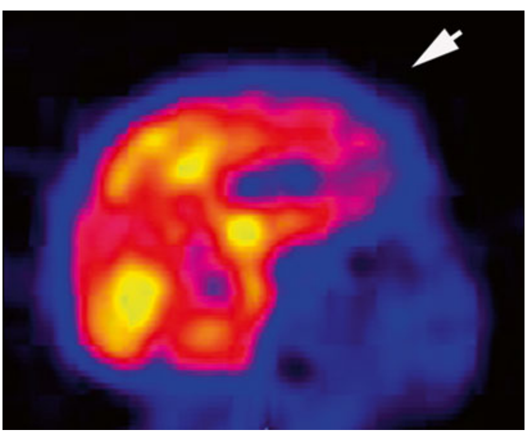


Fig. 1.11 Brain immaturity. ^{99m}Tc-ECD brain SPECT from a newborn showing relatively low cerebral perfusion in the anterior sensorimotor aspect of the brain (*arrow*)

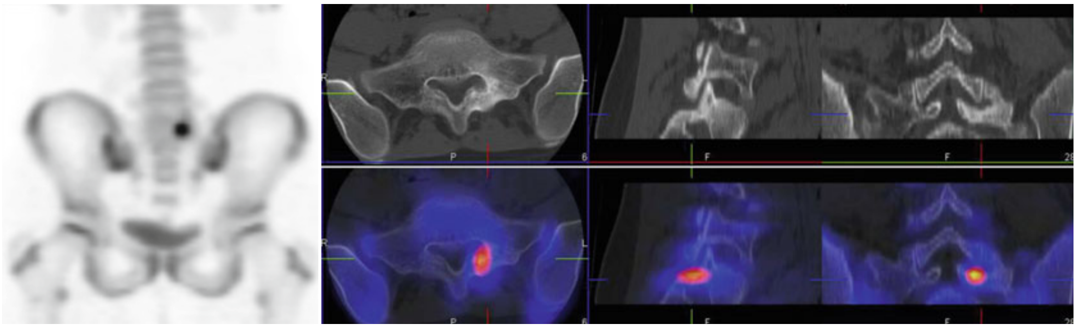


Fig. 1.12 Stress changes in the pars interarticularis. *Left*: MIP of the pelvis. *Right*: ^{18}F-NaF PET and CT fusion. Selected slices reveal intense fluoride uptake in the region of the right L5 pars. On CT, there is a linear defect through the right L5 pars interarticularis

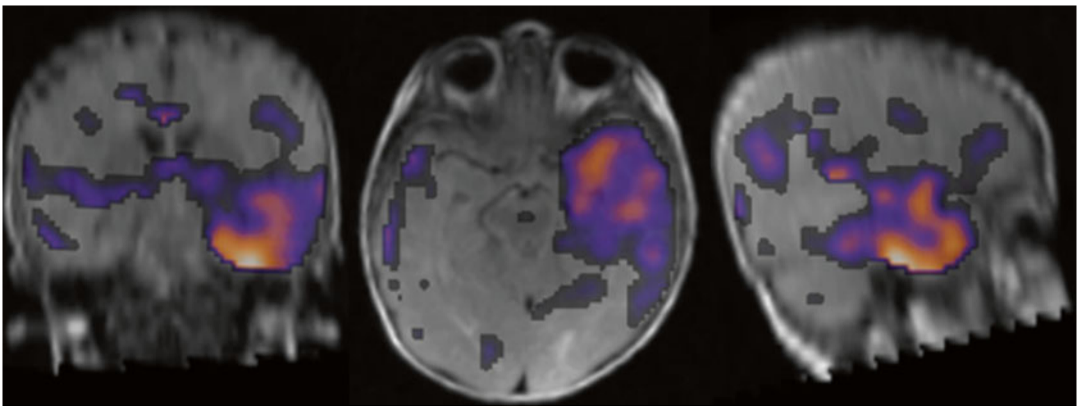


Fig. 1.13 ^{99m}Tc-ECD perfusion brain SPECT. Ictal minus interictal perfusion SPECT has been subtracted and fused to an MRI. There is differential ictal increase of cerebral blood flow in the left temporal lobe

rather difficult with children. Mobile cameras can be used for the evaluation of patients in operating rooms, intensive care units, recovery rooms, interventional radiography suites, and catheterization laboratories.

