The American College of Radiology, with more than 30,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice parameters and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice parameters and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice parameter and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review and approval. The practice parameters and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice parameter and technical standard by those entities not providing these services is not authorized.

Revised 2022 (Resolution 23)*

ACR–ASNR–ASSR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF COMPUTED TOMOGRAPHY (CT) OF THE SPINE

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 considering 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 variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and 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 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 831 N.W.2d 826 (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 Neuroradiology (ASNR), the American Society of Spine Radiology (ASSR), and the Society for Pediatric Radiology (SPR).

Computed tomography (CT) is a technology using ionizing radiation to generate images resulting from differential X-ray absorption of the specific tissues examined. CT produces cross-sectional displays and allows for multidimensional 2-D and 3-D reconstructions and offers a high degree of clinical utility for examining the spine. This practice parameter outlines the principles for performing high- quality CT imaging of the pediatric and adult spine.

II. INDICATIONS

The complete clinical evaluation of spinal disorders may require the use of several different imaging modalities. Depending on the nature of the disorder, CT may be the primary modality used or it may complement other modalities such as radiography, magnetic resonance (MR), ultrasound (US), or nuclear imaging studies. The strength of CT lies in the detailed depiction of bone; therefore, it has greatest utility in evaluating the osseous spine, as opposed to soft-tissue structures, such as the spinal cord. Additionally, CT may also play an important role in performing and monitoring invasive diagnostic and therapeutic procedures.

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

1. Adult Spine Trauma
   CT of the spine is considered a primary imaging evaluation of acute spine trauma in adults [1,2]. Meta-analysis of blunt thoracolumbar trauma has demonstrated that CT is more accurate than radiographs for detecting thoracic and lumbar spine fractures [3]. CT with intrathecal contrast (CT myelography) may be used to evaluate spinal canal pathology related to trauma when MRI is contraindicated.

   CT can be used for evaluating vertebral compression/insufficiency fractures in both acute and chronic clinical situations [1,4-17]. Advances such as dual-layer spectral CT have demonstrated higher accuracy in detection of acute osteoporotic vertebral body fracture bone marrow edema compared to conventional CT images [18].

2. Pediatric Spine Trauma
   CT is the primary modality of choice for pediatric patients who are obtunded or with low neurological score with multiple sites of injury and/or high risk of mechanism of injury [19]. In some institutions, brain CT will include C1 to C3 of the cervical spine in pediatric patients with multiple injuries [19,20]. Other practices advise obtaining a separate cervical spine CT with a lower dose than head CT if there is clinical concern of spinal injury. Given that the majority of cervical spine injuries in children <8 years old (especially those <3 years old) are of soft tissue rather than bone, the use of CT in this population may be of limited utility. If there is a clinical concern for spinal injury, MRI (by itself or in conjunction with clinical observation) should be considered in younger pediatric patients as an alternative or complement to a targeted CT of the area of concern.

3. Degenerative Changes
   CT is often used to study the spine for conditions such as spinal stenosis or in evaluating disc degeneration when MRI is contraindicated. CT with intrathecal contrast (CT myelography) is better at delineating the spinal canal and neural foramina in degenerative conditions. CT provides superior osseous delineation and may be complementary to MRI for surgical planning [21]. For more information on CT myelography, see the ACR–ASNR–SPR Practice Parameter for the Performance of Myelography and Cisternography [22]. Additionally, in evaluating these conditions, CT may be helpful for presurgical planning and is complementary to MRI.
4. Inflammatory Conditions

CT shows the presence and extent of osseous structural changes of the spine in the evaluation of inflammatory lesions and deposition diseases [23,24]. Structural changes of the bone in inflammatory spondyloarthropathies are well delineated on CT [25]. In ankylosing spondylitis, for example, CT is sensitive for syndesmophytes [25] and ankyloses [26], fracture, and Andersson lesions [27]. Progression of syndesmophytes in ankylosing spondylitis can be assessed on CT, which can contribute to sagittal malalignment [28]. CT for this application can be performed with the additional use of an intrathecal contrast agent to better delineate spinal canal or neural foraminal encroachment (see number 3).

5. Bone Mineral Density
   CT number measurements (in Hounsfield unit) on CT images reflect bone mineral density [29-34]. Opportunistic CT number measurements on abdominal CT images obtained for other reasons [35-38] or on CT scans obtained of arthropathy [39,40], degenerative disease [41], or for sacral fractures [42] can identify patients with osteoporotic bone mineral density without additional radiation exposure or cost. In patients with sacral insufficiency fractures, there is lower regional volumetric bone density of the sacrum when compared to a cohort without fracture; this local sacral volumetric bone density as measured by CT is independent from the areal bone mineral density (BMD) as measured by dual-energy X-ray absorptiometry of the lumbar spine [43]. Furthermore, deep learning can be used to predict BMD of lumbar vertebrae from unenhanced abdominal CT images [44]. In degenerative lumbar spine surgery, measurements with higher CT number results are associated with lower rates of pseudarthrosis [45]. Despite the opportunistic utility of lumbar spine CT number measurements in identifying osteoporosis in patients undergoing single-level fusion, these measurements have not been shown to be useful in adult spinal deformity patients [46]. Other CT related modalities for quantitatively measuring bone metabolism include areal bone mineral density measurement based on dual-layer spectral CT scout scans [47], quantitative bone SPECT/CT [48] and quantitative CT or spectral detector CT, which is a 3-D method that can measure the trabecular and cortical bone compartments [32,34,49-52].

6. Alignment
   Abnormalities related to alignment or orientation of the spine, such as scoliosis or spondylolysis, can be demonstrated by CT multiplanar reformations, recognizing that the CT is obtained in the supine position, which can affect alignment [53,54].

7. Postoperative Evaluation
   CT has shown utility in evaluating postoperative patients for accurate evaluation of osseous detail, implant/bone graft position, fusion, and spinal instrumentation integrity [55]. CT myelography may be useful for spinal canal and neural foraminal assessment in the setting of extensive hardware [56-59]. Quantitative CT can show decreased volumetric BMD in adjacent levels [60]. Integrated bone SPECT/CT is a useful problem-solving modality in evaluating patients with persistent or recurring pain after spinal surgery to identify areas of pseudarthrosis, adjacent segment degeneration, hardware failure, and/or segmental motion [61,62]. SPECT/CT can also provide structural and functional information to help identify pain generators in spine-related pain [63-66], which can guide treatment [67].

8. Infectious Processes
   Infectious processes of the spine and paraspinal tissues can be evaluated on CT, recognizing that osseous changes usually trail the clinical presentation [68]. Contrast-enhanced CT can be performed to demonstrate the extent of soft-tissue involvement, particularly when MRI is not feasible. CT is complementary to MRI in demonstrating osseous involvement and features that can optimize image-guided biopsy [69] and those that are associated with poor clinical outcome [70]. Bone and gallium SPECT/CT is complementary to MRI in the diagnosis of infectious spondylodiscitis [71].

