Revised 2014 (Resolution 3)*

ACR–ASER–SCBT-MR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF PEDIATRIC COMPUTED TOMOGRAPHY (CT)

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner in light of all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of this document is to assist practitioners in achieving this objective.

[1] Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, ___ N.W.2d ___ (Iowa 2013) Iowa Supreme Court refuses to find that the *ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures* (Revised 2008) sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.

I. INTRODUCTION

This practice parameter was developed collaboratively by the American College of Radiology (ACR), the American Society of Emergency Radiology (ASER), the Society of Computed Body Tomography and Magnetic Resonance (SCBT-MR), and the Society for Pediatric Radiology (SPR).

Computed tomography (CT) is a radiologic modality that provides clinical information in the detection, differentiation, and demarcation of disease. It is the primary diagnostic modality for a variety of presenting problems and is widely accepted as a supplement to other imaging techniques. In selected cases, CT is used for guidance of interventional procedures.

CT is a form of medical imaging that involves the exposure of patients to ionizing radiation. It should only be performed under the supervision of a physician with the necessary training in radiation protection to optimize examination safety. Medical physicists and trained technical staff must be available to evaluate the equipment and perform the examinations.

CT examinations should be performed only for a valid medical reason and with the minimum exposure that provides the image quality necessary for adequate diagnostic information.

Because children are more sensitive than adults to the effects of ionizing radiation, it is particularly important to tailor CT examinations to minimize exposure while providing diagnostic quality examinations[1]. Protocols should include CT scan parameters, contrast administration, and anatomical coverage. CT scan parameters (eg, rotation time, pitch, kVp, mAs, tube current modulation, beam collimation) should be tailored to the child's body size. If contrast is used, the type of contrast, volume, method of administration (IV, oral, rectal, intravesical), scan delay time, and rate of contrast injection should be specified [2-6].

Nonionizing imaging studies such as ultrasound (US) and MRI should be considered in some cases as an alternative to CT when appropriate. Reasons to consider using CT over MRI include the availability of CTs, higher spatial resolution, shorter examination, less need for sedation, and the presence of contraindications for MRI.

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT).

III. INDICATIONS

A. Chest

CT is the preferred cross-sectional imaging modality for detailed evaluation of anatomy and pathology of the lung and tracheobronchial tree. In addition to ultrasound (US) and MRI, CT may also be used for evaluation of certain thoracic bony, mediastinal, and cardiac abnormalities.

Primary indications for CT include, but are not limited to, the following:

1. Chest wall abnormalities [7-14]
    a. Extent of chest wall developmental deformities, such as pectus excavatum, pectus carinatum, and thoracic insufficiency syndrome secondary to scoliosis or rib anomalies. CT scan for some chest wall deformities (eg, pectus excavatum) may be limited to the area of deformity using very low dose technique.
    b. Chest wall injury, including penetrating trauma and injuries that are not adequately addressed by radiography such as sternal fractures, sternoclavicular dislocation, and occult rib fractures
    c. Chest wall mass and mass-like conditions including inflammatory/infectious processes. This includes evaluation of posttreatment complications and residual or recurrent mass.

2. Extracardiac vascular disorder [15-21]
   a. Congenital and syndromic vascular abnormalities such as vascular rings, pulmonary slings, pulmonary vein abnormalities (eg, anomalous course), systemic-to-pulmonary collateral vessels, coarctation of the aorta, or other congenital lesions with anomalous blood supply (eg, bronchopulmonary sequestration)
   b. Acquired disorders of the great vessels (eg, medium or large vessels vasculitides, aneurysms, stenoses, infectious or other inflammatory conditions) and posttraumatic evaluation. Assessment includes aortic dissection, transection, and pulmonary embolism.

3. Cardiac disease. See the ACR–NASCI–SPR Practice Parameter for the Performance and Interpretation of Cardiac Computed Tomography (CT).

4. Tracheobronchial abnormalities, including tracheal rings; tracheobronchial narrowing secondary to vascular anomaly, mass, inflammatory/infectious process, suspected foreign body, or congenital anomaly; and postoperative complications of lung transplant [21-26]

5. Mediastinal congenital abnormalities and masses [27-29].
   a. Neoplasms – These include, but are not restricted to, germ cell tumors, lymphoma, or thymic tumors. Posterior mediastinal neurogenic tumors can also be imaged by CT, particularly with multidetector technology and reformats, but MRI is often more useful to depict chest wall or vertebral, neural foraminal, or intraspinal, involvement.
   b. Congenital abnormalities such as ectopic thymic tissue and bronchopulmonary foregut malformations that affect the mediastinum. The latter include bronchogenic cyst, esophageal duplication cyst, and neuroenteric cyst. Congenital abnormalities in a paraspinal location may be better evaluated with MRI to assess for potential chest wall or vertebral, neural foraminal, or intraspinal disease.
   c. Infectious or inflammatory processes affecting the mediastinum such as lymphadenitis, mediastinitis, abscess, or sternal osteomyelitis. d. Trauma that is not adequately assessed by radiography. CT angiography can be considered for evaluation of suspected major thoracic vascular injury.

6. Lung – CT is the primary cross-sectional imaging modality to evaluate the lung parenchyma [30-48].
   a. Infection/pneumonia complicated by involvement of the pleural space (such as parapneumonic effusion, empyema, or bronchopleural fistula), the lung (such as cavitation/necrosis or abscess), or the pericardium (such as purulent pericarditis). For evaluation of parapneumonic effusion and empyema, US should be considered as the first and primary imaging modality, with CT reserved for evaluation of aerated portions of the lung and more complicated cases with parenchymal complications. In patients with persistent or recurrent pneumonias or whose plain film is atypical for pneumonia, CT is used to assess for possible underlying congenital lesion or mass. CT is also used to assess the sequelae of respiratory infections (such as bronchiectasis and bronchiolitis obliterans). In immunocompromised patients CT can be used in the absence of definite plain-film abnormality to detect early manifestations of opportunistic infections.
   b. Diffuse/interstitial lung disease, either primary or related to systemic processes such as collagen vascular, connective tissue, or autoimmune diseases. These studies may include inspiratory and expiratory scans. Additional limited imaging in a prone or decubitus position may help differentiate between dependent atelectasis and lung parenchymal abnormality. Some patients with cystic fibrosis may be followed with limited reduced-dose high-resolution CT.
   c. Congenital pulmonary abnormalities including bronchopulmonary foregut malformation, congenital pulmonary airway malformations (CPAM), congenital lung hyperinflation, pulmonary sequestration, bronchial atresia, tracheal diverticula, tracheal bronchus, pulmonary agenesis or hypoplasia, and related conditions such as horseshoe lung and pulmonary arteriovenous malformation
   d. Malignancy, including patients with underlying extrapulmonary primary malignancy that may metastasize to lung and primary lung neoplasms, including inflammatory myofibroblastic tumor (plasma cell granuloma), pleuropulmonary blastoma, bronchial carcinoid, and mucoepidermoid carcinoma. In

immunocompromised patients, CT is used in the evaluation for lymphoproliferative disease or smooth muscle (spindle cell) tumors
e. Traumatic injuries not adequately assessed by radiography, such as pulmonary contusions and lacerations

B. Abdomen and Pelvis

CT of the abdomen and pelvis is the preferred cross-sectional imaging for evaluation of abdominal and pelvic trauma. CT can be used as an alternative study to MRI in evaluation of solid viscus and bowel. CT is often used as an adjunct or follow-up to US when findings are equivocal or when there is a need for additional anatomic detail or other information (eg, nephrolithiasis, solid viscus, bowel and vascular pathology).