Image Fusion and Systems Integration

Image fusion overlays two or more three-dimensional (3D) image sets of the same or different imaging modality that are in the same orientation in the same space. Anatomic and functional imaging are complementary, and appropriate image registration and fusion software should be easily available. The introduction of hybrid PET/CT and SPECT/CT scanners has sparked increasing use and interest in image fusion. This hardware approach to image fusion often needs to be complemented by software adjustments on the images when patients move between the PET or SPECT and the CT. The PET/CT and SPECT/CT scanners limit image fusion to two modalities. Electronic image fusion, however, does not depend exclusively on hybrid instrumentation. Image fusion enables the direct comparison of function and structure [SPECT and MRI], function and function (SPECT and FDG-PET), structure and structure (MRI and CT), etc. (Figs. 1.12, 1.13, 1.14, 1.15, and 1.16).

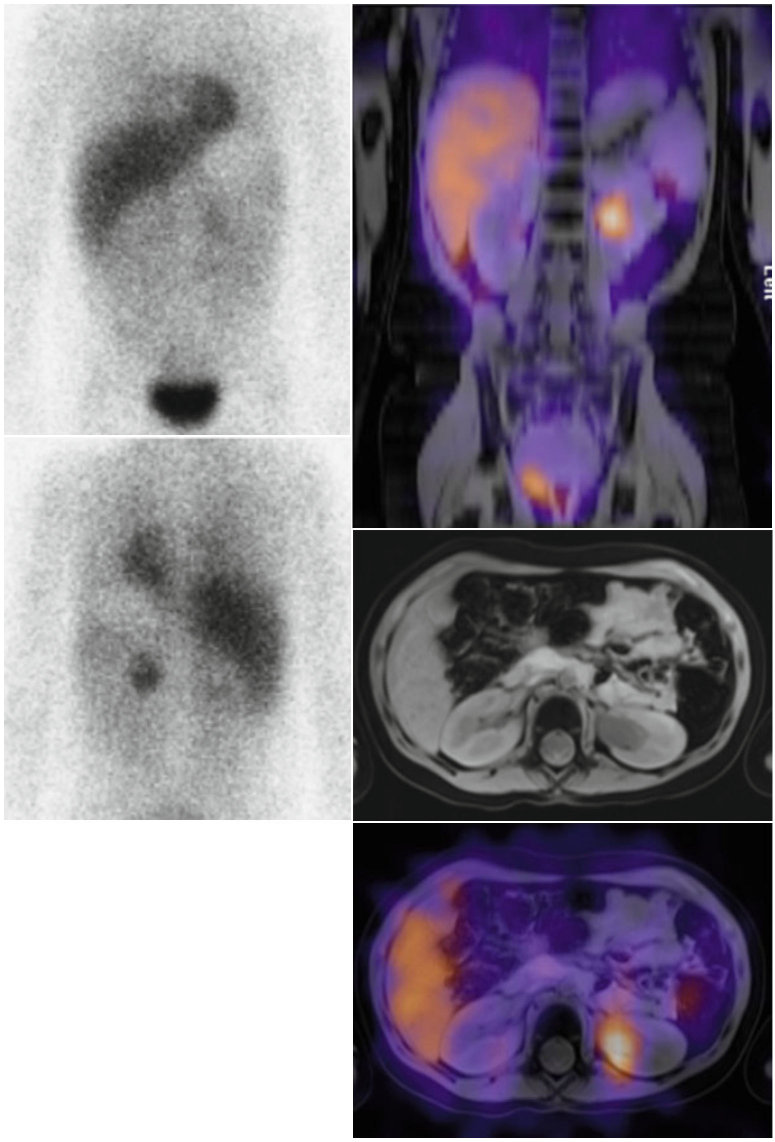


Fig. 1.14 A 3-year-old girl with neuroblastoma after chemotherapy and surgery. Fusion of ^{123}I-MIBG SPECT and MRI demonstrates retroperitoneal MIBG accumulation only in a dilated renal pelvis which was determined not to be a metastasis