9. Neoplastic Conditions and Complications
   CT can provide valuable information in the evaluation of primary or metastatic neoplasms of the spine, including marrow-replacing conditions such as multiple myeloma. MRI and CT are often complementary in evaluating the bone lesions. It can also provide valuable information in relation to complications of neoplastic disease, including malalignment and pathologic fractures [72,73], and can provide important information about osseous integrity to guide treatment planning.

10. Image Guidance
    CT of the spine can be used for imaging guidance before [74], during, and after various spine interventions (eg, biopsy [69,75,76], aspiration, radiotherapy, stereotactic surgery [77], and spine injection) [78-80]. CT with intrathecal contrast (CT myelography) may be helpful for preoperative planning. Vascular imaging with CT arteriography can be used to identify critical vascular structures that may be affected by a surgical approach [81]. Intraoperative CT-guided navigation has shown to improve the safety, accuracy, and reliability of pedicle screw placement [82,83] and to have a lower rate of malpositioned hardware and unplanned returns to the operating room [84-86]. Studies have also shown that intraoperative CT-guided navigation enables adequate neural decompression [87-89] and maximal tumor resection [90]. Additionally, intraoperative CT may reveal nonspinal findings during spine instrumentation surgery [91].

11. Developmental Spine Abnormalities
    CT can provide valuable information in the evaluation of the osseous components of developmental spinal anomalies and delineate developmental variants that might mimic fractures, complementary to MRI, which is typically the first line of imaging in these evaluations [92]. Three-dimensional surface rendering images can aid in visualization of these anatomic differences [93].

    Depending on the age of the pediatric patient, CT may aid in identifying variations in ossification centers in the setting of trauma or pain to rule out fracture [19].

Evaluation of intradural spinal canal pathologies, such as intradural metastases or arachnoid adhesions, is performed using CT with intrathecal contrast (CT myelography) in situations in which MRI is contraindicated. Primary spinal cord pathologies such as syrinxes are better assessed by MRI, but when MRI is contraindicated, CT with intrathecal contrast (CT myelography) may provide some limited information [94].

For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation [95].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [96].

IV. SPECIFICATIONS OF THE EXAMINATION

A. Written Request for the Examination

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

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). 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’s scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

B. General Considerations

CT protocols require close attention and development by the supervising physician; they should be tailored to the specific indication and to optimize the balance between image quality and radiation dose. See section VII for further information on radiation safety. Protocols should be reviewed and updated periodically in light of new information, techniques, and technology. The supervising physician should be familiar with indications for each examination and the patient history (including potential adverse reactions to contrast media). The supervising physician should also be familiar with the protocol specifications, including exposure factors, field of view (FOV), collimation, slice spacing or pitch, and image reconstruction algorithms. These factors should be adjusted to minimize radiation dosage to the minimum level required to adequately perform the specific examination. The location of axial images should be indicated relative to a scout image and/or reconstructed sagittal or coronal images.

C. Spine Imaging

Helical acquisition with reconstruction of contiguous or overlapping axial slices at an optimal slice thickness depending on the spinal segment of interest is required. It is beneficial in spine CT examinations to review multiplanar reformations.

Metal artifacts caused by osteosynthetic material can impair image quality and degrade the diagnostic yield of CT scans. In addition to conventional techniques (increasing tube current and increasing kV and peak voltage, narrow collimation), metal-related artifacts can be reduced to some extent in different image reconstruction algorithms such as iterative and projection-based approaches [97-99]. Other options such as dual-energy techniques [100,101] and raw-data-based metal artifact reduction with iterative or projection-based algorithms reported a significant reduction of metal artifacts and improved evaluation of periarticular soft tissues compared to iterative projections alone [97,99,102-107], when available.

Images should be reviewed at window and level settings that are appropriate for demonstrating a range of display densities, including soft-tissue and osseous abnormalities. This can be facilitated by reconstruction of images with soft-tissue and osseous algorithms. Given the availability of several different types of CT scanners from different manufacturers, consultation with the manufacturer regarding protocol recommendations is advised in order to optimize spatial and contrast resolution.

It is important that the clinical information be reviewed so that the examination is obtained at the appropriate level in which the patient is symptomatic. If the patient's signs and symptoms are limited to a given level, CT of the entire spine segment may not be necessary; for example, if spondylolysis at L5-S1 is suspected from clinical examination and from plain radiographs, CT of the entire lumbar spine from T12 down is not necessary. This is particularly important in pediatric patients [20]. Caution should be applied in the presence of transitional anatomy. It is also important to be familiar with development variants that might mimic fractures [92].

1. Cervical spine
   Multidetector CT imaging is the first choice modality for evaluation of cervical spine trauma in adults with excellent image quality, up to 99% sensitivity and 100% of specificity for cervical spine fractures [108].

   Evaluation of the craniocervical junction (skull base structures including sella and clivus) and cervical spine requires thin sections for definitive diagnosis. Multiplanar reformations (sagittal and coronal) help identify the exact location and displacement of fractures and define the extent of potential spinal canal, neural foraminal, or vascular compromise. The reconstructed scan width should be no greater than 2 mm [1]. Primary evaluation for the effects of cervical disc or facet degeneration should include 1- to 3-mm contiguous slices or axial reformats obtained from pedicle to pedicle for each disc space, assessed in both bone and soft-tissue algorithms. Oblique reformats perpendicular to the long axis of the neural foramina on both sides can sometimes be helpful in the assessment of neural foraminal stenosis.

2. Thoracic spine and lumbar spine
   Acceptable technique (for all entities except evaluation of spine fusion integrity): Effective slice thickness should be no greater than 2 mm [1] to allow for diagnostic reformation. The FOV should always be as small as appropriate to improve geometric resolution. For evaluating spine fusion, contiguous slices of the involved spinal segment(s) and at least a portion of the adjacent cranial and caudal normal segments within the acquisition volume will allow a greater degree of certainty in detecting pseudarthrosis. Three-dimensional and/or multiplanar reformations may be helpful for detecting solid or failed fusion. In

polytrauma patients, patients may undergo CT scans of the chest, abdomen, and pelvis to evaluate for other traumatic injuries. Current CT imaging capability allows for reformatting to obtain imaging for screening thoracic, lumbar, and sacral injuries without the need for repeat radiation exposure [109], but it needs to be optimized for this purpose.

D. Pediatric CT Spine Imaging

A systematic algorithm approach using a combination of physical examination findings and radiographs can be used to clear the cervical spine while minimizing radiation owing to the low rate of cervical spine injury in young patients [110]. Two major clinical decision rules, the National Emergency X-Radiography Utilization Study (NEXUS) criteria [111] and the Canadian C-Spine Rule [112], were demonstrated to have high negative predictive values (97% and 100%, respectively) to rule out cervical spine injury in adults without the need for imaging. A pediatric validation study showed that no clinically important injuries were missed when the NEXUS clinical decision rule was used [113]. The [ACR Appropriateness Criteria® Suspected Spine Trauma – Child] [114] uses the Pediatric Emergency Care Applied Research Network study to identify risk factors associated with cervical spine injury in children 3 to 16 years old and the Pieretti-Vanmarcke score for patients <3 years old [115].