1. Hollow viscera [49-64]
   a. Inflammatory or infectious processes affecting the GI tract, including the gastroesophageal junction, stomach, small intestine, colon, or appendix. These processes include, but are not limited to, appendicitis, infectious enteritis, inflammatory bowel disease, neutropenic colitis or radiation enteritis.
   b. Congenital abnormalities, including gastrointestinal duplication cysts, and complications of omphalomesenteric duct remnants, such as Meckel diverticulitis
   c. Benign and malignant neoplasms, including, but not limited to, lymphoma (particularly Burkitt lymphoma), gastrointestinal stromal tumor (GIST), lipoma and large polyps
   d. Trauma. Blunt or penetrating abdominal trauma to demonstrate bowel injury including intramural hematoma and perforation
   e. Bowel obstruction

2. Liver and gallbladder [65-72]
   a. Primary or secondary hepatic neoplasms, including, but not limited to, hemangioma, hepatoblastoma, and hepatocellular carcinoma, as well as liver metastases to evaluate for the presence and extent of tumor in the liver
   b. Blunt or penetrating trauma including nonaccidental trauma to assess the extent of parenchymal and hepatic vascular injury
   c. Hepatic infection including pyogenic or amebic liver abscesses
   d. Congenital abnormalities of the liver and biliary tree, including heterotaxy and associated anomalies
   e. Gallbladder and biliary tract disorders are typically best evaluated with US, MRI, and nuclear medicine studies. CT may be used in selected cases to supplement ultrasound in the evaluation of gallbladder and biliary tract disorders.

3. Pancreas [73-78]
   a. Complications of pancreatitis, including pancreatic hemorrhage or necrosis, peripancreatic vascular thrombosis, pseudocyst formation, secondary inflammation of hollow visceral structures or duct abnormalities, including stones or dilation
   b. Pancreatic tumors to further characterize the extent of lesion, staging, and involvement of adjacent structures
   c. Blunt or penetrating abdominal trauma to evaluate the integrity of the gland, the extent of pancreatic injury including fracture and/or pancreatic ductal injury, and injury to adjacent solid or hollow visceral structures

4. Kidneys [79-88]
   a. Urinary tract stones in children with hematuria. CT may be used when ultrasound and radiographs do not provide enough information for optimal management.
   b. Renal and/or ureteral trauma. Additional delayed imaging may be useful if injury to the collecting system is suspected. Split-dose IV contrast in suspected renal trauma can demonstrate both parenchymal and collecting system injury with one imaging acquisition.
   c. Detection and staging of renal tumors (benign and malignant), including vascular invasion
   d. Congenital anomalies of the genitourinary tract

e. Obstruction of the urinary tract secondary, but not limited to, nephrolithiasis, mass, infection/inflammation, or trauma
f. Complications of infection of the urinary tract (eg, acute pyelonephritis), including renal/perirenal abscess
g. Renovascular evaluation in the setting of traumatic injury, renal donor transplant evaluation, or regional masses. CT angiography can also be used in selected patients to evaluate for renovascular hypertension.

5. Adrenal gland [89-93]
   a. Evaluation of blunt or penetrating trauma with suspected adrenal hemorrhage
   b. Adrenal neoplasms, such as neuroblastoma, ganglioneuroma, ganglioneuroblastoma, adrenocortical neoplasms (adenoma and carcinoma), and pheochromocytoma

6. Spleen [94-100]
   a. Splenic injury in the setting of blunt or penetrating trauma
   b. Primary cystic or solid lesions of the spleen
   c. Other conditions such as infarction, sequestration (sickle cell disease), granulomatous disease, wandering spleen/torsion

7. Pelvis [101-103]
   a. Mass or mass-like conditions of the pelvic organs, including inflammatory/infectious processes**,** vascular malformations, and evaluation of lymph nodes
   b. Anomalies of the genital tract not adequately assessed by ultrasound or genitogram, or where MRI is contraindicated or not available
   c. Bladder rupture after trauma or bladder surgery. Dedicated CT cystography techniques can be performed as indicated.

8. Mesentery/omentum/peritoneum/retroperitoneum/vascular/abdominal wall/diaphragm [104-108]
   a. Inflammatory or infectious processes affecting the mesentery, peritoneum, or omentum, such as an abscess and generalized peritonitis
   b. Peritoneal fluid characterization and quantification, when appropriate
   c. Pneumoperitoneum
   d. Cystic malformations, including mesenteric/omental cyst and lymphatic malformation
   e. Benign or malignant neoplastic processes, including teratoma, sarcoma, and spread of disease to the peritoneum and/or retroperitoneum
   f. Omental infarction
   g. Posttraumatic abnormalities of the mesentery, abdominal wall, or diaphragm
   h. Congenital abnormalities of the abdominal wall or diaphragm
   i. Arterial and venous abnormalities such as vasculitis, thrombosis, narrowing, aneurysm, dissection, and varices

C. Extremities/Musculoskeletal

CT may supplement plain radiography for characterization and evaluation of extent of bone lesions and fractures, evaluation of orthopedic implant complications, and assessment of alignment deformities. CT is better than MRI in assessment of cortical and trabecular bone abnormalities. CT has lower contrast resolution and less sensitivity compared to MRI in evaluation of bone marrow and soft-tissues pathology, but CT can be used in selected cases where MRI is contraindicated or not readily available.

1. General indications [109-134]
   a. Bone abnormality not adequately assessed by radiographs
   b. Congenital bone malformations
   c. Inflammatory conditions such as osteomyelitis and myositis, when MRI is contraindicated or unavailable

d. Fractures and follow-up of fracture complications (such as premature growth plate fusion and intra-articular loose bodies)
e. Tumors of the bone or soft tissues
f. Osteochondral lesions, when MRI is contraindicated or unavailable
g. Foreign bodies

2. Shoulder [119-121]
   Evaluation of glenoid morphology, glenoid dysplasia, and acquired glenohumeral deformity related to perinatal brachial plexus injury

3. Pelvis, hip, and thigh [122-127]
   a. Congenital malformations not adequately assessed by radiographs or sonography, including postoperative assessment of reduction of developmental dysplasia of the hip
   b. Measurement of femoral and acetabular version
   c. Deformity related to epiphyseal osteonecrosis (including Legg-Calve-Perthes)
   d. Femoral head impingement syndrome
   e. Sacroiliitis
   f. Apophysitis

4. Knee and leg [128-130]
   a. Kinematic assessment of patellofemoral joint
   b. Preoperative tibial tuberosity trochlear groove assessment in patients with patellar tracking abnormalities
   c. Tibial torsion

D. Foot and Ankle [131-134]

1. Fractures in the foot or ankle not optimally assessed by radiographs, including, but not limited to, Tillaux and triplane fractures of the ankle or other fractures involving the tibial plafond
2. Tarsal coalition, diagnosis, and follow-up after surgery

E. Head and Spine

See the ACR–ASNR Practice Parameter for the Performance of Computed Tomography (CT) of the Brain, and the ACR–ASNR–ASSR–SPR Practice Parameter for the Performance of Computed Tomography (CT) of the Spine.

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for pediatric CT should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). The provision of additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state scope of practice requirements. (ACR Resolution 35, adopted in 2006)

Images should be labeled with the following: a) patient identification, b) facility identification, c) examination date, and d) the side (right or left) of the anatomic site imaged.

Additionally, an attempt should be made to obtain and review prior studies.

A. General Considerations [2-6]

Pediatric CT may require different examination preparation and performance than in adults. Preparation includes ensuring appropriate NPO status if moderate sedation or general anesthesia is potentially necessary.