With advances in electronic communications, computer processing power, high-capacity networks, and the wider acceptance of imaging standards, image fusion is rather easy to obtain and is now within the reach of routine practice. With the increasing sophistication of picture archiving and communication systems (PACS), all imaging methods can be viewed on most modern workstations. More recently, PET/MRI scanners are being introduced in practice. These systems show promise for the assessment of a variety of disorders and have the advantage over PET/CT of not utilizing X-rays, therefore resulting in lower radiation exposure to the patient. At present, PET/MRI systems are rather expensive and may not be within the reach of most institutions. However, electronic image fusion is very effective and does not require

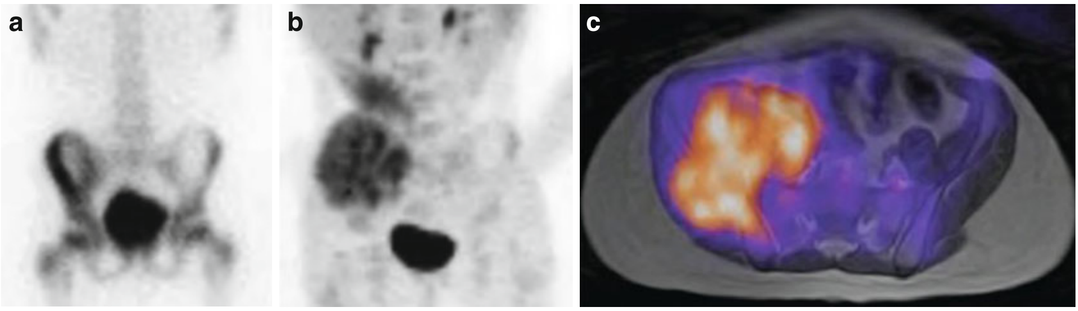


Fig. 1.15 Ewing sarcoma. (**a**) ^{99m}Tc-MDP bone scan shows increased tracer uptake in the left iliac bone, left acetabulum, and proximal femur. (**b**) ^{18}F-FDG MIP shows a larger region of increased tracer uptake also involving the soft tissue component of the tumor. (**c**) ^{18}F-FDG fused to an MRI allowing to correlate increased metabolism within the tumor mass

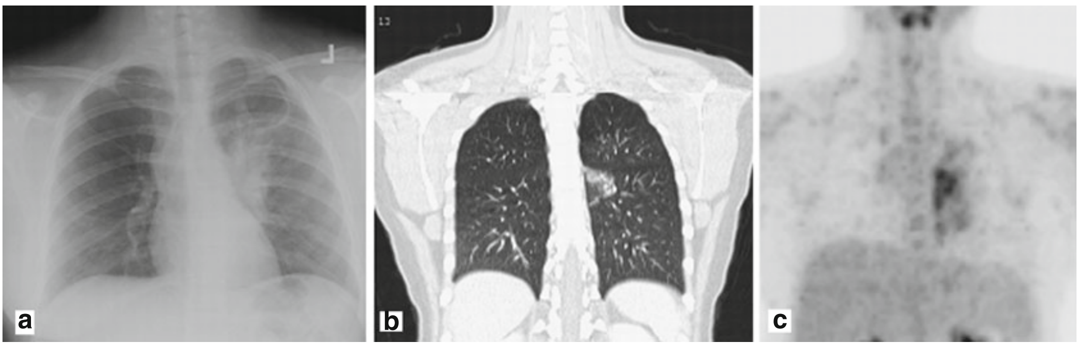


Fig. 1.16 ^{18}F-FDG uptake in pneumonia. A 13-year-old girl following chemotherapy and radiation therapy for Hodgkin's lymphoma presented with 5 days of fever and cough. (**a**) The chest X-ray revealed left lower lobe pneumonia. (**b**) A selected coronal computed tomography (CT) slice also reveals a lesion in the left thorax. (**c**) The ^{18}F-FDG-PET reveals increased tracer uptake in the same region, indicating active inflammatory disease extending beyond the visible CT lesion

the investment in these expensive devices. Electronic image fusion of brain studies (SPECT/MRI, PET/MRI) is relatively easy, while image fusion of body images obtained with the patient in different anatomic positions may be more difficult.

