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ACR–ASNR–SCBT-MR–SSR PRACTICE PARAMETER FOR THE PERFORMANCE OF MAGNETIC RESONANCE IMAGING (MRI) OF THE ADULT 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 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 revised collaboratively by the American College of Radiology (ACR), the American Society of Neuroradiology (ASNR), the Society of Computed Body Tomography and Magnetic Resonance (SCBT-MR), and the Society for Skeletal Radiology (SSR).

Magnetic resonance imaging (MRI) of the spine is a powerful tool for the evaluation, assessment of severity, and follow-up of diseases of the spine. Spine MRI should be performed only for a valid medical reason. While spinal MRI is one of the most sensitive diagnostic tests for detecting anatomic abnormalities of the spine and adjacent structures, findings may be misleading if not closely correlated with the clinical history, clinical examination, and physiologic tests. Adherence to the following practice parameter will enhance the probability of detecting such abnormalities.

Spine MRI has important attributes that make it valuable in assessing spinal disease. Other diagnostic imaging tests that can be used to evaluate the spine include radiography, computed tomography (CT), nuclear medicine examinations, myelography, and combined CT-myelography. Compared with these other modalities, MRI does not use ionizing radiation. This is particularly advantageous in the lumbar area, where gonadal exposure may occur, and in the cervical spine to avoid radiation to the thyroid. Myelography requires an invasive procedure to introduce intrathecal contrast agents. Both the puncture and the contrast agent can produce side effects and rarely significant adverse reactions. MRI allows direct visualization of the spinal cord, nerve roots, and discs, while their location and morphology can only be inferred on plain radiography and less completely evaluated on CT, myelography, or CT-myelography. Compared to CT, MRI provides better soft-tissue contrast and the ability to directly image in the sagittal and coronal planes. It is also the only modality for evaluating the internal structure of the cord. Another imaging test, ultrasound, that also uses no ionizing radiation, has limitations for evaluating spine pathology but can be used to evaluate soft tissues around the spine and the extraspinal nerves, such as in the brachial plexus.

Although more useful in most circumstances, MRI has not completely supplanted CT for spine imaging. For example, CT provides better visualization of cortical bone and calcifications than MRI, and some patients who have contraindications to MRI will require other tests, usually CT, for primary evaluation. While not a contraindication to spine MRI, metallic hardware in the area of scanning may in some cases limit the usefulness of MRI. In selected cases, more than one imaging modality will be needed for a complete evaluation.

II. INDICATIONS

This section includes most but not all of the reasons one might perform spine MRI. Disorders affecting the spine that may warrant MRI include, but are not limited to, the evaluation of:

1. Congenital spine and spinal cord malformations
2. Inflammatory/autoimmune disorders
    a. Demyelinating disease
        i. Multiple sclerosis
        ii. Acute disseminated encephalomyelitis
        iii. Acute inflammatory demyelinating polyradiculopathy (Guillian-Barre syndrome)
        iv. Chronic inflammatory demyelinating polyradiculopathy, aka chronic relapsing polyneuropathy
    b. Connective tissue disorders, eg, systemic lupus erythematosus
    c. Muscular dystrophies and myopathies
3. Infectious conditions
    a. Spinal infection, including disc space infection, vertebral osteomyelitis, epidural abscess, and surrounding soft-tissue infection, including postoperative infections
    b. Spinal cord infection, including abscess
4. Vascular disorders
    a. Spinal vascular malformations and/or the cause of occult subarachnoid hemorrhage
    b. Spinal cord infarction
    c. Extraspinal vascular malformations and neoplasms

5. Degenerative conditions
   a. Degenerative disc disease and its sequelae in the lumbar, thoracic, and cervical spine, including myelopathy
   b. Disc herniation and radiculopathy
   c. Neurodegenerative disorders, such as subacute combined degeneration, spinal muscular atrophy, amyotrophic lateral sclerosis
   d. Spinal Stenosis
6. Trauma
   Nature and extent of injury to spinal cord, vertebral column, ribs, and skull base; ligaments, thecal sac, and paraspinal soft tissues following trauma (CT is considered the Gold Standard primary tool for the initial evaluation of the traumatized spine, with MRI often performed to provide complementary data, particularly when the patients' clinical findings are discrepant with the initial CT findings.)
7. Neoplastic abnormalities
   a. Intramedullary masses
   b. Intradural extramedullary masses
   c. Intradural leptomeningeal disease
   d. Bone tumors
   e. Extradural soft-tissue neoplasms
   f. Treatment fields for radiation therapy
   g. Soft-tissue masses
   h. Tumors of nerves
   i. Tumors of muscle and connective tissues
8. Miscellaneous
   a. Syringohydromyelia (multiple etiologies, including Chiari malformations, trauma, etc)
   a. Postoperative fluid collections and soft-tissue changes (extradural and intradural)
   b. Epidural and subdural fluid collections
   c. Preprocedure assessment for vertebroplasty and kyphoplasty
   d. Amyloid deposition in the spine
   e. Cerebrospinal fluid (CSF) leak, intracranial hypotension
   f. Spinal cord herniation
   g. Symptoms that create the concern for the presence of any of the above disorders
   h. Follow up of findings seen on other imaging examinations

III. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI), the ACR Manual on Contrast Media, and the ACR Guidance Document on MR Safe Practices [1-3].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis.

IV. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [1].

V. APPLICATIONS OF MRI

A. Neoplasms

MRI is an excellent way of defining tumors of and around the spine. It defines anatomy and, because of its ability to differentiate tissue types, can be used to characterize tumors and suggest histologic diagnoses.

In evaluation of intraspinal soft-tissue tumors, MRI facilitates localizing disease into various compartments (intramedullary, intradural-extramedullary, and extradural), which is an important step in creating differential diagnoses of tumors. CT is also complimentary for evaluating bone in tumors with osseous involvement. MRI is

well suited for delineating an abnormal intraspinal lesion, assessing its extent within and outside the spinal canal, and evaluating involvement of the spinal cord and spinal nerves. The administration of intravenous (IV) gadolinium-based paramagnetic contrast agents further improves sensitivity for most lesion detection and characterization.

In addition to spinal soft-tissue tumor evaluation, MRI provides an accurate assessment of osseous neoplasms involving the vertebral column, both primary and metastatic. It helps not only demonstrate the presence and extent of bony involvement but also shows the presence and location of epidural and paravertebral extension and the degree of spinal cord and neural foraminal compression. Overall, MRI appears to be more sensitive than bone scintigraphy using single-photon emission computed tomography (SPECT) for detecting metastatic disease [4-6] but may not be as sensitive for detecting small metastases in the posterior elements [7]. MRI is also more sensitive and specific than 18F-FDG-PET (but slightly less sensitive and specific than 18F-NaF PET/CT) for detecting bone marrow metastases and infiltration of the spine and has a great impact in staging cancer patients [8,9].

B. Infection

In a patient with suspected spinal infection, MRI demonstrates high sensitivity and specificity compared to radiographs and bone scans [10-12]. It can localize the site(s) of infection (eg, within the disc space, vertebral bodies, or both), assess the extent of epidural and paravertebral involvement, and determine presence of a frank abscess [10,13], and, given the ability to perform large field-of-view (FOV) series of the remaining portion of the spinal column, it is ideally suited to identify or exclude additional, potentially clinically occult sites of infection. IV administration of gadolinium-based contrast agents increases the sensitivity, conspicuity, and observer confidence in the diagnosis, especially in early stages, and is considered mandatory for distinguishing abscess from phlegmon [10,12].

MRI can also diagnose and characterize the presence of infections in other spinal regions, such as the facet joints, meninges, and spinal cord. MRI is useful to characterize postoperative changes, including fluid collections and bone and soft-tissue abnormalities that may suggest infection.

C. Spinal Cord Herniation

Spinal cord herniation is a rare cause of myelopathy that has been increasingly recognized. While it is rare, it can be diagnosed preoperatively on MRI with resolution of symptoms after surgery, thereby making it essential to be aware of the imaging findings of this condition [14-17]. MRI helps demonstrate the location of the cord herniation through the dural defect, to assess the degree of herniation and determine if there are any cord signal changes, all of which impact patient management and prognosis [14-17]. The MRI appearance may not be pathognomonic for a spinal cord herniation as it may be difficult to distinguish from an arachnoid web or arachnoid cyst.

D. Degenerative Disc Disease

MRI provides a precise representation of the anatomy and the degenerative conditions of the disc, spinal canal, discovertebral complex, and facet joints that will promote accurate diagnosis of degenerative disc disease and influence therapeutic decision making [18]. It is well established as the modality of choice for evaluating degenerative disease of the spine, although in selected patients CT +/- myelography may provide complementary and alternative information for assessing the lumbar and cervical spine [19].

E. Spinal Stenosis

The anatomic assessment provided by MRI allows accurate evaluation of both acquired and developmental spinal stenosis. MRI can assess the morphology of the spinal canal and the intervertebral foramina and can characterize the presence [20,21] as well as type of stenosis [20]. It may also be useful in identifying other causes of spinal stenosis, such as epidural lipomatosis [22].