Certain indications require administration of IV contrast media. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution's policy on IV contrast utilization. (See the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media and the ACR Manual on Contrast Media.)

For scan performance, single-phase scanning is the standard rather than the exception. Only the necessary scan coverage should be obtained, and scan parameters—including beam collimation, tube current, gantry cycle time, pitch, and peak kilovoltage—should be adjusted for the size of the child, the region scanned, and the clinical indications.

The physician responsible for the examination must supervise patient selection and preparation and be available for consultation. All personnel who inject intravascular contrast media (ICM) should be prepared to 1) recognize the variety of adverse events that may occur following ICM administration and 2) institute appropriate measures to manage the reaction. These measures include notifying the supervising radiologist (or his/her designee), monitoring the patient, administering certain medications, and/or calling for additional assistance (emergency service providers, "code team," etc). (See the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media and the ACR Manual on Contrast Media.)

Appropriate emergency equipment and medications must be immediately available for consultation or to treat adverse reactions associated with administered medications. See Table 6 of the ACR Manual on Contrast Media.

B. Examination Technique [2-6,135-155]

General Observations:

Scanning parameters should be optimized to obtain diagnostic image quality while adhering to the as low as reasonably achievable (ALARA) principle. The scan area should be restricted according to the clinical indication, with areas not involved in the clinical problem excluded from the scan. The scanning parameters, including kVp and exposure time product (mAs), should be changed according to body size, regions of interest, and clinical indication. This can be achieved by using weight-based or cross-sectional size tables and by using automatic exposure control (see www.imagegently.org). In addition, mAs should be further reduced if noncontrast scans are performed only to evaluate calcifications or for cases in which only gross bony relationships are being evaluated, such as scans done for preoperative pectus excavatum evaluation. Noise-reducing reconstruction technique (eg, iterative reconstruction), if available, can be used to improve image quality and decrease dose [135].

1. Chest [2-6,144-151]
    a. The use of bismuth shields is controversial. Shielding can reduce dose to anterior organs such as breast, lens of the eye, and thyroid in CT scanning. There are disadvantages associated with the use of bismuth shields. Bismuth shields may induce image artifacts and increased image noise, which limit measurements of attenuation. If used, the shield needs to be elevated from the anterior chest wall (eg, by laying it on several towels or a sponge), and it should be flat without internal bends to decrease artifacts. In addition, if shielding is in place during scout image acquisition when using automatic exposure control or tube current modulation, the radiation dose to the patient may increase. Other techniques can provide the same level of anterior dose reduction at equivalent or superior image quality.

b. The examination may be conducted with or without IV contrast as clinically indicated. A contrast dosage of 1.5-2 mL/kg (to a maximum not exceeding the usual adult dose) is used routinely. Volume of contrast, rate of injection, scan delay time, and hand/power injection should be determined according to the location, size, and type of the IV access, the child's body size, the underlying disease (such as congestive heart failure), and the clinical indication.
c. High-resolution algorithms for reconstruction of CT data may be useful if the primary indication is for the evaluation of interstitial lung disease, as sharper algorithms are helpful in the evaluation of lung parenchyma in older children. The original dataset can be reconstructed with both routine and high-resolution algorithms if both soft-tissue and pulmonary parenchymal information is needed, without need to rescan the patient. It is important to remember that not all diagnostic chest CT studies in infants and children require imaging of the entire anatomy of the chest. In certain clinical situations, if only a sampling of the lung parenchyma is required to answer a specific clinical question (eg, to rule out bronchiectasis or diffuse/interstitial lung disease), a limited number (eg, 4 to 6 slices) of 1 to 1.25 mm noncontiguous axial slices can be obtained and reconstructed in a high-resolution algorithm. The gap between the noncontiguous axial images may be increased incrementally as patient size increases. Expiratory images at larger intervals can be useful for evaluation of diseases of the small bronchi.
d. Postprocessing 2-D reformations, maximum intensity projection (MIP) reconstructions, and 3-D volume rendering may be useful adjuncts in displaying the anatomy. 2-D reformation and sliding thin-slab MIP techniques have been found to increase sensitivity in the detection of lung nodules and arteriovenous malformations.

2. Abdomen [2-6,152-155]
   a. Scanning parameters should be optimized to obtain diagnostic image quality while adhering to the ALARA principle. The scan area should be minimized according to the clinical indication. The scanning parameters, including kVp, tube current, and exposure time (mAs), should be changed according to body size, area of interest, and clinical indication. This can be achieved by using weight or dimension-based tables or by using automatic exposure control (see www.imagegently.org). The testicles should not be included in the scanned area unless absolutely necessary for the clinical indication. If precontrast images are needed solely to determine whether calcification is present, these can be done with additional decrease in mAs.
   b. IV contrast injection is usually used in the CT evaluation of the pediatric abdomen due to the paucity of body fat in many pediatric patients. There are some exceptions, including renal stone evaluation. A routine dose of 1.5 to 2 mL/kg is generally used. Volume of contrast, rate of injection, scan delay time, and hand/power injection should be determined according to the location, size, and type of the IV access, the child's body size, the underlying disease and the clinical indication.
   c. Enteric contrast may be used in the CT evaluation of the pediatric abdomen. Choices of administration route (eg, oral, rectal, or enteric tube) and type of contrast (eg, positive or neutral attenuation) will depend on factors such as the clinical questions to be answered and patient age. Enteric contrast is not typically used in renal stone protocol, CT angiography, or acute trauma.
   d. In the evaluation of the pediatric patient for suspected appendicitis, IV contrast is typically used, particularly to avoid potential repeat scans due to equivocal findings. Precontrast scans and delayed scans are usually not necessary. Some centers use oral or rectal enteric contrast material. If oral contrast is given, sufficient time should be allowed to elapse for the contrast to reach the right lower quadrant prior to scanning.
   e. Postprocessing 2-D reformations, maximum intensity projection (MIP) reconstructions, and 3-D volume rendering may be useful adjuncts in displaying the anatomy, especially in evaluation of vascular anatomy.

3. Extremities
   a. IV contrast is usually not necessary if only evaluation of the bone structure is needed. IV contrast may be necessary for assessment of blood vessels and soft tissues when indicated.
   b. Sharper reconstruction algorithms are needed for better spatial resolution and bone detail. Smoother algorithms are better for soft-tissue evaluation and 3-D postprocessing.

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings.

VI. EQUIPMENT SPECIFICATIONS [2-6,136-139,141-143,148,154]

In the interest of pediatric patient safety, it is necessary to have a general knowledge of the CT equipment including the use of weight or dimension-adjusted mA and kVp, beam collimation, slice thickness, pitch, rotation time, matrix, image filter, noise-reducing reconstruction technique (eg, iterative reconstruction), display field of view (DFOV) and tube current modulation techniques (longitudinal and angular). In some CT scanners the tube current can be automatically adjusted by a predetermined selection of the quality (eg, noise level or reference mAs) of the study. Other dose-reduction techniques include automatic exposure control or organ-based angular modulation that reduces mA to anterior organs such as the breasts. Optimal kVp can be achieved by manual charts according to patient size and type of study (eg, routine or CT angiography) or with automated selection technology. The equipment should be in good working order, meet manufacturer and regulatory standards, and be operated safely. The equipment needs to be tested for spatial and low-contrast resolution and be well-calibrated at all times. Technologists and radiologists should be aware of important artifacts and know how to avoid problems associated with them.