General radiography remains the first-line modality for the traumatized pediatric spine. CT imaging of the spine, especially the cervical spine, can be problematic in the infant because of epiphyseal variants, incomplete ossification of synchondroses, normal ligamentous laxity, and the propensity for ligamentous rather than bone injury. Anatomic and age-related variants may mimic injury and prompt additional, potentially unnecessary, imaging. Cervical spine injury in young children most commonly occurs from the occiput through C3 and typically involves the ligaments to a greater extent than osseous structures. Although CT with multiplanar reconstruction improves the detection of fractures, CT is insensitive to ligamentous, capsular, and soft-tissue injury, and the potential risk from the radiation to the thyroid should be considered. Spinal cord injury may occur without radiographic abnormalities, and a normal CT may result in a false-negative diagnosis after accidental or nonaccidental trauma. MR is therefore the preferred modality in traumatized infants. In older children**,** generally 7 years and older, cervical spine injury has a similar distribution as in adults, and imaging workup strategies should be similar to those employed in adults [116-123].

MRI is a more suitable investigation when spinal injuries are suspected, providing better information on soft-tissue injuries as well as bone edema related to osseous injury. Although unstable cervical spine injuries are better detected with CT scans, it is unlikely that these will be missed in the initial radiographs, and most of these patients will be subjected to whole-body CT because of the severity of injury on presentation [124]. In children with clinically suspected spinal fracture in the absence of red flag signs/symptoms and with negative radiographs, further discussion between the emergency department, trauma, surgical spinal team (orthopedic or neurosurgery), and radiology department should consider alternative radiation-free assessment or investigations such as an MRI scan or clinical observation if appropriate to reduce the risk of CT-related radiation and its associated hazards [125,126].

The effective dose to children from CT of the spine varies significantly depending on age and protocol. One study recorded pediatric variations from 0.6 to 42 mSv [127]. Pediatric CT spine imaging should therefore be limited to regions of radiographic and/or clinical concern and acquired using the lowest possible radiation exposure. A number of public resources are available to medical personnel that stress the importance of dose reduction in children. They include Image Gently (www.imagegently.org), *Radiation Risks and Pediatric Computed Tomography: A Guide for Health Care Providers* (https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/pediatric-ct-scans), and the FDA Public Health Notification, *Reducing Radiation Risk from Computed Tomography for Pediatric and Small Adult Patients* (http://www.fda.gov/MedicalDevices/Safety/AlertsandNotices/PublicHealthNotifications/ucm062185.htm).

E. Contrast Studies

Certain clinical indications require the use of intravenous, intrathecal, epidural, perineural, or intra-articular contrast agents. Intravenous contrast administration should be performed using appropriate injection protocols and in accordance with the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [128]. Intrathecal contrast administration should be performed in accordance with parameters outlined in the ACR–ASNR–SPR Practice Parameter for the Performance of Myelography and Cisternography [22] and the ACR Manual on Contrast Media [129].

F. Advanced Applications

In addition to directly acquired axial images, 2-D reformatted images in any plane, 3-D reformatted images as appropriate, and/or other more complex planes may be constructed from the axial data set to address specific clinical questions, or the images may be manipulated in order to allow selective visualization of specific tissues. Such applications are optimally performed with the original data sets as acquired on a multidetector CT scanner.

SPECT of the spine may be used as a complementary modality to allow more specific anatomic localization of subtle, nonspecific abnormalities on bone scans, such as pars interarticularis fractures [130], facet joint arthritis, or endplate osteophyte formation [131,132]. It can help distinguish compression fractures from severe degenerative disease. Localizing activity in patients who have had spinal fusion can provide insight into the causes of operative failures [61,62,133]. Functional information from SPECT/CT can guide treatment, such as facet joint injection [134,135] or arthrodesis. Gallium SPECT/CT may be helpful in detection of the site of spinal infections [131].

The applications for dual-energy CT in neuroradiology are expanding. Dual-energy CT offers tissue differentiation and characterization, reduction of artifacts, and remodeling of contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR). Monoenergetic reconstructions can be used in patients with or without metal implants in the brain and spine to reduce artifacts, improve CNR and SNR, or to improve iodine conspicuity [136-138].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [139].

VI. EQUIPMENT SPECIFICATIONS

A. Equipment

Patient monitoring equipment and facilities for cardiopulmonary resuscitation, including vital signs monitoring, support equipment, and an emergency crash cart, should be immediately available. Radiologists, technologists, and staff members should be able to assist with procedures, patient monitoring, and patient support. A written policy should be in place for dealing with emergency situations such as cardiopulmonary arrest.

For diagnostic-quality spine CT, the scanner should meet or exceed the following specifications [140-142]:

1. Type of scanner: multiple detector row, helical capability
2. Gantry rotation period: 1 second or less
3. Tube heat capacity to allow for study completion
4. Acquisition slice thickness: <1 mm
5. Reconstructed scan width: 1 to 5 mm
6. Beam pitch: no greater than 2:1 Spatial resolution: > 8 LP/cm for Display FOV 32 cm or greater and >10 LP/cm for Display FOV 24 cm or smaller
7. Dose reduction techniques, such as tube-current modulation, variable tube potential, and advanced reconstruction (eg, iterative), should be used to reduce exposure to patients.
8. Radiation monitoring techniques and the equipment to track radiation exposure

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be monitored for inventory and drug expiration dates on a regular basis. The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [143].

B. Quality Control

A comprehensive CT quality control program should be documented and maintained at the facility. The program should help to minimize radiation risk to the patient, facility personnel, and the public and to maximize the quality of the diagnostic information. CT facility personnel must adhere to radiation safety regulations when inside the scanner room. Overall program responsibility should remain with the physician, but specific program implementation should be supervised by the Qualified Medical Physicist in compliance with local and state regulations, as well as manufacturer specifications. A list of quality control tests, frequency of performance, and description of the procedure as well as a list of individuals or groups performing each should be maintained. Moreover, the parameters of technique, equipment testing, and acceptability of limits for each test should also be maintained in addition to sample records from each test. Quantitative dose determination should be conducted periodically by a Qualified Medical Physicist in addition to equipment performance monitoring, as per ACR recommendations.

The supervising physician should review all practices and policies at least annually. Policies with respect to contrast and sedation must be administered in accordance with institutional policy as well as state and federal regulations. A physician should be available on site whenever contrast and/or sedation is administered.

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, non-physician radiology providers**,** 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 who work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection, application of dose constraints and limits) and the principles of proper management of radiation dose to patients (justification, optimization including the use of dose reference levels). https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1775_web.pdf

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

Facilities should have and adhere to policies and procedures that require ionizing radiation examination protocols (radiography, fluoroscopy, interventional radiology, CT) to vary according to diagnostic requirements and patient body habitus to optimize the relationship between appropriate radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used, except when inappropriate for a specific exam. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available from the following websites – Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org). 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 periodically measured by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Monitoring or regular review of dose indices from patient imaging should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry and relevant publications relying on its data, applicable ACR Practice Parameters, 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; 2006, 2009, amended 2013, revised 2023 (Res. 2d).