F. Intramedullary Disease

MR imaging, without and/or with IV contrast, is the optimal imaging test to demonstrate the presence and extent of a range of spinal cord disease processes, eg, demyelinating, neoplastic, degenerative, inflammatory, metabolic, traumatic, ischemic, vascular, congenital, etc.

G. Trauma [3,23-32]

MR imaging is a valuable tool for assessing patients with known vertebral injury. In addition to assessing the fractures and their extent and acuity, it can aid in evaluating the integrity of ligaments, which are critical to spinal stability. It also contributes to imaging the spinal cord for transection, contusion, edema, and hematoma. Cord compression by bone fragments, disc herniation, and epidural or subdural hematomas can also be demonstrated. Serial examination of patients with hemorrhagic contusion within the cord can reveal the onset of posttraumatic progressive myelopathy. MR imaging is also useful in patients with equivocal findings on CT examinations by searching for evidence of occult injury (edema, ligament injury). In instances of cervical trauma, MR imaging and MR angiography (MRA) can provide information about the vertebral and carotid arteries.

H. Changes from radiation therapy to the Spine

Radiation therapy has been a mainstay of treatment of neoplastic diseases. Unfortunately, radiation therapy that includes the spine can also result in unintended iatrogenic complications. These complications can occur to both the vertebral column and the underlying spinal cord.

In the vertebral column, the most benign changes are well seen by MRI and initially consist of marrow edema, followed by fatty replacement of the marrow. These changes can occur as soon as a few weeks after the cessation of radiation therapy. More serious complications include radiation osteonecrosis [33,34]. Radiation osteonecrosis is most common after treatment for head and neck tumors, although it can be seen following radiation therapy for other neoplasms (such as in the pelvis). Typically, radiation osteonecrosis results in degeneration and collapse of the involved vertebral body. Superimposed osteomyelitis may complicate the clinical scenario. MRI is superb in localizing the involved bones and can suggest a diagnosis, although a history of radiation is a sine qua non.

Radiation therapy can also induce complications of radiation myelopathy [35-44]. Acute radiation myelopathy does not produce MR findings. Later stages of radiation myelopathy typically result in mass effect, swelling, and solid or rim enhancement, followed by atrophy [45]. MRI is particularly suited in making the diagnosis of radiation myelopathy because of its ability to portray the underlying cord lesion, with characteristic ring enhancement associated with radiation changes in the spinal column, ranging from fatty infiltration to radiation-induced bone infarcts and necrosis.

Radiation therapy can lead to the development of treatment-related tumors several years to several decades later [46]. These include bony neoplasms of the vertebral column, intradural extramedullary tumors, such as meningiomas, and gliomas of the cord. Again, MRI can portray the association of the neoplasm with the classic changes of prior radiation in the vertebral column.

I. Vascular Lesions of the Spine

Multiple vascular lesions can affect the spine. There are two general categories, spinal cord ischemia and vascular malformations. MRI is the most sensitive method of verifying the presence of abnormalities of the cord that may represent ischemia and infarction [47-49]. As in the brain, diffusion-weighted imaging (DWI) is particularly sensitive and diagnostic in the appropriate clinical settings. Conventional MRI, however, can also demonstrate classic findings of cord infarction, with abnormal T2 signal acutely involving the anterior half to two thirds of the cord or being centered primarily in the grey matter. Because of the small size of the multiple collaterals that feed the cord, MR angiography is generally not as useful in this clinical setting.

Vascular malformations include arteriovenous fistulas, including dural arteriovenous fistulas (dAVF), arteriovenous malformations (AVMs) and cavernous hemangiomas [50-54]. MR imaging is the most successful

noninvasive method of assessing the spine for vascular malformations. Multiple findings can be seen, including a characteristic intramedullary lesion in cavernous hemangioma, a nidus of serpentine signal voids in AVMs, or posteriorly draining enlarged veins in dAVFs. In addition, MR imaging is also sensitive to secondary changes in the cord, such as edema from venous congestion. MRA, generally with contrast administration and particularly helpful if time resolved, helps to detect and characterize these lesions [55]. It is helpful in depicting the presence of an arteriovenous shunt and can be useful in guiding subsequent spinal angiography.

Occult vascular malformations, as in the brain, generally appear as focal lesions containing byproducts of hemoglobin degradation [51]. In the majority of cases, virtually no surrounding edema is present, unless there has been recent bleeding. Using sequences sensitive to local variations in magnetic susceptibility, MR is the most sensitive technique available for detecting suspected cavernous hemangiomas. In addition, the absence of surrounding cord swelling and edema are also well depicted on MR imaging, allowing differentiation from neoplasms.