A. Performance Standards

To achieve acceptable clinical CT scans of body, the CT scanner should meet or exceed the following specifications:

1. Gantry rotation time: ≤1 second
2. Detector width: ≤1 mm
3. Tube voltage: ranging from 70 kVp to 120 kVp
4. Limiting spatial resolution: 8 lp/cm for ≥32 cm DFOV and ≥10 lp/cm for <24 cm DFOV

B. Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. See Table 6 of the ACR Manual on Contrast Media. The equipment, medications, and other emergency support must be appropriate for the range of age and size in the patient populations.

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, registered radiologist assistants, radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel that work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection and application of dose limits) and the principles of proper management of radiation dose to patients (justification, optimization and the use of dose reference levels) http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf

Nationally developed guidelines, such as the ACR's Appropriateness Criteria®, should be used to help choose the most appropriate imaging procedures to prevent unwarranted radiation exposure.

Facilities should have and adhere to policies and procedures that require varying ionizing radiation examination protocols (plain radiography, fluoroscopy, interventional radiology, CT) to take into account patient body habitus (such as patient dimensions, weight, or body mass index) to optimize the relationship between minimal radiation dose and adequate image quality. Automated dose reduction technologies

available on imaging equipment should be used whenever appropriate. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available at the Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org) websites. These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be measured and patient radiation dose estimated for representative examinations and types of patients by a Qualified Medical Physicist in accordance with the applicable ACR technical standards. Regular auditing of patient dose indices should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry, the NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference of Radiation Control Program Director's National Evaluation of X-ray Trends. (ACR Resolution 17 adopted in 2006 – revised in 2009, 2013, Resolution 52).

A medical physicist and radiologist together should verify that any dose reduction devices or utilities maintain acceptable image quality while actually reducing radiation dose.

Dose estimates for typical examinations should be compared against reference levels described in the ACR–AAPM Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-Ray Imaging.

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR website (http://www.acr.org/guidelines).

Equipment monitoring and the continuous quality control program should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment.

ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading *The Process for Developing ACR Practice Parameters and Technical Standards* on the ACR website (http://www.acr.org/guidelines) by the Committee on Practice Parameters – Pediatric Radiology of the ACR Commissions on Pediatric Radiology in collaboration with the ASER, SCBT-MR, and SPR.

Collaborative Committee
Members represent their societies in the initial and final revision of this practice parameter.

ACR
Boaz K. Karmazyn, MD, Chair
Jonathan R. Dillman, MD
Monica S. Epelman, MD
J. Herman Kan, MD

ASER
Susan D. John, MD, FACR
Jenifer W. Siegelman, MD, MPH
Carlos J. Sivit, MD

SCBT-MR
Marilyn J. Siegel, MD, FACR

SPR
Anil G. Rao, DMRD, DNB
Sabah Servaes, MD

Sjirk J. Westra, MD

Committee on Practice Parameters – Pediatric Radiology
(ACR Committee responsible for sponsoring the draft through the process)

Eric N. Faerber, MD, FACR, Chair
Sara J. Abramson, MD, FACR
Richard M. Benator, MD, FACR
Lorna P. Browne, MB, BCh
Brian D. Coley, MD, FACR
Monica S. Epelman, MD
Kate A. Feinstein, MD, FACR
Lynn A. Fordham, MD, FACR
Tal Laor, MD
Beverley Newman, MB, BCh, BSc, FACR
Marguerite T. Parisi, MD, MS
Sumit Pruthi, MBBS
Nancy K. Rollins, MD

Marta Hernanz-Schulman, MD, FACR, Chair, Commission on Pediatric Radiology
Debra L. Monticciolo, MD, FACR, Chair, Commission on Quality and Safety
Julie K. Timins, MD, FACR, Chair, Committee on Parameters & Standards – Q&S

Comments Reconciliation Committee
Jonathan Breslau, MD, FACR, Chair
C. Matthew Hawkins, MD, Co-Chair
Kimberly E. Applegate, MD, MS, FACR
Jonathan R. Dillman, MD
Monica S. Epelman, MD
Eric N. Faerber, MD, FACR
Kate A. Feinstein, MD, FACR
Marta Hernanz-Schulman, MD, FACR
William T. Herrington, MD, FACR
Susan D. John, MD, FACR
J. Herman Kan, MD
Boaz K. Karmazyn, MD
Jane Park Ko, MD
Paul A Larson, MD, FACR
Debra L. Monticciolo, MD, FACR
Anil G. Rao, DMRD, DNB
Sabah Servaes, MD
Marilyn J. Siegel, MD, FACR
Jenifer W. Siegelman, MD, MPH
Carlos J. Sivit, MD
Julie K. Timins, MD, FACR
Sjirk J. Westra, MD

REFERENCES

1. Brenner DJ, Hall EJ. Computed tomography an increasing source of radiation exposure. *N Engl J Med.* 2007;357:2277-2284.

2. Cody DD, Moxley DM, Krugh KT, O'Daniel JC, Wagner LK, Eftekhari F. Strategies for formulating appropriate MDCT techniques when imaging the chest, abdomen, and pelvis in pediatric patients. *AJR Am J Roentgenol.* 2004;182(4):849-859.
3. Donnelly LF, Frush DP. Pediatric multidetector body CT. *Radiol Clin North Am.* 2003;41(3):637-655.
4. Paterson A, Frush DP. Dose reduction in paediatric MDCT: general principles. *Clin Radiol.* 2007;62(6):507-517.
5. Siegel MJ. *Pediatric Body CT.* 2nd ed. Philadelphia, Pa: Lippincott, Williams and Wilkins; 2007.
6. Siegel MJ FD, Brody AS. Multidetector CT in pediatrics (RSP1504RC). RSNA refresher course; 2005; Oak Brook, IL.
7. Donnelly LF. Use of three-dimensional reconstructed helical CT images in recognition and communication of chest wall anomalies in children. *AJR Am J Roentgenol.* 2001;177(2):441-445.
8. Emans JB, Caubet JF, Ordonez CL, Lee EY, Ciarlo M. The treatment of spine and chest wall deformities with fused ribs by expansion thoracostomy and insertion of vertical expandable prosthetic titanium rib: growth of thoracic spine and improvement of lung volumes. *Spine.* 2005;30(17 Suppl):S58-68.
9. Haller JA, Jr., Kramer SS, Lietman SA. Use of CT scans in selection of patients for pectus excavatum surgery: a preliminary report. *J Pediatr Surg.* 1987;22(10):904-906.
10. Miller LA. Chest wall, lung, and pleural space trauma. *Radiol Clin North Am.* 2006;44(2):213-224, viii.
11. Morris BS, Maheshwari M, Chalwa A. Chest wall tuberculosis: a review of CT appearances. *Br J Radiol.* 2004;77(917):449-457.
12. Schulman H, Newman-Heinman N, Kurtzbart E, Maor E, Zirkin H, Laufer L. Thoracoabdominal peripheral primitive neuroectodermal tumors in childhood: radiological features. *Eur Radiol.* 2000;10(10):1649-1652.
13. Shamberger RC, Grier HE. Chest wall tumors in infants and children. *Semin Pediatr Surg.* 1994;3(4):267-276.
14. Wong KS, Hung IJ, Wang CR, Lien R. Thoracic wall lesions in children. *Pediatr Pulmonol.* 2004;37(3):257-263.
15. Bruckner BA, DiBardino DJ, Cumbie TC, et al. Critical evaluation of chest computed tomography scans for blunt descending thoracic aortic injury. *Ann Thorac Surg.* 2006;81(4):1339-1346.
16. Kim TH, Kim YM, Suh CH, et al. Helical CT angiography and three-dimensional reconstruction of total anomalous pulmonary venous connections in neonates and infants. *AJR Am J Roentgenol.* 2000;175(5):1381-1386.
17. Lee EY, Siegel MJ, Hildebolt CF, Gutierrez FR, Bhalla S, Fallah JH. MDCT evaluation of thoracic aortic anomalies in pediatric patients and young adults: comparison of axial, multiplanar, and 3D images. *AJR Am J Roentgenol.* 2004;182(3):777-784.
18. Melton SM, Kerby JD, McGiffin D, et al. The evolution of chest computed tomography for the definitive diagnosis of blunt aortic injury: a single-center experience. *J Trauma.* 2004;56(2):243-250.
19. Qanadli SD, Hajjam ME, Mesurolle B, et al. Pulmonary embolism detection: prospective evaluation of dual-section helical CT versus selective pulmonary arteriography in 157 patients. *Radiology.* 2000;217(2):447-455.
20. Stein PD, Fowler SE, Goodman LR, et al. Multidetector computed tomography for acute pulmonary embolism. *N Engl J Med.* 2006;354(22):2317-2327.
21. Siegel MJ. Multiplanar and three-dimensional multi-detector row CT of thoracic vessels and airways in the pediatric population. *Radiology.* 2003;229(3):641-650.
22. Choo KS, Lee HD, Ban JE, et al. Evaluation of obstructive airway lesions in complex congenital heart disease using composite volume-rendered images from multislice CT. *Pediatr Radiol.* 2006;36(3):219-223.
23. Heyer CM, Nuesslein TG, Jung D, et al. Tracheobronchial anomalies and stenoses: detection with low-dose multidetector CT with virtual tracheobronchoscopy--comparison with flexible tracheobronchoscopy. *Radiology.* 2007;242(2):542-549.
24. Honnef D, Wildberger JE, Das M, et al. Value of virtual tracheobronchoscopy and bronchography from 16-slice multidetector-row spiral computed tomography for assessment of suspected tracheobronchial stenosis in children. *Eur Radiol.* 2006;16(8):1684-1691.
25. Long FR. Imaging evolution of airway disorders in children. *Radiol Clin North Am.* 2005;43(2):371-389.
26. Pacharn P, Poe SA, Donnelly LF. Low-tube-current multidetector CT for children with suspected extrinsic airway compression. *AJR Am J Roentgenol.* 2002;179(6):1523-1527.
27. Franco A, Mody NS, Meza MP. Imaging evaluation of pediatric mediastinal masses. *Radiol Clin North Am.* 2005;43(2):325-353.