It is common that pediatric patients referred for PET or SPECT have had a CT study in the recent past. In these cases it is advantageous to use the CT already obtained and fuse it with the PET or the SPECT, thus avoiding additional CT exposures (see Chap. 31).

Radiopharmaceutical Administration

Routes of radiopharmaceutical administration include intravenous, oral, inhalation, subcutaneous, intradermal, instillation, and intrathecal.

Intravenous Administration

Intravenous injection is the most frequent route of radiopharmaceutical administration and warrants special attention. In advance of tracer administration, a tray lined with absorbent paper should be prepared for each patient dose. This tray should contain disposable gloves, skin antiseptic, needles, gauze, the radiopharmaceutical dose, adhesive tape, and a tourniquet. The radiopharmaceutical syringe should be shielded, clearly labeled with the name of the patient, the name of the tracer, the dose, the date and time of calibration, and the volume.

When dealing with venous access in small infants, there is no substitute for an experienced nuclear medicine technologist, nurse, or physician. Volume and site of injection are important. A 23–25-gauge needle of the butterfly type can be used. A disposable T-type connector with a one-way valve permits rapid injection of the tracer followed by a saline flush. The radiopharmaceutical should be in a small volume (0.2–0.5 mL) of solution. Premature and newborn infants may require smaller volumes (0.1–0.2 mL). A large vein, such as an antecubital vein, is usually adequate to permit rapid administration of the radiopharmaceutical and the saline flush. Other veins may be used as long as they can tolerate the rapid bolus and the saline flush. Patients usually lie supine for the injection. The site of injection should not overlap the area of interest. Once an appropriate vein is identified, a tourniquet is applied and the skin is cleaned with an antiseptic. The tubing is filled with sterile saline. The extremity is immobilized or held by an aide if necessary, and the vein is entered. As soon as blood return occurs, the tourniquet is released. If there is no free retrograde venous flow into the tube of the butterfly needle, no attempt should be made to inject the radiopharmaceutical, and another injection site should be identified.

After successful venous entry, the needle should be carefully secured in place with adhesive tape. One should check once more to make sure that there is free flow into the vein. It is good practice to flush the tubing with a small volume (1–3 mL) of normal saline before injecting the tracer. The radiopharmaceutical should then be injected and the tubing flushed with normal saline.

Injection technique varies for static and dynamic studies. The injection speed for static studies can be delivered slowly, and a rapid bolus injection is not needed. For dynamic studies requiring high temporal resolution, a proximal injection site, a small volume of radiopharmaceutical solution, and a rapid speed of injection are important for successful examination.

Radiopharmaceutical Dose Adjustment

In nuclear medicine, dosing of radiopharmaceuticals in the adult population is roughly standardized. Pediatric radiopharmaceutical doses should be determined by the minimum amount necessary to ensure satisfactory examination in a reasonable period of time. Administered doses in pediatric nuclear medicine have been developed by experience, taking into account the body mass, absorbed radiation dose, type of examination, available photon flux, instrumentation, and examination time. High doses (which do not result in improved diagnostic sensitivity or accuracy) or low doses (which do not permit adequate examination) should be considered unnecessary radiation exposures. The amount of radioactivity administered to a child for a nuclear medicine procedure should be adjusted according to the patient's body weight or other expressions of body size. Several methods for the determination of radiopharmaceutical doses in children have been used. The resulting calculated doses using these various methods have varied considerably among the different approaches [6]. Also, administered doses of radiopharmaceuticals in children have varied considerably even among pediatric institutions. In the past, there has been no standardized approach to scaling the administered radiopharmaceutical doses in children (Fig. 1.17).

More recently, the North American Expert Consensus Guidelines for Pediatric Administered

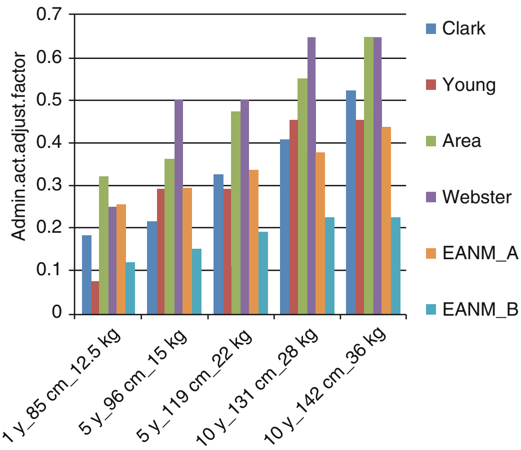


Fig. 1.17 Various methods used to calculate pediatric radiopharmaceutical administered doses