J. Congenital Lesions

Congenital abnormalities of the spine and spinal cord can be detected in screening tests of scoliosis, in patients with clinical suspicion or incidentally. MRI of the entire spine can be used as a screening test for anomalies.

Coil selection and field of view will depend on patient size and the region imaged. A spine coil should be considered while larger patients may be imaged with a cardiac, torso, spine, or body coil. Commercially available combined coil arrays may also be suitable.

Imaging sequences should include T1- and T2-weighted sequences, preferably in two planes with slice thickness dependent on the area to be imaged (usually 3 to 5 mm).

In case of spinal curvature (scoliosis), sagittal and cross-sectional imaging in the plane of the spine, may require multiple acquisitions or reformatted images with compound and/or complex angles to cover the areas of concern. Coronal large FOV series, especially T2, are specifically useful in characterizing and fully displaying spinal curvature, as well as assessing for vertebral anomalies.

K. Demyelinating Diseases

MR imaging, without and with IV contrast, is the examination of choice for the imaging diagnosis and follow up of demyelinating processes affecting the spinal cord. MR is the best available imaging technique for identifying the extent of disease. Lesion burden does not correlate well with clinical status in patients with multiple sclerosis [56]. Advanced imaging techniques, such as diffusion tensor imaging and spectroscopy, may be valuable adjuncts [57,58]. Brain imaging is typically performed if a spinal cord abnormality suggests a demyelinating disease.

Application of this practice parameter should be in accordance with the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) and the ACR–SIR Practice Parameter for Sedation/Analgesia [1,59].

VI. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have complete understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures. The physician must be familiar with potential hazards associated with MRI; including potential adverse reactions to contrast media (potential hazards might include spinal hardware if recently implanted, especially in the case of neoplasia or significant trauma). The physician should be familiar with relevant ancillary studies that the patient may have undergone. The physician performing MRI interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI examination.

The written or electronic request for MRI of the adult 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)

The supervising physician must also understand the imaging parameters, including pulse sequences and field of view, and their effect on the appearance of the images, including the potential generation of image artifacts. Standard imaging protocols may be established and optimized on a case-by-case basis when necessary. These protocols should be reviewed and updated periodically.

A. Patient Selection

The physician responsible for the examination should supervise patient selection and preparation and be available in person or by phone for consultation. Patients must be screened and interviewed prior to the examination to exclude individuals who may be at risk by exposure to the MR environment.

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 [60].)

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [59].

B. Facility Requirements

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.

C. Examination Technique

1. General principles
   MRI should depict structures as clearly as possible. Standard protocols should be created and implemented that are appropriate for most patients suspected of having spinal pathology. The precise details of that performance may vary among equipment (magnets, coils, and software), patient body habitus, and the personal preferences of the radiologists who manage and interpret the studies. Generally, images should cover the relevant anatomy/pathology.

   The MR signal that is produced from a region of the spine (cervical, thoracic, and lumbosacral) in response to a particular pulse sequence is often, but not always, detected using surface coil receivers, commonly in a phased array configuration.

   Contrast
   In addition to images with contrast based on intrinsic MR properties of the spinal and paraspinal tissues, some images may be acquired after the IV administration of a paramagnetic MR contrast agent (eg, a chelate of gadolinium). This agent is used to detect regions where the normal vascular circulation has

been altered by injury or disease. For example, the use of IV paramagnetic contrast is recommended for distinguishing disc material from scar tissue in patients who have undergone prior spinal surgery.

Artifacts

Imaging sequences should minimize artifacts as much as possible.

Physicians and technologists who determine the pulse sequences to be used and interpret spine MR examinations must understand the artifacts associated with and the limitations of the various imaging pulse sequences. They must use techniques to minimize inherent artifacts (such as pulsation artifact) when it is likely to obscure pathology. Some of the techniques that are used to move/reduce artifacts include changing phase and frequency directions (to move pulsation artifact), increase resolution (to reduce frequency misregistration), apply saturation bands, flow sensitization (for CSF or blood), alterations in patient/coil position to improve comfort, respiratory compensation.

Saturation bands, or spatial saturation zones, can be applied outside of the spinal region of interest. They suppress signal from these regions so that motion outside the intended field of view (eg, breathing, blood flow, bowel motion) produces less conspicuous artifact in the areas of clinical interest.