28. Kato M, Hara M, Ozawa Y, Shimizu S, Shibamato Y. Computed tomography and magnetic resonance imaging features of posterior mediastinal ganglioneuroma. *J Thorac Imaging.* 2012;27(2):100-106.
29. McAdams HP, Kirejczyk WM, Rosado-de-Christenson ML, Matsumoto S. Bronchogenic cyst: imaging features with clinical and histopathologic correlation. *Radiology.* 2000;217(2):441-446.
30. Brody AS. Imaging considerations: interstitial lung disease in children. *Radiol Clin North Am.* 2005;43(2):391-403.
31. Cooper P, MacLean J. High-resolution computed tomography (HRCT) should not be considered as a routine assessment method in cystic fibrosis lung disease. *Paediatr Respir Rev.* 2006;7(3):197-201.
32. Copley SJ. Application of computed tomography in childhood respiratory infections. *Br Med Bull.* 2002;61:263-279.
33. Donnelly LF. Imaging in immunocompetent children who have pneumonia. *Radiol Clin North Am.* 2005;43(2):253-265.
34. Fan LL, Deterding RR, Langston C. Pediatric interstitial lung disease revisited. *Pediatr Pulmonol.* 2004;38(5):369-378.
35. Hall A, Johnson K. The imaging of paediatric thoracic trauma. *Paediatr Respir Rev.* 2002;3(3):241-247.
36. Daltro P, Fricke BL, Kuroki I, Domingues R, Donnelly LF. CT of congenital lung lesions in pediatric patients. *AJR Am J Roentgenol.* 2004;183(5):1497-1506.
37. Lee EY, Tracy DA, Mahmood SA, Weldon CB, Zurakowski D, Boiselle PM. Preoperative MDCT evaluation of congenital lung anomalies in children: comparison of axial, multiplanar, and 3D images. *AJR Am J Roentgenol.* 2011;196(5):1040-1046.
38. Lim GY, Newman B, Kurland G, Webber SA. Posttransplantation lymphoproliferative disorder: manifestations in pediatric thoracic organ recipients. *Radiology.* 2002;222(3):699-708.
39. Mott LS, Park J, Murray CP, et al. Progression of early structural lung disease in young children with cystic fibrosis assessed using CT. *Thorax.* 2012;67(6):509-516.
40. Newman B. Congenital bronchopulmonary foregut malformations: concepts and controversies. *Pediatr Radiol.* 2006;36(8):773-791.
41. O'Connor OJ, Vandeleur M, McGarrigle AM, et al. Development of low-dose protocols for thin-section CT assessment of cystic fibrosis in pediatric patients. *Radiology.* 2010;257(3):820-829.
42. Orazi C, Inserra A, Schingo PM, et al. Pleuropulmonary blastoma, a distinctive neoplasm of childhood: report of three cases. *Pediatr Radiol.* 2007;37(4):337-344.
43. Paterson A. Imaging evaluation of congenital lung abnormalities in infants and children. *Radiol Clin North Am.* 2005;43(2):303-323.
44. Thomas KE, Owens CM, Britto J, Nadel S, Habibi P, Nicholson R. Efficacy of chest CT in a pediatric ICU: a prospective study. *Chest.* 2000;117(6):1697-1705.
45. Tiddens HA. Chest computed tomography scans should be considered as a routine investigation in cystic fibrosis. *Paediatr Respir Rev.* 2006;7(3):202-208.
46. Brody AS, Tiddens HA, Castile RG, et al. Computed tomography in the evaluation of cystic fibrosis lung disease. *Am J Respir Crit Care Med.* 2005;172(10):1246-1252.
47. Hernanz-Schulman M. CT as an outcome surrogate in patients with cystic fibrosis: does the effort justify the risks? *Radiology.* 2012;262(3):746-749.
48. Islam S, Calkins CM, Goldin AB, et al. The diagnosis and management of empyema in children: a comprehensive review from the APSA Outcomes and Clinical Trials Committee. *J Pediatr Surg.* 2012;47(11):2101-2110.
49. Bennett GL, Birnbaum BA, Balthazar EJ. CT of Meckel's diverticulitis in 11 patients. *AJR Am J Roentgenol.* 2004;182(3):625-629.
50. Brandon JL, Schroeder S, Furuta GT, Capocelli K, Masterson JC, Fenton LZ. CT imaging features of eosinophilic colitis in children. *Pediatr Radiol.* 2013;43(6):697-702.
51. Callahan MJ, Rodriguez DP, Taylor GA. CT of appendicitis in children. *Radiology.* 2002;224(2):325-332.
52. Chen JJ, Lee HC, Yeung CY, Chan WT, Jiang CB, Sheu JC. Meta-analysis: the clinical features of the duodenal duplication cyst. *J Pediatr Surg.* 2010;45(8):1598-1606.
53. Davis JS, Ryan ML, Fields JM, Neville HL, Perez EA, Sola JE. Use of CT enterography for the diagnosis of lower gastrointestinal bleeding in pediatric patients. *J Pediatr Surg.* 2013;48(3):681-684.