Decisions regarding the use of CT should take into account the potential adverse effects of ionizing radiation exposure, especially in the pediatric population. Accordingly, the use of other imaging techniques that do not rely on ionizing radiation should be considered where appropriate.

Facilities should have specifically designated size-appropriate protocols distinct from adult protocols for performing CT in pediatric patients.

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 Quality Control & Improvement, Safety, Infection Control, and Patient Education* on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

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 (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Practice Parameters – Neuroradiology of the ACR Commission on Neuroradiology and the Committee on Practice Parameters – Pediatric Radiology of the ACR Commission on Pediatric Radiology in collaboration with the ASNR, ASSR, and the SPR.

Writing Committee – members represent their societies in the initial and final revision of this practice parameter

ACR
Lubdha M. Shah, MD, Chair
Kristine A. Blackham, MD
Lauren P. Golding, MD

ASNR
Kavita K. Erickson, MD
David A. Joyner, MD

ASSR
Vikas Agarwal, MD
Adam E. Flanders, MD
Allison M. Grayev, MD
Troy A. Hutchins, MD
Vinil N. Shah, MD

SPR
Mariaem Andres, MD
Nicholas V. Stence, MD

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

Steven W. Hetts, MD, Chair
Lubdha M. Shah, MD, Vice Chair
Ashley H. Aiken, MD
Sameer A. Ansari, MD, PhD
Kristine A. Blackham, MD
Gloria C Chiang, MD
Gerald Drocton, MD
Kavita K. Erickson, MD
Adam E. Flanders, MD
Masis Isikbay, MD, BS
Raymond K. Tu, MD, FACR
Max Wintermark, MD

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

Terry L. Levin, MD, FACR, Chair
John B. Amodio, MD, FACR
Jesse Berman, MD
Tara M. Catanzano, MB, BCh
Harris L. Cohen, MD, FACR
Kassa Darge, MD, PhD
Dorothy L. Gilbertson-Dahdal, MD
Lauren P. Golding, MD
Adam Goldman-Yassen, MD
Safwan S. Halabi, MD
Jane Sun Kim, MD
Jennifer A Knight, MD
Jessica Kurian, MD
Helen R. Nadel, MD
Erica Poletto, MD
Richard B. Towbin, MD, FACR
Andrew T. Trout, MD
Esben S. Vogelius, MD
Jason Wright, MD

John E. Jordan, MD, MPP, FACR, Chair, Commission on Neuroradiology
Richard A. Barth, MD, FACR, Chair, Commission on Pediatric Radiology
David B. Larson, MD, MBA, Chair, Commission on Quality and Safety
Mary S. Newell, MD, FACR, Chair, Committee on Practice Parameters and Technical Standards

Comments Reconciliation Committee
Daniel G. Gridley, MD, Chair
Gaurang V. Shah, MD, FACR, Co-Chair
Vikas Agarwal, MD
Mariaem Andres, MD
Richard A. Barth, MD, FACR
Nicholas M. Beckmann, MD
Mark P. Bernstein, MD
Kristine A. Blackham, MD
Timothy A. Crummy, MD, FACR
Kavita K. Erickson, MD
Adam E. Flanders, MD
Lauren P. Golding, MD
Allison M. Grayev, MD
Steven W. Hetts, MD
Troy A. Hutchins, MD
John E. Jordan, MD, MPP, FACR
David A. Joyner, MD
Jane S. Kim, MD
Amy L. Kotsenas, MD, FACR
David B. Larson, MD, MBA
Paul A. Larson, MD, FACR
Terry L. Levin, MD, FACR
Neel Madan, MD
Douglas N. Mintz, MD, FACR
Mary S. Newell, MD, FACR
Lorenz T. Ramseyer, MD, FACR
William F. Sensakovic, PhD
Lubdha M. Shah, MD
Vinil N. Shah, MD
Nicholas V. Stence, MD
Roland Wong, ScM

REFERENCES

1. Bernstein MP, Young MG, Baxter AB. Imaging of Spine Trauma. Radiol Clin North Am 2019;57:767-85.
2. Izzo R, Popolizio T, Balzano RF, Pennelli AM, Simeone A, Muto M. Imaging of cervical spine traumas. Eur J Radiol 2019;117:75-88.
3. VandenBerg J, Cullison K, Fowler SA, Parsons MS, McAndrew CM, Carpenter CR. Blunt Thoracolumbar-Spine Trauma Evaluation in the Emergency Department: A Meta-Analysis of Diagnostic Accuracy for History, Physical Examination, and Imaging. J Emerg Med 2019;56:153-65.
4. Atlas SW, Regenbogen V, Rogers LF, Kim KS. The radiographic characterization of burst fractures of the spine. AJR Am J Roentgenol 1986;147:575-82.
5. Barba CA, Taggert J, Morgan AS, et al. A new cervical spine clearance protocol using computed tomography. J Trauma 2001;51:652-6; discussion 56-7.
6. Blackmore CC, Mann FA, Wilson AJ. Helical CT in the primary trauma evaluation of the cervical spine: an evidence-based approach. Skeletal Radiol 2000;29:632-9.
7. Blackmore CC, Ramsey SD, Mann FA, Deyo RA. Cervical spine screening with CT in trauma patients: a cost-effectiveness analysis. Radiology 1999;212:117-25.
8. Cornelius RS, Leach JL. Imaging evaluation of cervical spine trauma. Neuroimaging Clin N Am 1995;5:451-63.