Physiologic motion suppression techniques and software may help reduce artifacts from patient motion.

When dealing with imaging around metal, such as fixation devices, short tau inversion recovery (STIR) for fat suppression, high-receiver bandwidth, fat-water separation, or multispectral methods for metal artifact, suppression may be helpful to reduce artifacts. Specialized metal reduction sequences are available, depending upon software and hardware being used.

2. Pulse sequences

The choice of MR pulse sequences is generally standardized for particular studies but can be guided by the clinical history and physical examination (see section III, Indications). Commonly used sequences in MR imaging of the spine include: T1; intermediate TE, proton density, or FLAIR; T2-weighted sequences; T2*; and various fat-suppression techniques. These techniques can be employed as 2-D or 3-D acquisitions. Vascular techniques can be used for angiography. The types of fat suppression include frequency select fat saturation, STIR, and chemical shift techniques (Dixon). Although these techniques are not all T2-weighted, they can substitute for the T2-weighted sequences noted below.

For the purpose of comparison or subtraction, images with fat suppression are sometimes acquired both before and after administration of the contrast agent.

T2* or gradient-echo images have a good signal and contrast and are sensitive to local magnetic field heterogeneity (eg, greater signal loss at interfaces between bone and CSF or between bone and soft tissue) and are less sensitive to CSF flow–induced artifacts (eg, signal voids due to brisk or pulsatile CSF flow).

Because of anatomical and physiological differences in three major spinal regions, radiologists may prefer to use different sequences in different regions. In the cervical and thoracic spine, CSF flow rate is greater than in the lumbosacral spine. T2*-weighted images are apt to have less CSF flow–related artifacts than are T2-weighted fast-spin echo images.

In the cervical spine, where the neural foramina are small and have an oblique orientation, direct oblique imaging or a T2 volume acquisition with reformations may improve the detection and characterization of neural foraminal pathology. CT provides additional information about bony proliferation that may narrow the neural foramina.

Minimum recommended pulse sequences for evaluating the spine for routine imaging to evaluate back pain, radiculopathy, or suspected stenosis may include:

a. Cervical/thoracic spine

-Sagittal T1- or PD-weighted
-Sagittal fat-suppressed non-T1-weighted (ie, water sensitive) or T2-weighted -Axial T2-weighted and T2*-weighted b. Lumbar spine
-Sagittal T1- or PD-weighted
-Sagittal fat-suppressed non-T1-weighted (ie, water sensitive) or T2-weighted -Axial T2-weighted
Coronal PD or T2-weighted sequences are very helpful, especially in the lumbar and thoracic spines. Axial T1-weighted sequences are sometimes performed, especially in the lumbar spine for detection of fat in the filum terminale, or after IV contrast administration.

In postoperative cases when trying to differentiate scar from disc, postcontrast sagittal and axial T1-weighted sequences, with or without fat suppression, are useful. Coronal sequences may also be helpful, particulary in a postoperative patient who had an operation for a foraminal or extraforaminal disc herniation.

When evaluating spinal bone marrow for tumor, sagittal T1-weighted sequences should be performed. Fat-suppressed T2-weighted or STIR sequences can make focal lesions more conspicuous, as well as short TI inversion recovery (STIR) sequences; fat-suppressed T2-weighted fast-spin echo sequences or other fat-suppressed acquisitions are also recommended. When evaluating soft-tissue neoplasms, infections, trauma, muscles, and equivocal cord signal, an axial fluid–sensitive sequence may be helpful. For neoplasms, a contrast-enhanced study may be helpful to further define extraosseous extension of a neoplastic process.

3. Slice thickness

The following are recommended maximum slice thicknesses for performing the typical spine examinations:[2]

Sequence	**Slice Thickness**
Cervical spine - sagittal	≤3 mm
Cervical spine - axial	≤3 mm
Thoracic spine – sagittal	≤4 mm
Thoracic spine – axial	≤4 mm
Lumbar spine – sagittal	≤4 mm
Lumbar spine – axial	≤4 mm

When attempting to diagnose particular pathologies, thinner slices may be appropriate. For example, when evaluating for a pars defect, 3-mm or less sections in the sagittal plane may be warranted. When attempting to detect and characterize spinal cord pathology, 2-mm sections may be appropriate. Interslice gaps will depend on hardware and software. Contiguous imaging has the advantage of not missing any anatomy.