54. Fischerauer E, Zotsch S, Capito C, et al. Paediatric and adolescent traumatic gastrointestinal injuries: results of a European multicentre analysis. *Acta Paediatr.* 2013.
55. Garcia K, Hernanz-Schulman M, Bennett DL, Morrow SE, Yu C, Kan JH. Suspected appendicitis in children: diagnostic importance of normal abdominopelvic CT findings with nonvisualized appendix. *Radiology.* 2009;250(2):531-537.
56. Hammer MR, Podberesky DJ, Dillman JR. Multidetector computed tomographic and magnetic resonance enterography in children: state of the art. *Radiol Clin North Am.* 2013;51(4):615-636.
57. Kaiser S, Finnbogason T, Jorulf HK, Soderman E, Frenckner B. Suspected appendicitis in children: diagnosis with contrast-enhanced versus nonenhanced Helical CT. *Radiology.* 2004;231(2):427-433.
58. Kamona AA, El-Khatib MA, Swaidan MY, et al. Pediatric Burkitt's lymphoma: CT findings. *Abdom Imaging.* 2007;32(3):381-386.
59. Karmazyn B, Ash S, Goshen Y, Yaniv I, Horev G, Kornreich L. Significance of residual abdominal masses in children with abdominal Burkitt's lymphoma. *Pediatr Radiol.* 2001;31(11):801-805.
60. Kaste SC, McCarville MB. Imaging pediatric abdominal tumors. *Semin Roentgenol.* 2008;43(1):50-59.
61. Kharbanda AB, Taylor GA, Bachur RG. Suspected appendicitis in children: rectal and intravenous contrast-enhanced versus intravenous contrast-enhanced CT. *Radiology.* 2007;243(2):520-526.
62. Liu Y, Peng Y, Li J, Zeng J, Sun G, Gao P. MSCT manifestations with pathologic correlation of abdominal gastrointestinal tract and mesenteric tumor and tumor-like lesions in children: a single center experience. *Eur J Radiol.* 2010;75(3):293-300.
63. Olson DE, Kim YW, Ying J, Donnelly LF. CT predictors for differentiating benign and clinically worrisome pneumatosis intestinalis in children beyond the neonatal period. *Radiology.* 2009;253(2):513-519.
64. Wang Q, Chavhan GB, Babyn PS, Tomlinson G, Langer JC. Utility of CT in the diagnosis and management of small-bowel obstruction in children. *Pediatr Radiol.* 2012;42(12):1441-1448.
65. Adeyiga AO, Lee EY, Eisenberg RL. Focal hepatic masses in pediatric patients. *AJR Am J Roentgenol.* 2012;199(4):W422-440.
66. Guo WL, Huang SG, Wang J, Sheng M, Fang L. Imaging findings in 75 pediatric patients with pancreaticobiliary maljunction: a retrospective case study. *Pediatr Surg Int.* 2012;28(10):983-988.
67. Hilmes MA, Hernanz-Schulman M, Greeley CS, Piercey LM, Yu C, Kan JH. CT identification of abdominal injuries in abused pre-school-age children. *Pediatr Radiol.* 2011;41(5):643-651.
68. Joyner BL, Jr., Levin TL, Goyal RK, Newman B. Focal nodular hyperplasia of the liver: a sequela of tumor therapy. *Pediatr Radiol.* 2005;35(12):1234-1239.
69. Mishra K, Basu S, Roychoudhury S, Kumar P. Liver abscess in children: an overview. *World J Pediatr.* 2010;6(3):210-216.
70. Towbin AJ, Luo GG, Yin H, Mo JQ. Focal nodular hyperplasia in children, adolescents, and young adults. *Pediatr Radiol.* 2011;41(3):341-349.
71. Yen TY, Huang LM, Lee PI, Lu CY, Shao PL, Chang LY. Clinical characteristics of hepatosplenic fungal infection in pediatric patients. *J Microbiol Immunol Infect.* 2011;44(4):296-302.
72. Zhang DY, Ji ZF, Shen XZ, Liu HY, Pan BJ, Dong L. Caroli's disease: a report of 14 patients and review of the literature. *J Dig Dis.* 2012;13(9):491-495.
73. Berrocal T, Pajares MP, Zubillaga AF. Pancreatic cystosis in children and young adults with cystic fibrosis: sonographic, CT, and MRI findings. *AJR Am J Roentgenol.* 2005;184(4):1305-1309.
74. Fabre A, Petit P, Gaudart J, et al. Severity scores in children with acute pancreatitis. *J Pediatr Gastroenterol Nutr.* 2012;55(3):266-267.
75. Lautz TB, Turkel G, Radhakrishnan J, Wyers M, Chin AC. Utility of the computed tomography severity index (Balthazar score) in children with acute pancreatitis. *J Pediatr Surg.* 2012;47(6):1185-1191.
76. Hu S, Lin X, Song Q, Chen K. Solid pseudopapillary tumour of the pancreas in children: clinical and computed tomography manifestation. *Radiol Med.* 2012;117(7):1242-1249.
77. van den Akker M, Angelini P, Taylor G, Chami R, Gerstle JT, Gupta A. Malignant pancreatic tumors in children: a single-institution series. *J Pediatr Surg.* 2012;47(4):681-687.
78. Yamana I, Kawamoto S, Kamitani T, Ishikura H, Yamashita Y. Pancreatic injury in children: review of 7 cases and the pertinent literature. *Hepatogastroenterology.* 2012;59(114):574-577.
79. Agrons GA, Wagner BJ, Davidson AJ, Suarez ES. Multilocular cystic renal tumor in children: radiologic-pathologic correlation. *Radiographics.* 1995;15(3):653-669.