Radiopharmaceuticals have been developed and approved by the Society of Nuclear Medicine and Molecular Imaging (SNMMI), the American College of Radiology (ACR), and the Society for Pediatric Radiology (SPR) and were published recently and widely disseminated by the Image Gently Campaign [7, 8]. In addition the European Association of Nuclear Medicine has developed and published a Dosage Card that closely resembles the North American Guidelines [9].

Estimations of administered doses of activity for pediatric patients that are based on adult dose corrected for body weight or body surface area are generally good guides for children over 1 year of age. Premature infants and newborns require special consideration, and the concept of minimum total dose should be considered. Minimum total dose can be defined as the minimum dose of radiopharmaceutical below which the study would likely be inadequate regardless of the patient's body weight or surface area. The minimum dosage is determined by the type of study: dynamic or static. As a general rule, dynamic studies require a higher dose of tracer than do static studies. Matching the acquisition framing rate with the timing of the physiologic process to be investigated also allows for an optimal determination of administered tracer dose in cases such as hepatobiliary or dynamic renal imaging.

Radionuclide Therapy

Therapy with internally administered radionuclides is employed less often in children than in adults. However, in the past few years there seems to be an increase in the use of this treatment method in children. The most frequently performed radionuclide therapy in children is with ^{131}I in patients suffering from hyperthyroidism refractory to medical treatment and those who refuse surgery. Reasons for the increase in the use of ^{131}I treatment for hyperthyroidism include undesirable side effects from medical therapy or lack of patient compliance with treatment. Another use of ^{131}I is for the treatment of patients with metastatic papillary carcinoma of the thyroid (see Chap. 5).

During the past few years, treatment of neuroblastoma has included therapy with intravenous ^{131}I-MIBG. ^{131}I-MIBG therapy has become popular, and centers have developed specific programs to deal with this method of treatment. One approach utilizes a single, relatively high dose of the agent and requires in-hospital admission with patient isolation. This is the most frequently utilized approach. Another method employs smaller-fractionated doses of the same agent, which does not require hospitalization (see Chap. 20).

Radiation Exposure and Risk

The objective of pediatric nuclear medicine is to obtain the best diagnostic information employing the highest quality imaging in the shortest period of time and with the lowest patient radiation exposure. In general, nuclear medicine procedures involve exposure to low levels of ionizing radiation, and the diagnostic value of these procedures when used appropriately far outweighs potential radiation risk (see Chap. 31).

Appendix 1: Example of a Patient/Parent Brochure About a Nuclear Medicine Procedure

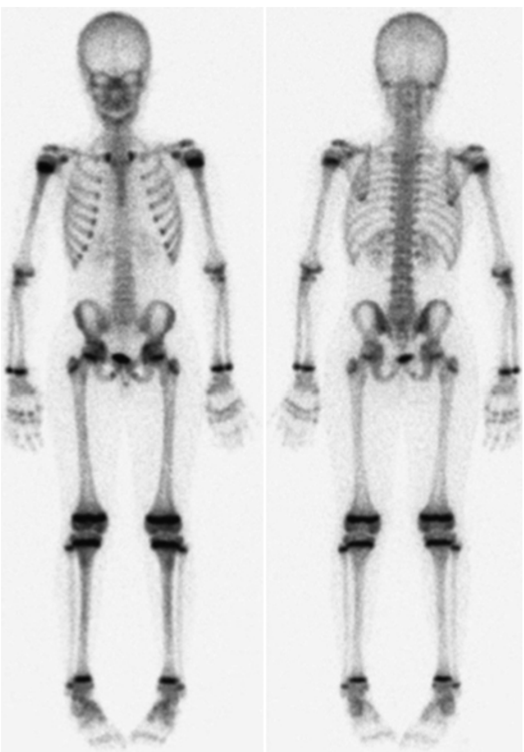
Bone Scan in Nuclear Medicine

What is a bone scan? A bone scan is an image that shows bone blood flow, metabolism, and cell activity in the bones. There are two types of bone scans – planar and 3D (SPECT).