4. Area of coverage

The imaging protocol should be designed to cover the area of clinical interest. Because the clinical situation is a crucial determinant of treatment, the following are general recommendations and not strict

[2]Thicker slices may be acceptable when the goal of the examination is primarily to survey most or the entire spine.

criteria. In addition to covering the area of clinical interest, technologists may further evaluate areas of pathology identified on scans while they are being performed. It is recommended that a physician's order be obtained if the scope of the additional area imaged by technologist discretion includes a complete separate body region.

For routine imaging, for example, for pain, radiculopathy, suspected stenosis, or other degenerative conditions:

Cervical spine: Sagittal images should include from the skull base through at least the C7 to T1 intervertebral disc. The axial images should have contiguous slices from the skull base through C7-T1.

Sagittal imaging should include the entire cervical spine, including parasagittal imaging through all of the neural foramina on both sides. Coronal imaging, if performed, should include the proximal brachial plexus unless there is a specific area of clinical concern, in which case that area should be covered.

Thoracic spine: Sagittal and axial images should include the area of clinical interest. If the entire thoracic spine is to be studied, C7 to L1 should be imaged in the sagittal plane, with axial images obtained as warranted. If no area of interest is identified, axial images should span the entire thoracic spine. In patients being evaluated for disc pathology, axial images should be approximately parallel to the discs. In patients whose spines are curved, this may necessitate several axial sequences or reformatted images at different angles. For optimal imaging of the thoracic spinal cord on axial images, the plane of imaging should be as close as possible to perpendicular to the spinal cord (this may require a few sequences in patients with significant thoracic kyphosis).

For thoracic imaging, visualization of the C2-3 disc or the first rib is useful for accurate localization of thoracic levels and pathology. The upper cervical spine can be obtained on a separate low-resolution sagittal sequence.

Sagittal imaging should include the entire thoracic spine, including parasagittal imaging through all of the neural foramina on both sides. Coronal imaging, if performed, should include the exiting nerves in the area of concern, as well as the proximal ribs.

Lumbar spine: The entire lumbar spine should be imaged in the sagittal sequences and include the entire neural foramina and immediate paraspinal soft tissue (T12 to S1). Contiguous axial images (not just through the disc) should be obtained through at least the lowest three lumbar discs (L3/4, L4/5, and L5/S1) and preferentially also L1/2 and L2/3. The stacked axial images should be as perpendicular to the central spinal canal and parallel to the disc spaces as possible, and typically two or three overlapping axial sequences or reformatted images are needed to cover all lumbar segments. If 2-D or nonisotropic voxels are used, the axial images should be approximately parallel to the discs. Coronal imaging can be tailored to the pathology, often to include the exiting nerves at the lower lumbar levels. Imaging should provide enough anatomic coverage to detect transitional anatomy at the lumbosacral junction. Tailored examinations may be appropriate for follow-up of known pathology.

For tumor and infection, sagittal and axial images should include the area of clinical interest, and fat suppression on the postcontrast images may be helpful. If other imaging modalities or the clinical evaluation narrow the levels of suspected abnormalities, then it may be appropriate to limit an MRI to these areas of interest. If MRI is to be used as the only diagnostic imaging modality for clinically occult disease, screening of the entire spine may be indicated.

Screening:

Occasionally, screening of the entire spine is performed to look for anatomic variations. In these situations, larger fields of view and thicker slices may be appropriate.

Other techniques

a. Parallel Imaging [61-67]

Parallel imaging (PI) uses the spatial sensitivity information from phased-array radiofrequency coils to reduce the number of phase-encoding steps and therefore shortens the time of image acquisition. These time savings imply a loss of signal-to-noise ratios, but without compromising image contrast or spatial resolution. The coil sensitivity information is obtained by performing a prescan calibration or by obtaining additional lines of k-space with each sequence as "auto calibration." Numerous image reconstruction algorithms have been developed, including space domain–based techniques (SENSE), k-space regenerative techniques (SMASH, generalized SMASH and GRAPPA) and other hybrid techniques (SPACE-RIP). The maximum reduction in imaging time, reflected in parallel imaging acceleration factor, is 2 to 3 in each phase-encoding direction. The limitation of the accelerating factor is due to increased noise associated with both reduced temporal averaging and the reconstruction process. The reduction in signal-to-noise ratio associated with higher parallel imaging factors can be counterbalanced by the increased signal-to-noise ratio at higher fields, improved surface coils, and advanced acquisition schemes. When imaging a small field of view, the sensitivity maps may be used to reduce wraparound artifact if the images are acquired without reduced k-space sampling.