80. Fernbach SK, Feinstein KA, Donaldson JS, Baum ES. Nephroblastomatosis: comparison of CT with US and urography. *Radiology.* 1988;166(1 Pt 1):153-156.
81. Weinberger E, Rosenbaum DM, Pendergrass TW. Renal involvement in children with lymphoma: comparison of CT with sonography. *AJR Am J Roentgenol.* 1990;155(2):347-349.
82. Johnson EK, Faerber GJ, Roberts WW, et al. Are stone protocol computed tomography scans mandatory for children with suspected urinary calculi? *Urology.* 2011;78(3):662-666.
83. Kurian J, Epelman M, Darge K, Meyers K, Nijs E, Hellinger JC. The role of CT angiography in the evaluation of pediatric renovascular hypertension. *Pediatr Radiol.* 2013;43(4):490-501; quiz 487-499.
84. Bartley JM, Santucci RA. Computed tomography findings in patients with pediatric blunt renal trauma in whom expectant (nonoperative) management failed. *Urology.* 2012;80(6):1338-1343.
85. Cheng CH, Tsau YK, Chen SY, Lin TY. Clinical courses of children with acute lobar nephronia correlated with computed tomographic patterns. *Pediatr Infect Dis J.* 2009;28(4):300-303.
86. Jacobs MA, Hotaling JM, Mueller BA, Koyle M, Rivara F, Voelzke BB. Conservative management vs early surgery for high grade pediatric renal trauma--do nephrectomy rates differ? *J Urol.* 2012;187(5):1817-1822.
87. Karmazyn B, Frush DP, Applegate KE, Maxfield C, Cohen MD, Jones RP. CT with a computer-simulated dose reduction technique for detection of pediatric nephroureterolithiasis: comparison of standard and reduced radiation doses. *AJR Am J Roentgenol.* 2009;192(1):143-149.
88. Kawashima A, LeRoy AJ. Radiologic evaluation of patients with renal infections. *Infect Dis Clin North Am.* 2003;17(2):433-456.
89. Berdon WE, Ruzal-Shapiro C, Abramson SJ, Garvin J. The diagnosis of abdominal neuroblastoma: relative roles of ultrasonography, CT, and MRI. *Urol Radiol.* 1992;14(4):252-262.
90. Burks DW, Mirvis SE, Shanmuganathan K. Acute adrenal injury after blunt abdominal trauma: CT findings. *AJR Am J Roentgenol.* 1992;158(3):503-507.
91. Sivit CJ, Ingram JD, Taylor GA, Bulas DI, Kushner DC, Eichelberger MR. Posttraumatic adrenal hemorrhage in children: CT findings in 34 patients. *AJR Am J Roentgenol.* 1992;158(6):1299-1302.
92. Westra SJ, Zaninovic AC, Hall TR, Kangarloo H, Boechat MI. Imaging of the adrenal gland in children. *Radiographics.* 1994;14(6):1323-1340.
93. Balassy C, Navarro OM, Daneman A. Adrenal masses in children. *Radiol Clin North Am.* 2011;49(4):711-727, vi.
94. Wadsworth DT, Newman B, Abramson SJ, Carpenter BL, Lorenzo RL. Splenic lymphangiomatosis in children. *Radiology.* 1997;202(1):173-176.
95. Davies DA, Ein SH, Pearl R, et al. What is the significance of contrast "blush" in pediatric blunt splenic trauma? *J Pediatr Surg.* 2010;45(5):916-920.
96. Ferrozzi F, Bova D, Draghi F, Garlaschi G. CT findings in primary vascular tumors of the spleen. *AJR Am J Roentgenol.* 1996;166(5):1097-1101.
97. Gayer G, Zissin R, Apter S, Atar E, Portnoy O, Itzchak Y. CT findings in congenital anomalies of the spleen. *Br J Radiol.* 2001;74(884):767-772.
98. Paterson A, Frush DP, Donnelly LF, Foss JN, O'Hara SM, Bisset GS, 3rd. A pattern-oriented approach to splenic imaging in infants and children. *Radiographics.* 1999;19(6):1465-1485.
99. St Peter SD, Keckler SJ, Spilde TL, Holcomb GW, 3rd, Ostlie DJ. Justification for an abbreviated protocol in the management of blunt spleen and liver injury in children. *J Pediatr Surg.* 2008;43(1):191-193; discussion 193-194.
100. van der Vlies CH, Saltzherr TP, Wilde JC, van Delden OM, de Haan RJ, Goslings JC. The failure rate of nonoperative management in children with splenic or liver injury with contrast blush on computed tomography: a systematic review. *J Pediatr Surg.* 2010;45(5):1044-1049.
101. Chan DP, Abujudeh HH, Cushing GL, Jr., Novelline RA. CT cystography with multiplanar reformation for suspected bladder rupture: experience in 234 cases. *AJR Am J Roentgenol.* 2006;187(5):1296-1302.
102. Shah RU, Lawrence C, Fickenscher KA, Shao L, Lowe LH. Imaging of pediatric pelvic neoplasms. *Radiol Clin North Am.* 2011;49(4):729-748, vi.
103. Sivit CJ, Cutting JP, Eichelberger MR. CT diagnosis and localization of rupture of the bladder in children with blunt abdominal trauma: significance of contrast material extravasation in the pelvis. *AJR Am J Roentgenol.* 1995;164(5):1243-1246.

104. Hamrick-Turner JE, Chiechi MV, Abbitt PL, Ros PR. Neoplastic and inflammatory processes of the peritoneum, omentum, and mesentery: diagnosis with CT. *Radiographics.* 1992;12(6):1051-1068.
105. Pickhardt PJ, Siegel MJ. Abdominal manifestations of posttransplantation lymphoproliferative disorder. *AJR Am J Roentgenol.* 1998;171(4):1007-1013.
106. Al-Salem AH. Traumatic diaphragmatic hernia in children. *Pediatr Surg Int.* 2012;28(7):687-691.
107. Ruess L, Frazier AA, Sivit CJ. CT of the mesentery, omentum, and peritoneum in children. *Radiographics.* 1995;15(1):89-104.
108. Tang V, Daneman A, Navarro OM, Miller SF, Gerstle JT. Internal hernias in children: spectrum of clinical and imaging findings. *Pediatr Radiol.* 2011;41(12):1559-1568.
109. Chapman V, Grottkau B, Albright M, Elaini A, Halpern E, Jaramillo D. MDCT of the elbow in pediatric patients with posttraumatic elbow effusions. *AJR Am J Roentgenol.* 2006;187(3):812-817.
110. Chapman VM, Grottkau BE, Albright M, Salamipour H, Jaramillo D. Multidetector computed tomography of pediatric lateral condylar fractures. *J Comput Assist Tomogr.* 2005;29(6):842-846.
111. Fayad LM, Johnson P, Fishman EK. Multidetector CT of musculoskeletal disease in the pediatric patient: principles, techniques, and clinical applications. *Radiographics.* 2005;25(3):603-618.
112. Fayad LM, Carrino JA, Fishman EK. Musculoskeletal infection: role of CT in the emergency department. *Radiographics.* 2007;27(6):1723-1736.
113. Laurence N, Epelman M, Markowitz RI, Jaimes C, Jaramillo D, Chauvin NA. Osteoid osteomas: a pain in the night diagnosis. *Pediatr Radiol.* 2012;42(12):1490-1501; quiz 1540-1492.
114. Satake H, Takahara M, Harada M, Maruyama M. Preoperative imaging criteria for unstable osteochondritis dissecans of the capitellum. *Clin Orthop Relat Res.* 2013;471(4):1137-1143.
115. Silber JS, Flynn JM, Katz MA, Ganley TJ, Koffler KM, Drummond DS. Role of computed tomography in the classification and management of pediatric pelvic fractures. *J Pediatr Orthop.* 2001;21(2):148-151.
116. Stiletto RJ, Baacke M, Gotzen L. Comminuted pelvic ring disruption in toddlers: management of a rare injury. *J Trauma.* 2000;48(1):161-164.
117. Viani RM, Bromberg K, Bradley JS. Obturator internus muscle abscess in children: report of seven cases and review. *Clin Infect Dis.* 1999;28(1):117-122.
118. Vo NJ, Gash J, Browning J, Hutson RK. Pelvic imaging in the stable trauma patient: is the AP pelvic radiograph necessary when abdominopelvic CT shows no acute injury? *Emerg Radiol.* 2004;10(5):246-249.
119. Cho TJ, Choi IH, Chung CY, Hwang JK. The Sprengel deformity. Morphometric analysis using 3D-CT and its clinical relevance. *J Bone Joint Surg Br.* 2000;82(5):711-718.
120. Sibinski M, Wozniakowski B, Drobniewski M, Synder M. Secondary gleno-humeral joint dysplasia in children with persistent obstetric brachial plexus palsy. *Int Orthop.* 2010;34(6):863-867.
121. Waters PM, Smith GR, Jaramillo D. Glenohumeral deformity secondary to brachial plexus birth palsy. *J Bone Joint Surg Am.* 1998;80(5):668-677.
122. Akiyama M, Nakashima Y, Fujii M, et al. Femoral anteversion is correlated with acetabular version and coverage in Asian women with anterior and global deficient subgroups of hip dysplasia: a CT study. *Skeletal Radiol.* 2012;41(11):1411-1418.
123. Eggli KD, King SH, Boal DK, Quiogue T. Low-dose CT of developmental dysplasia of the hip after reduction: diagnostic accuracy and dosimetry. *AJR Am J Roentgenol.* 1994;163(6):1441-1443.
124. Jia J, Li L, Zhang L, Zhao Q, Liu X. Three dimensional-CT evaluation of femoral neck anteversion, acetabular anteversion and combined anteversion in unilateral DDH in an early walking age group. *Int Orthop.* 2012;36(1):119-124.
125. Monazzam S, Bomar JD, Dwek JR, Hosalkar HS, Pennock AT. Development and prevalence of femoroacetabular impingement-associated morphology in a paediatric and adolescent population: a CT study of 225 patients. *Bone Joint J.* 2013;95-B(5):598-604.
126. Stevens MA, El-Khoury GY, Kathol MH, Brandser EA, Chow S. Imaging features of avulsion injuries. *Radiographics.* 1999;19(3):655-672.
127. Chin MS, Betz BW, Halanski MA. Comparison of hip reduction using magnetic resonance imaging or computed tomography in hip dysplasia. *J Pediatr Orthop.* 2011;31(5):525-529.
128. Delgado-Martinez AD, Rodriguez-Merchan EC, Ballesteros R, Luna JD. Reproducibility of patellofemoral CT scan measurements. *Int Orthop.* 2000;24(1):5-8.