9. Cowan IA, Inglis GS. Atlanto-axial rotatory fixation: improved demonstration using spiral CT. Australas Radiol 1996;40:119-24.
10. Dreizin D, Letzing M, Sliker CW, et al. Multidetector CT of blunt cervical spine trauma in adults. Radiographics 2014;34:1842-65.
11. Genant HK, Cann CE, Ettinger B, et al. Quantitative computed tomography for spinal mineral assessment: current status. J Comput Assist Tomogr 1985;9:602-4.
12. Kudo K, Terae S, Asano T, et al. Anterior spinal artery and artery of Adamkiewicz detected by using multi-detector row CT. AJNR Am J Neuroradiol 2003;24:13-7.
13. McAfee PC, Yuan HA, Fredrickson BE, Lubicky JP. The value of computed tomography in thoracolumbar fractures. An analysis of one hundred consecutive cases and a new classification. J Bone Joint Surg Am 1983;65:461-73.
14. Obenauer S, Alamo L, Herold T, Funke M, Kopka L, Grabbe E. Imaging skeletal anatomy of injured cervical spine specimens: comparison of single-slice vs multi-slice helical CT. Eur Radiol 2002;12:2107-11.
15. Rivas LA, Fishman JE, Munera F, Bajayo DE. Multislice CT in thoracic trauma. Radiol Clin North Am 2003;41:599-616.
16. Takase K, Sawamura Y, Igarashi K, et al. Demonstration of the artery of Adamkiewicz at multi- detector row helical CT. Radiology 2002;223:39-45.
17. Wintermark M, Mouhsine E, Theumann N, et al. Thoracolumbar spine fractures in patients who have sustained severe trauma: depiction with multi-detector row CT. Radiology 2003;227:681-9.
18. Schwaiger BJ, Gersing AS, Hammel J, et al. Three-material decomposition with dual-layer spectral CT compared to MRI for the detection of bone marrow edema in patients with acute vertebral fractures. Skeletal Radiol 2018;47:1533-40.
19. McAllister AS, Nagaraj U, Radhakrishnan R. Emergent Imaging of Pediatric Cervical Spine Trauma. Radiographics 2019;39:1126-42.
20. Sun R, Skeete D, Wetjen K, et al. A pediatric cervical spine clearance protocol to reduce radiation exposure in children. J Surg Res 2013;183:341-6.
21. Song KJ, Choi BW, Kim GH, Kim JR. Clinical usefulness of CT-myelogram comparing with the MRI in degenerative cervical spinal disorders: is CTM still useful for primary diagnostic tool? J Spinal Disord Tech 2009;22:353-7.
22. American College of Radiology. ACR–ASNR–SPR practice parameter for the performance of myelography and cisternography. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Myelog-Cisternog.pdf. Accessed November 25, 2020.
23. Moshrif A, Laredo JD, Bassiouni H, et al. Spinal involvement with calcium pyrophosphate deposition disease in an academic rheumatology center: A series of 37 patients. Semin Arthritis Rheum 2019;48:1113-26.
24. Ward MM, Tan S. Better Quantification of Syndesmophyte Growth in Axial Spondyloarthritis. Curr Rheumatol Rep 2018;20:46.
25. Tan S, Yao L, Ward MM. Thoracic Syndesmophytes Commonly Occur in the Absence of Lumbar Syndesmophytes in Ankylosing Spondylitis: A Computed Tomography Study. J Rheumatol 2017;44:1828-32.
26. Sloan VS, Grosskleg S, Pohl C, Wells GA, Singh JA. The OMERACT First-time Participant Program: Fresh Eye from the New Guys. J Rheumatol 2017;44:1560-63.
27. Chan FL, Ho EK, Chau EM. Spinal pseudarthrosis complicating ankylosing spondylitis: comparison of CT and conventional tomography. AJR Am J Roentgenol 1988;150:611-4.
28. Liu GP, Qian BP, Qiu Y, Huang JC, Qiao M, Wang B. Is Any Correlation Present Between the Severity of Syndesmophytes and Spinopelvic and Clinical Parameters in Advanced Ankylosing Spondylitis? World Neurosurg 2020;137:e618-e25.
29. Burns JE, Yao J, Summers RM. Vertebral Body Compression Fractures and Bone Density: Automated Detection and Classification on CT Images. Radiology 2017;284:788-97.
30. Hendrickson NR, Pickhardt PJ, Del Rio AM, Rosas HG, Anderson PA. Bone Mineral Density T-Scores Derived from CT Attenuation Numbers (Hounsfield Units): Clinical Utility and Correlation with Dual-energy X-ray Absorptiometry. Iowa Orthop J 2018;38:25-31.
31. Roski F, Hammel J, Mei K, et al. Bone mineral density measurements derived from dual-layer spectral CT enable opportunistic screening for osteoporosis. Eur Radiol 2019;29:6355-63.

32. Salzmann SN, Shirahata T, Yang J, et al. Regional bone mineral density differences measured by quantitative computed tomography: does the standard clinically used L1-L2 average correlate with the entire lumbosacral spine? Spine J 2019;19:695-702.
33. Schwaiger BJ, Gersing AS, Baum T, Noel PB, Zimmer C, Bauer JS. Bone mineral density values derived from routine lumbar spine multidetector row CT predict osteoporotic vertebral fractures and screw loosening. AJNR Am J Neuroradiol 2014;35:1628-33.
34. Van Hedent S, Su KH, Jordan DW, et al. Improving Bone Mineral Density Assessment Using Spectral Detector CT. J Clin Densitom 2019;22:374-81.
35. Alacreu E, Moratal D, Arana E. Opportunistic screening for osteoporosis by routine CT in Southern Europe. Osteoporos Int 2017;28:983-90.
36. Li YL, Wong KH, Law MW, et al. Opportunistic screening for osteoporosis in abdominal computed tomography for Chinese population. Arch Osteoporos 2018;13:76.
37. Michalski AS, Besler BA, Michalak GJ, Boyd SK. CT-based internal density calibration for opportunistic skeletal assessment using abdominal CT scans. Med Eng Phys 2020;78:55-63.
38. Taki M, Miura T, Inagaki M, et al. Influence of granulocyte elastase-like proteinase (ELP) on platelet functions. Thromb Res 1986;41:837-46.
39. Patel ND, Ward RD, Calle J, Remer EM, Monga M. CT-Based Diagnosis of Low Vertebral Bone Mineral Density Is Associated with Hypercalciuria and Hypocitraturia on Opportunistic Imaging. J Endourol 2018;32:878-83.
40. Perrier-Cornet J, Omorou AY, Fauny M, Loeuille D, Chary-Valckenaere I. Opportunistic screening for osteoporosis using thoraco-abdomino-pelvic CT-scan assessing the vertebral density in rheumatoid arthritis patients. Osteoporos Int 2019;30:1215-22.
41. Zou D, Li W, Deng C, Du G, Xu N. The use of CT Hounsfield unit values to identify the undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases. Eur Spine J 2019;28:1758-66.
42. Berger-Groch J, Thiesen DM, Ntalos D, et al. Determination of bone density in patients with sacral fractures via CT scan. Orthop Traumatol Surg Res 2018;104:1037-41.
43. Schonenberg D, Guggenberger R, Frey D, Pape HC, Simmen HP, Osterhoff G. CT-based evaluation of volumetric bone density in fragility fractures of the pelvis-a matched case-control analysis. Osteoporos Int 2018;29:459-65.
44. Yasaka K, Akai H, Kunimatsu A, Kiryu S, Abe O. Prediction of bone mineral density from computed tomography: application of deep learning with a convolutional neural network. Eur Radiol 2020;30:3549-57.
45. Schreiber JJ, Hughes AP, Taher F, Girardi FP. An association can be found between hounsfield units and success of lumbar spine fusion. HSS J 2014;10:25-9.
46. Kohan EM, Nemani VM, Hershman S, Kang DG, Kelly MP. Lumbar computed tomography scans are not appropriate surrogates for bone mineral density scans in primary adult spinal deformity. Neurosurg Focus 2017;43:E4.
47. Laugerette A, Schwaiger BJ, Brown K, et al. DXA-equivalent quantification of bone mineral density using dual-layer spectral CT scout scans. Eur Radiol 2019;29:4624-34.
48. Huang K, Feng Y, Liu D, Liang W, Li L. Quantification evaluation of (99m)Tc-MDP concentration in the lumbar spine with SPECT/CT: compare with bone mineral density. Ann Nucl Med 2020;34:136-43.
49. Engelke K. Quantitative Computed Tomography-Current Status and New Developments. J Clin Densitom 2017;20:309-21.
50. Loffler MT, Sollmann N, Mei K, et al. X-ray-based quantitative osteoporosis imaging at the spine. Osteoporos Int 2020;31:233-50.
51. Mao SS, Li D, Syed YS, et al. Thoracic Quantitative Computed Tomography (QCT) Can Sensitively Monitor Bone Mineral Metabolism: Comparison of Thoracic QCT vs Lumbar QCT and Dual-energy X-ray Absorptiometry in Detection of Age-relative Change in Bone Mineral Density. Acad Radiol 2017;24:1582-87.
52. Paggiosi MA, Debono M, Walsh JS, Peel NFA, Eastell R. Quantitative computed tomography discriminates between postmenopausal women with low spine bone mineral density with vertebral fractures and those with low spine bone mineral density only: the SHATTER study. Osteoporos Int 2020;31:667-75.
53. Johnson BA, Tanenbaum LN. Contemporary spinal CT applications. Neuroimaging Clin N Am 1998;8:559-75.
54. Tatsuno S, Fukuda K. [Helical CT for lumbosacral spinal]. Nippon Igaku Hoshasen Gakkai Zasshi