Parallel imaging is applicable to all pulse sequences and complementary to other existing acceleration methods. In spine imaging, pulse sequences with high contrast and spatial resolution can be combined with PI and allow evaluation of disc pathology, cord, and nerve root impingement, and neural foraminal patency. In 3-D imaging, the phase-encoding steps can be reduced in 2 directions, for a maximum parallel imaging factor of 6 to 9. Coronal plane reconstruction from 3-D imaging may be helpful for evaluating scoliosis and extraforaminal disease.

b. CSF flow imaging of the spine [68-71]

CSF flow can be imaged with phase-contrast cine MRI evaluation. Cardiac gating with either ECG or peripheral leads can be used to reduce cardiac-dependent flow artifacts. These approaches also permit quantitative velocity and qualitative vector measurements of CSF flow. Spinal CSF flow imaging is performed in the axial and/or sagittal planes.

Typical parameters are as follows: Cardiac gating; flip angle, 20°; TR/TE, 20/5 ms; slice thickness, 5 mm; field of view, 180 mm; matrix, 256 × 256; and encoding velocity (venc), 10 cm/s.

Common indications for phase contrast cine imaging in the spine include evaluation of flow dynamics at the craniocervical junction in patients with Chiari I malformation as well as craniocervical and whole-spine imaging of patients with idiopathic syringomyelia in the search for myelographically occult arachnoid cysts or webs.

c. T1-FLAIR versus T1 fast spin-echo imaging of the spine [72-75]

T1 fast spin-echo (FSE) is a routine pulse sequence for imaging of the spine and can provide anatomic detail at a relatively short acquisition time compared with conventional spin-echo imaging. However, T1 FSE often suffers from poor image contrast.

Fast T1-fluid-attenuated inversion recovery (FLAIR) imaging takes advantage of short image acquisition with T1-weighting as well as suppression of CSF signal. While both T1 FSE and fast T1-FLAIR of the spine are useful for demonstrating normal anatomic structures and determining the presence of both degenerative and neoplastic processes of the spine, there are advantages to using fast T1-FLAIR imaging of the spine at higher magnetic field strengths. 3T fast T1-FLAIR imaging appears to allow for superior conspicuity of normal tissue interfaces as well as spinal cord lesions and abnormal vertebral body marrow at 3T. Because of the increased T1 values at higher magnetic field strengths that result in reduced T1 contrast, fast T1-FLAIR has improved CSF nulling and higher

contrast-to-noise ratio, as compared to T1 FSE. Additionally, there is a reduction in susceptibility artifacts from the presence of metallic hardware using T1-FLAIR as compared to T1 FSE. T1-FLAIR may also reduce specific absorption rate, which can be a limiting factor at higher fields.

d. Chemical shift imaging [76-80]

Chemical shift imaging, also known as opposed-phase or in-and-out-of-phase imaging, is a modality that takes advantage of small differences in precession frequencies of lipid and water protons to determine the presence of intracellular lipid and water within the same imaging voxel. It can therefore be used to aid in distinguishing between marrow-replacing processes and marrow-preserving processes. Specifically, the technique has shown promise in the ability to distinguish pathologic from benign compression fractures, and there are data that support the ability of opposed-phase imaging to differentiate benign vertebral lesions (hemangiomas, degenerative endplate changes, etc) from malignancy. The T1-weighted GRE sequences can be rapidly acquired, with a total scanning time of less than 5 minutes. Chemical shift imaging can also be used as a technique for fat suppression.

e. Perfusion

MR perfusion-weighted imaging (PWI) has enjoyed great clinical and research success in assessment of cerebrovascular reserve and as an adjunct for assessing biologic behavior of cerebral neoplasms. PWI use rapid data acquisition techniques to generate temporal data series that capture the first pass kinetics of a contrast agent as it passes through a tissue matrix. PWI uses three general contrast mechanisms: (1) dynamic susceptibility contrast, which is sensitive to transient changes in magnetic susceptibility caused by a contrast bolus; (2) dynamic contrast enhancement, which tracks T1 changes caused by IV contrast; and (3) arterial spin labeling, which does not require contrast administration and uses radiofrequency tagging of spins to depict blood flow. PWI has been less commonly used in the spine; however, several investigators have examined its potential in helping to discriminate spine lesions and to assess the vascular reserve in the spinal cord.

In the setting of neoplasia, MR-PWI is thought to provide physiologic information about the microcirculation of tumors, with the PWI metrics being a direct reflection of angiogenesis, vascular density, and capillary permeability. It has also been utilized to discriminate pathologic and benign insufficiency fractures with variable success, and, in conjunction with DWI, to improve the specificity in discriminating benign and malignant spine bone tumors [81,82].