129. Kristiansen LP, Gunderson RB, Steen H, Reikeras O. The normal development of tibial torsion. *Skeletal Radiol.* 2001;30(9):519-522.
130. Pandya NK, Edmonds EW, Roocroft JH, Mubarak SJ. Tibial tubercle fractures: complications, classification, and the need for intra-articular assessment. *J Pediatr Orthop.* 2012;32(8):749-759.
131. Crim J. Imaging of tarsal coalition. *Radiol Clin North Am.* 2008;46(6):1017-1026, vi.
132. Liporace FA, Yoon RS, Kubiak EN, et al. Does adding computed tomography change the diagnosis and treatment of Tillaux and triplane pediatric ankle fractures? *Orthopedics.* 2012;35(2):e208-212.
133. Wuerz TH, Gurd DP. Pediatric physeal ankle fracture. *J Am Acad Orthop Surg.* 2013;21(4):234-244.
134. Brown SD, Kasser JR, Zurakowski D, Jaramillo D. Analysis of 51 tibial triplane fractures using CT with multiplanar reconstruction. *AJR Am J Roentgenol.* 2004;183(5):1489-1495.
135. Schindera ST, Diedrichsen L, Muller HC, et al. Iterative reconstruction algorithm for abdominal multidetector CT at different tube voltages: assessment of diagnostic accuracy, image quality, and radiation dose in a phantom study. *Radiology.* 2011;260(2):454-462.
136. Lungren MP, Yoshizumi TT, Brady SM, et al. Radiation dose estimations to the thorax using organ-based dose modulation. *AJR Am J Roentgenol.* 2012;199(1):W65-73.
137. Mieville FA, Berteloot L, Grandjean A, et al. Model-based iterative reconstruction in pediatric chest CT: assessment of image quality in a prospective study of children with cystic fibrosis. *Pediatr Radiol.* 2013;43(5):558-567.
138. Siegel MJ, Hildebolt C, Bradley D. Effects of Automated Kilovoltage Selection Technology on Contrast-enhanced Pediatric CT and CT Angiography. *Radiology.* 2013;268(2):538-547.
139. Smith EA, Dillman JR, Goodsitt MM, Christodoulou EG, Kesharvarzi N, Strouse PJ. Model-Based Iterative Reconstruction (MBIR): Effect on Patient Radiation Dose and Image Quality in Pediatric Body CT. *Radiology* 2013 (In Press).
140. Coursey C, Frush DP, Yoshizumi T, Toncheva G, Nguyen G, Greenberg SB. Pediatric chest MDCT using tube current modulation: effect on radiation dose with breast shielding. *AJR Am J Roentgenol.* 2008;190(1):W54-61.
141. Lee SH, Kim MJ, Yoon CS, Lee MJ. Radiation dose reduction with the adaptive statistical iterative reconstruction (ASIR) technique for chest CT in children: an intra-individual comparison. *Eur J Radiol.* 2012;81(9):e938-943.
142. Singh S, Kalra MK, Shenoy-Bhangle AS, et al. Radiation dose reduction with hybrid iterative reconstruction for pediatric CT. *Radiology.* 2012;263(2):537-546.
143. Greess H, Lutze J, Nomayr A, et al. Dose reduction in subsecond multislice spiral CT examination of children by online tube current modulation. *Eur Radiol.* 2004;14(6):995-999.
144. AAPM Position Statement on the Use of Bismuth Shielding for the Purpose of Dose Reduction in CT Scanning. Feb, 2012. http://www.aapm.org/public general/BismuthShielding.pdf.
145. Geleijns J, Wang J, McCollough C. The use of breast shielding for dose reduction in pediatric CT: arguments against the proposition. *Pediatr Radiol.* 2010;40(11):1744-1747.
146. Kim S, Frush DP, Yoshizumi TT. Bismuth shielding in CT: support for use in children. *Pediatr Radiol.* 2010;40(11):1739-1743.
147. McCollough CH, Wang J, Berland LL. Bismuth shields for CT dose reduction: do they help or hurt? *J Am Coll Radiol.* 2011;8(12):878-879.
148. Kim JE, Newman B. Evaluation of a radiation dose reduction strategy for pediatric chest CT. *AJR Am J Roentgenol.* 2010;194(5):1188-1193.
149. Kawel N, Seifert B, Luetolf M, Boehm T. Effect of slab thickness on the CT detection of pulmonary nodules: use of sliding thin-slab maximum intensity projection and volume rendering. *AJR Am J Roentgenol.* 2009;192(5):1324-1329.
150. Peloschek P, Sailer J, Weber M, Herold CJ, Prokop M, Schaefer-Prokop C. Pulmonary nodules: sensitivity of maximum intensity projection versus that of volume rendering of 3D multidetector CT data. *Radiology.* 2007;243(2):561-569.
151. Siegel MJ, Bhalla S, Gutierrez FR, Hildebolt C, Sweet S. Post-lung transplantation bronchiolitis obliterans syndrome: usefulness of expiratory thin-section CT for diagnosis. *Radiology.* 2001;220(2):455-462.
152. Bae KT, Shah AJ, Shang SS, et al. Aortic and hepatic contrast enhancement with abdominal 64-MDCT in pediatric patients: effect of body weight and iodine dose. *AJR Am J Roentgenol.* 2008;191(5):1589-1594.

153. Chan FP, Rubin GD. MDCT angiography of pediatric vascular diseases of the abdomen, pelvis, and extremities. *Pediatr Radiol.* 2005;35(1):40-53.
154. Karmazyn B, Liang Y, Klahr P, Jennings SG. Effect of tube voltage on CT noise levels in different phantom sizes. *AJR Am J Roentgenol.* 2013;200(5):1001-1005.
155. Reid J, Gamberoni J, Dong F, Davros W. Optimization of kVp and mAs for pediatric low-dose simulated abdominal CT: is it best to base parameter selection on object circumference? *AJR Am J Roentgenol.* 2010;195(4):1015-1020.

---

*Practice parameters and technical standards are published annually with an effective date of October 1in the year in which amended, revised, or approved by the ACR Council. For practice parameters and technical standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Practice Parameter
2008 (Resolution 22)
Amended 2009 (Resolution 11)
Revised 2014 (Resolution 3)