Why bone scans at this hospital? Our department of nuclear medicine is committed to providing a safe, comfortable, and child-friendly atmosphere with specialized:

- Nuclear medicine physicians with expertise in interpreting bone scans in children of all ages
- Technologists with experience imaging children
- Equipment adapted for pediatric use
- Protocols that keep radiation exposure as low as possible while assuring high image quality

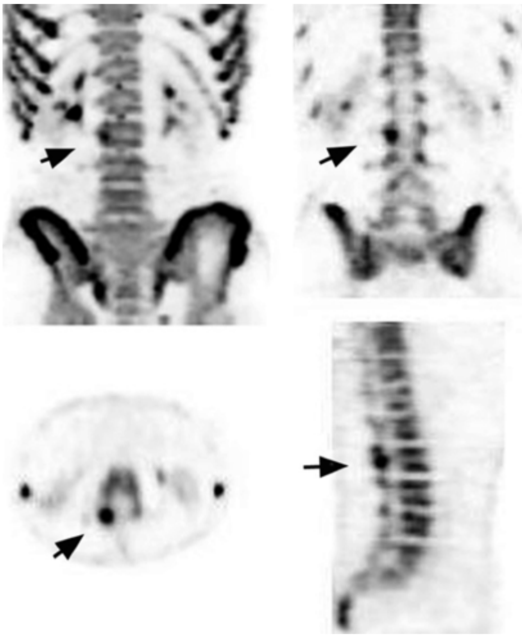
When is a bone scan needed? A bone scan can detect very small changes in your child's bones, even ones that may not be seen on regular X-rays. Bone scans can detect subtle injuries, stress changes, or small fractures that may result from intense playing or sports activity as well as infection or inflammation.



How should I prepare for a bone scan? There is no special preparation needed for this test. However, between the injection of the radiopharmaceutical and the scan, there is a 3–4-h waiting period. In addition, the scan time is approximately 30–60 min. Please schedule your day accordingly.

How is a bone scan obtained? Scans are obtained using special cameras called gamma cameras. Before the images are taken, a tiny volume of a radiotracer (radiopharmaceutical, ^{99m}Tc-MDP) is injected in one of your child's veins using a very small needle (smaller than the needles used for blood tests). Two-minute pictures showing blood flow to the bones may be obtained while the tracer is injected. The actual images of the bones are obtained approximately 3–4 h after the injection of the tracer.

After the injection, your child can continue with his or her normal activities while waiting for the scan to begin. When you return to nuclear medicine, the bone scan is obtained. Your child will lie on an imaging table, and the camera will slowly move around his or her body as several pictures are taken. The camera does not touch your child and does not produce radiation. It is very important that your child remains still during the imaging in order to obtain the best quality images. The number of images obtained and the total imaging time will vary depending on the diagnosis under consideration, although the average imaging time is about 1 h. Some of the images are three-dimensional (3D), and such images are also evaluated by "slicing" the image through different planes.



Bone scan in a young gymnast with back pain. His X-rays were normal, but you can see that on the bone SPECT, there is stress injury in the spine (arrows). The picture on the right upper quadrant is a volume-rendered image, while the others are slices of the 3D image. The slices help localize the lesion

What happens after the bone scan? Once the pictures are ready, the nuclear medicine physician will evaluate them and will produce and send a report to your child's doctor. You will be free to leave and your child can resume normal activity.

What about radiation exposure? Your child will be exposed to a very small amount of radiation that is within the lower range of what is received from routine diagnostic imaging procedures that use X-rays. Nuclear medicine has been used on babies and children for more than 40 years with no known adverse effects from the low doses employed. We are committed to ensuring that your child receives the smallest radiation dose needed to obtain the desired result. Our doctors balance the medical benefits of any imaging test with potential radiation risks even if these are minuscule.

More information about nuclear medicine radiation safety can be found on the Image Gently website (www.imagegently.org).

This pamphlet is written to provide patients, parents, and caregivers with information about bone scans and radiation exposure. This information should not be used as a substitute for the advice from your doctor. If you are concerned or have any unanswered questions, you should talk with a nuclear medicine physician before the study begins.

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