1996;56:822-7.
55. Splendiani A, D'Orazio F, Patriarca L, et al. Imaging of post-operative spine in intervertebral disc pathology. Musculoskelet Surg 2017;101:75-84.
56. Mirza SK, Wiggins GC, Kuntz Ct, et al. Accuracy of thoracic vertebral body screw placement using standard fluoroscopy, fluoroscopic image guidance, and computed tomographic image guidance: a cadaver study. Spine (Phila Pa 1976) 2003;28:402-13.
57. Tsuchiya K, Katase S, Aoki C, Hachiya J. Application of multi-detector row helical scanning to postmyelographic CT. Eur Radiol 2003;13:1438-43.
58. Ghodasara N, Yi PH, Clark K, Fishman EK, Farshad M, Fritz J. Postoperative Spinal CT: What the Radiologist Needs to Know. Radiographics 2019;39:1840-61.
59. Ortiz AO, de Moura A, Johnson BA. Postsurgical Spine: Techniques, Expected Imaging Findings, and Complications. Semin Ultrasound CT MR 2018;39:630-50.
60. Okano I, Jones C, Salzmann SN, et al. Postoperative decrease of regional volumetric bone mineral density measured by quantitative computed tomography after lumbar fusion surgery in adjacent vertebrae. Osteoporos Int 2020;31:1163-71.
61. Al-Riyami K, Gnanasegaran G, Van den Wyngaert T, Bomanji J. Bone SPECT/CT in the postoperative spine: a focus on spinal fusion. Eur J Nucl Med Mol Imaging 2017;44:2094-104.
62. Gnanasegaran G, Paycha F, Strobel K, et al. Bone SPECT/CT in Postoperative Spine. Semin Nucl Med 2018;48:410-24.
63. Kato S, Demura S, Matsubara H, et al. Utility of bone SPECT/CT to identify the primary cause of pain in elderly patients with degenerative lumbar spine disease. J Orthop Surg Res 2019;14:185.
64. Smids C, Kouijzer IJ, Vos FJ, et al. A comparison of the diagnostic value of MRI and (18)F-FDG-PET/CT in suspected spondylodiscitis. Infection 2017;45:41-49.
65. Tender G, Constantinescu A, Conger A, DiGiorgio A. Primary pain generator identification by CT-SPECT in a patient with low back pain: a case report. BMC Res Notes 2017;10:132.
66. Tender GC, Davidson C, Shields J, et al. Primary pain generator identification by CT-SPECT in patients with degenerative spinal disease. Neurosurg Focus 2019;47:E18.
67. Brusko GD, Perez-Roman RJ, Tapamo H, Burks SS, Serafini AN, Wang MY. Preoperative SPECT imaging as a tool for surgical planning in patients with axial neck and back pain. Neurosurg Focus 2019;47:E19.
68. Wagner SC, Schweitzer ME, Morrison WB, Przybylski GJ, Parker L. Can imaging findings help differentiate spinal neuropathic arthropathy from disk space infection? Initial experience. Radiology 2000;214:693-9.
69. Foreman SC, Schwaiger BJ, Gempt J, et al. MR and CT Imaging to Optimize CT-Guided Biopsies in Suspected Spondylodiscitis. World Neurosurg 2017;99:726-34 e7.
70. Foreman SC, Schwaiger BJ, Meyer B, et al. Computed Tomography and Magnetic Resonance Imaging Parameters Associated with Poor Clinical Outcome in Spondylodiscitis. World Neurosurg 2017;104:919-26 e2.
71. Tamm AS, Abele JT. Bone and Gallium Single-Photon Emission Computed Tomography-Computed Tomography is Equivalent to Magnetic Resonance Imaging in the Diagnosis of Infectious Spondylodiscitis: A Retrospective Study. Can Assoc Radiol J 2017;68:41-46.
72. Chimelli L. Tumors and tumorlike lesions of the spine and spinal cord. Neuroimaging Clin N Am 2001;11:viii, 79-110.
73. Pinter NK, Pfiffner TJ, Mechtler LL. Neuroimaging of spine tumors. Handb Clin Neurol 2016;136:689-706.
74. De Iure F, Lofrese G, De Bonis P, Cultrera F, Cappuccio M, Battisti S. Vertebral body spread in thoracolumbar burst fractures can predict posterior construct failure. Spine J 2018;18:1005-13.
75. Kasalak O, Wouthuyzen-Bakker M, Adams HJA, et al. CT-guided biopsy in suspected spondylodiscitis: microbiological yield, impact on antimicrobial treatment, and relationship with outcome. Skeletal Radiol 2018;47:1383-91.
76. Sertic M, Parkes L, Mattiassi S, Pritzker K, Gardam M, Murphy K. The Efficacy of Computed Tomography-Guided Percutaneous Spine Biopsies in Determining a Causative Organism in Cases of Suspected Infection: A Systematic Review. Can Assoc Radiol J 2019;70:96-103.
77. Waschke A, Walter J, Duenisch P, Reichart R, Kalff R, Ewald C. CT-navigation versus fluoroscopy-guided placement of pedicle screws at the thoracolumbar spine: single center experience of 4,500 screws. Eur Spine J 2013;22:654-60.

78. Paulson EK, Sheafor DH, Enterline DS, McAdams HP, Yoshizumi TT. CT fluoroscopy--guided interventional procedures: techniques and radiation dose to radiologists. Radiology 2001;220:161-7.
79. Silbergleit R, Mehta BA, Sanders WP, Talati SJ. Imaging-guided injection techniques with fluoroscopy and CT for spinal pain management. Radiographics 2001;21:927-39; discussion 40-2.
80. Soh E, Karmakar MK. Assessment of the spine with CT and MRI prior to interspinous/interlaminar spinal procedures: a pictorial review. Br J Radiol 2013;86:20130066.
81. Yoshioka K, Tanaka R, Takagi H, et al. Ultra-high-resolution CT angiography of the artery of Adamkiewicz: a feasibility study. Neuroradiology 2018;60:109-15.
82. Knez D, Nahle IS, Vrtovec T, Parent S, Kadoury S. Computer-assisted pedicle screw trajectory planning using CT-inferred bone density: A demonstration against surgical outcomes. Med Phys 2019;46:3543-54.
83. Uehara M, Takahashi J, Ikegami S, et al. Optimal cervical screw insertion angle determined by means of computed tomography scans pre- and postoperatively. Spine J 2017;17:190-95.
84. Baky FJ, Milbrandt T, Echternacht S, Stans AA, Shaughnessy WJ, Larson AN. Intraoperative Computed Tomography-Guided Navigation for Pediatric Spine Patients Reduced Return to Operating Room for Screw Malposition Compared With Freehand/Fluoroscopic Techniques. Spine Deform 2019;7:577-81.
85. Carl B, Bopp M, Pojskic M, Voellger B, Nimsky C. Standard navigation versus intraoperative computed tomography navigation in upper cervical spine trauma. Int J Comput Assist Radiol Surg 2019;14:169-82.
86. Ouchida J, Kanemura T, Satake K, et al. True accuracy of percutaneous pedicle screw placement in thoracic and lumbar spinal fixation with a CT-based navigation system: Intraoperative and postoperative assessment of 763 percutaneous pedicle screws. J Clin Neurosci 2020;79:1-6.
87. Hayama S, Nakano A, Nakaya Y, et al. The Evaluation of Indirect Neural Decompression After Lateral Lumbar Interbody Fusion Using Intraoperative Computed Tomography Myelogram. World Neurosurg 2018;120:e710-e18.
88. Janssen I, Lang G, Navarro-Ramirez R, et al. Can Fan-Beam Interactive Computed Tomography Accurately Predict Indirect Decompression in Minimally Invasive Spine Surgery Fusion Procedures? World Neurosurg 2017;107:322-33.
89. Oyelese A, Telfeian AE, Gokaslan ZL, et al. Intraoperative Computed Tomography Navigational Assistance for Transforaminal Endoscopic Decompression of Heterotopic Foraminal Bone Formation After Oblique Lumbar Interbody Fusion. World Neurosurg 2018;115:29-34.
90. Konakondla S, Albers JA, Li X, et al. Maximizing Sacral Chordoma Resection by Precise 3-Dimensional Tumor Modeling in the Operating Room Using Intraoperative Computed Tomography Registration with Preoperative Magnetic Resonance Imaging Fusion and Intraoperative Neuronavigation: A Case Series. World Neurosurg 2019;125:e1125-e31.
91. Park C, Kouam RW, Foster NA, Abd-El-Barr MM, Goodwin CR, Karikari IO. "The eye sees only what the mind is prepared to comprehend": Unrecognized incidental findings on intraoperative computed tomography during spine instrumentation surgery. Clin Imaging 2021;72:64-69.
92. Carr RB, Fink KR, Gross JA. Imaging of trauma: Part 1, Pseudotrauma of the spine--osseous variants that may simulate injury. AJR Am J Roentgenol 2012;199:1200-6.
93. Pretorius ES, Fishman EK. Volume-rendered three-dimensional spiral CT: musculoskeletal applications. Radiographics 1999;19:1143-60.
94. Heiss JD, Jarvis K, Smith RK, et al. Origin of Syrinx Fluid in Syringomyelia: A Physiological Study. Neurosurgery 2019;84:457-68.
95. American College of Radiology. ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Pregnant-Pts.pdf. Accessed November 25, 2020.
96. American College of Radiology. ACR practice parameter for performing and interpreting diagnostic computed tomography (CT). Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CT-Perf-Interpret.pdf. Accessed November 25, 2020.
97. Axente M, Paidi A, Von Eyben R, et al. Clinical evaluation of the iterative metal artifact reduction algorithm for CT simulation in radiotherapy. Med Phys 2015;42:1170-83.
98. Huang JY, Kerns JR, Nute JL, et al. An evaluation of three commercially available metal artifact reduction methods for CT imaging. Phys Med Biol 2015;60:1047-67.
99. Morsbach F, Bickelhaupt S, Wanner GA, Krauss A, Schmidt B, Alkadhi H. Reduction of metal artifacts from hip prostheses on CT images of the pelvis: value of iterative reconstructions. Radiology 2013;268:237-44.

100. Nakamoto A, Kim T, Hori M, et al. Clinical evaluation of image quality and radiation dose reduction in upper abdominal computed tomography using model-based iterative reconstruction; comparison with filtered back projection and adaptive statistical iterative reconstruction. Eur J Radiol 2015;84:1715-23.
101. Zhu Z, Zhao XM, Zhao YF, Wang XY, Zhou CW. Feasibility Study of Using Gemstone Spectral Imaging (GSI) and Adaptive Statistical Iterative Reconstruction (ASIR) for Reducing Radiation and Iodine Contrast Dose in Abdominal CT Patients with High BMI Values. PLoS One 2015;10:e0129201.
102. Boas FE, Fleischmann D. Evaluation of two iterative techniques for reducing metal artifacts in computed tomography. Radiology 2011;259:894-902.
103. Feldhaus FW, Boning G, Kahn J, et al. Improvement of image quality and diagnostic confidence using Smart MAR - a projection-based CT protocol in patients with orthopedic metallic implants in hip, spine, and shoulder. Acta Radiol 2020;61:1421-30.
104. Lee MJ, Kim S, Lee SA, et al. Overcoming artifacts from metallic orthopedic implants at high-field-strength MR imaging and multi-detector CT. Radiographics 2007;27:791-803.
105. Subhas N, Polster JM, Obuchowski NA, et al. Imaging of Arthroplasties: Improved Image Quality and Lesion Detection With Iterative Metal Artifact Reduction, a New CT Metal Artifact Reduction Technique. AJR Am J Roentgenol 2016;207:378-85.
106. Komlosi P, Grady D, Smith JS, et al. Evaluation of monoenergetic imaging to reduce metallic instrumentation artifacts in computed tomography of the cervical spine. J Neurosurg Spine 2015;22:34-8.
107. McLellan AM, Daniel S, Corcuera-Solano I, Joshi V, Tanenbaum LN. Optimized imaging of the postoperative spine. Neuroimaging Clin N Am 2014;24:349-64.
108. Antevil JL, Sise MJ, Sack DI, Kidder B, Hopper A, Brown CV. Spiral computed tomography for the initial evaluation of spine trauma: A new standard of care? J Trauma 2006;61:382-7.
109. Imran JB, Madni TD, Pruitt JH, et al. Can CT imaging of the chest, abdomen, and pelvis identify all vertebral injuries of the thoracolumbar spine without dedicated reformatting? Am J Surg 2018;216:52-55.
110. Arbuthnot M, Mooney DP. The sensitivity and negative predictive value of a pediatric cervical spine clearance algorithm that minimizes computerized tomography. J Pediatr Surg 2017;52:130-35.
111. Hoffman JR, Schriger DL, Mower W, Luo JS, Zucker M. Low-risk criteria for cervical-spine radiography in blunt trauma: a prospective study. Ann Emerg Med 1992;21:1454-60.
112. Stiell IG, Clement CM, McKnight RD, et al. The Canadian C-spine rule versus the NEXUS low-risk criteria in patients with trauma. N Engl J Med 2003;349:2510-8.
113. Eltringham JR, Kaplan HS. Immunodeficiency in Hodgkin disease. Birth Defects Orig Artic Ser 1975;11:278-88.
114. American College of Radiology. ACR Appropriateness Criteria®: suspected spine trauma–child Available at: https://acsearch.acr.org/docs/3101274/Narrative/. Accessed July 20, 2021.
115. Leonard JC, Kuppermann N, Olsen C, et al. Factors associated with cervical spine injury in children after blunt trauma. Ann Emerg Med 2011;58:145-55.
116. Booth TN. Cervical spine evaluation in pediatric trauma. AJR Am J Roentgenol 2012;198:W417-25.
117. Brockmeyer DL, Ragel BT, Kestle JR. The pediatric cervical spine instability study. A pilot study assessing the prognostic value of four imaging modalities in clearing the cervical spine for children with severe traumatic injuries. Childs Nerv Syst 2012;28:699-705.
118. Cullen A, Terris M, Ford R. Spinal clearance in unconscious children following traumatic brain injury. Paediatr Anaesth 2014;24:711-6.
119. Egloff AM, Kadom N, Vezina G, Bulas D. Pediatric cervical spine trauma imaging: a practical approach. Pediatr Radiol 2009;39:447-56.
120. Gargas J, Yaszay B, Kruk P, Bastrom T, Shellington D, Khanna S. An analysis of cervical spine magnetic resonance imaging findings after normal computed tomographic imaging findings in pediatric trauma patients: ten-year experience of a level I pediatric trauma center. J Trauma Acute Care Surg 2013;74:1102-7.
121. Kadom N, Khademian Z, Vezina G, Shalaby-Rana E, Rice A, Hinds T. Usefulness of MRI detection of cervical spine and brain injuries in the evaluation of abusive head trauma. Pediatr Radiol 2014;44:839-48.
122. Mortazavi M, Gore PA, Chang S, Tubbs RS, Theodore N. Pediatric cervical spine injuries: a comprehensive review. Childs Nerv Syst 2011;27:705-17.
123. Murphy RF, Davidson AR, Kelly DM, Warner WC, Jr., Sawyer JR. Subaxial cervical spine injuries in children and adolescents. J Pediatr Orthop 2015;35:136-9.
124. Qualls D, Leonard JR, Keller M, Pineda J, Leonard JC. Utility of magnetic resonance imaging in diagnosing

cervical spine injury in children with severe traumatic brain injury. J Trauma Acute Care Surg 2015;78:1122-8.
125. Banerjee P, Thomas M. CT scans to exclude spine fractures in children after negative radiographs may lead to increase in future cancer risk. Eur J Orthop Surg Traumatol 2019;29:983-88.
126. Eren B, Karagoz Guzey F. Is spinal computed tomography necessary in pediatric trauma patients? Pediatr Int 2020;62:29-35.
127. Miglioretti DL, Johnson E, Williams A, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr 2013;167:700-7.
128. American College of Radiology. ACR–SPR practice parameter for the use of intravascular contrast media. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/IVCM.pdf. Accessed November 25, 2020.
129. American College of Radiology. ACR manual on contrast media. Available at: https://www.acr.org/Clinical-Resources/Contrast-Manual. Accessed July 20, 2021.
130. Leone A, Cianfoni A, Cerase A, Magarelli N, Bonomo L. Lumbar spondylolysis: a review. Skeletal Radiol 2011;40:683-700.
131. Scharf S. SPECT/CT imaging in general orthopedic practice. Semin Nucl Med 2009;39:293-307.
132. Scheyerer MJ, Pietsch C, Zimmermann SM, Osterhoff G, Simmen HP, Werner CM. SPECT/CT for imaging of the spine and pelvis in clinical routine: a physician's perspective of the adoption of SPECT/CT in a clinical setting with a focus on trauma surgery. Eur J Nucl Med Mol Imaging 2014;41 Suppl 1:S59-66.
133. Waldman LE, Scharf SC. Bone SPECT/CT of the Spine, Foot, and Ankle: Evaluation of Surgical Patients. Semin Nucl Med 2017;47:639-46.
134. Perolat R, Kastler A, Nicot B, et al. Facet joint syndrome: from diagnosis to interventional management. Insights Imaging 2018;9:773-89.
135. Yolcu YU, Lehman VT, Bhatti AUR, Goyal A, Alvi MA, Bydon M. Use of Hybrid Imaging Techniques in Diagnosis of Facet Joint Arthropathy: A Narrative Review of Three Modalities. World Neurosurg 2020;134:201-10.
136. Guggenberger R, Winklhofer S, Osterhoff G, et al. Metallic artefact reduction with monoenergetic dual-energy CT: systematic ex vivo evaluation of posterior spinal fusion implants from various vendors and different spine levels. Eur Radiol 2012;22:2357-64.
137. Srinivasan A, Hoeffner E, Ibrahim M, Shah GV, LaMarca F, Mukherji SK. Utility of dual-energy CT virtual keV monochromatic series for the assessment of spinal transpedicular hardware-bone interface. AJR Am J Roentgenol 2013;201:878-83.
138. Wang Y, Qian B, Li B, et al. Metal artifacts reduction using monochromatic images from spectral CT: evaluation of pedicle screws in patients with scoliosis. Eur J Radiol 2013;82:e360-6.
139. American College of Radiology. ACR practice parameter for communication of diagnostic imaging findings. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CommunicationDiag.pdf. Accessed November 25, 2020.
140. Geyer LL, Korner M, Hempel R, et al. Evaluation of a dedicated MDCT protocol using iterative image reconstruction after cervical spine trauma. Clin Radiol 2013;68:e391-6.
141. McCollough CH, Zink FE. Performance evaluation of a multi-slice CT system. Med Phys 1999;26:2223-30.
142. Rybicki F, Nawfel RD, Judy PF, et al. Skin and thyroid dosimetry in cervical spine screening: two methods for evaluation and a comparison between a helical CT and radiographic trauma series. AJR Am J Roentgenol 2002;179:933-7.
143. American College of Radiology. ACR–AAPM technical standard for diagnostic medical physics performance monitoring of computed tomography (CT) equipment. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CT-Equip.pdf. Accessed November 25, 2020.

*Practice parameters and technical standards are published annually with an effective date of October 1 in 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.

<u>Development Chronology for This Practice Parameter</u>
2006 (Resolution 11, 17, 35)
Amended 2009 (Resolution 11)
Revised 2011 (Resolution 34)
Amended 2014 (Resolution 39)
Revised 2016 (Resolution 15)
Revised 2022 (Resolution 23)
Amended 2023 (Resolution 2c, 2d)