Small case series have used PWI to assess spinal cord vascular reserve in specific clinical applications. It has also been used to predict outcomes of spinal metastases [83].

f. Dynamic imaging/motion studies

Dynamic MR imaging of the spine is the natural extension of other types of imaging that attempt to visualize the relationships of the spinal components during physiologic loading or in varying stages of position. The most conventional form of imaging that is in common use historically is lateral flexion-extension radiography of the spine to assess for areas of segmental instability. There are known alterations in spinal canal diameter and neural foraminal size between extremes of flexion and extension. Hyperextension produces bulking of the ligamentum flavum that can produce dynamic mechanical causes of cervical spondylotic myelopathy. Prior investigations principally used myelography and CT with intrathecal contrast media, although more recently MRI has been used.

As MRI provides exceptional simultaneous soft-tissue and bone detail in unlimited imaging planes, it is a logical next approach to evaluate dynamic dimensional changes to neural axis and neural elements. However, capabilities to study the spine under physiologic load are limited on most conventional scanners. Although flexion/extension radiography is performed in an upright position to simulate physiologic loading, conventional MRI is performed recumbent. This deficiency has led to several technical developments that more closely replicate physiologic loading by incorporating

gravity and thus direct axial loading to the spinal axis. This includes upright MRI and compression devices that can provide an equivalent axial load to the spinal axis even while imaging in the supine position. The latter is more limited in capability in that it does not facilitate imaging in extremes of position; rather it only replicates normal physiologic load imposed by gravity in the upright position.

Upright MRI units in particular are designed to image the spine in a variety of normal physiologic conditions: supine, upright, sitting, flexion, extension, or a combination of postures. Moreover, these devices are designed to demonstrate anatomic changes between modes of positioning. A number of investigations have been performed using flexion/extension MRI to study changes in the disc/ligament complexes and their effect on the spinal cord and neural elements. Studies have shown correlation of changes with loading and motion with symptoms [84,85]. They may improve conspicuity of pathology, such as annular tears and disc herniation. Compared to high-field MRI examinations, overall image quality may be reduced if a larger field of view, thicker sections, or a reduced matrix is employed.

Although kinematic or dynamic MRI offers some intriguing physiologic information regarding potential segmental instability, there is very little supportive evidence that this additional information correlates with individual patient symptoms or improves patient outcomes after therapy. Currently, access to kinematic or dynamic MRI is extremely limited.

g. Diffusion

Diffusion imaging has been applied for imaging of vertebral body disease and spinal cord abnormalities. Reports of the performance for bone lesions have been variable, with some authors finding relatively poor sensitivity and specificity when diffusion imaging is considered in isolation, but a useful adjunct to T1-weighted imaging when used in combination [86]. Smaller diffusion coefficients in osseous metastases than normal marrow have been attributed to higher cellular density in malignant than in benign conditions. For example, Bun et al reported perfect separation of sacral insufficiency fractures from metastases by diffusion MR [87]. Similar findings have been reported, and the same mechanism invoked by other authors [88-90], but others have found no incremental contribution of diffusion to distinguishing benign from metastatic disease [91].

For spinal cord lesions, there is ample evidence and more reason to expect that diffusion imaging should be of similar value as in the brain. However, spinal diffusion imaging faces technical limitations not encountered when studying the head. The most challenging are motion of the spinal cord, and susceptibility artifacts that cause image distortion, particularly for echo planar approaches. Currently, popular solutions revolve around reduced FOV imaging, and two major approaches are under active investigation. One method is to perform conventional excitation and suppress the signal from outside the desired field of view. These outer volume suppression methods have been successfully applied in spinal cord imaging, often with fast spin-echo acquisitions to further control susceptibility artifacts [92]. Another approach is to selectively induce signal only from the desired FOV. Several authors have also used these inner volume excitation methods; for example, the interleaved multisection inner volume approaches [93].

Using these methods, authors have applied diffusion-weighted spinal cord imaging to map the characteristics of normal tissue [93,94] in chronic spinal cord injury [95], cervical spontaneity myelopathy [96], intramedullary neoplasms [97], and demyelinating disease [98,99]. In all of these conditions, diffusion imaging helps identify axonal loss, myelin loss, and, in the early stages of disease, axonal injury. Tractography can highlight axonal injury as seen as loss of fractional anisotropy. The usual application of tractography, to determine fiber direction, is of little significance in the spinal cord, where one knows the fiber orientation.

Although diffusion imaging is a critical component of MR evaluation of brain stroke, it has been far less studied for spinal cord ischemia. This is likely due to the relative rarity of spinal cord infarction. The abovementioned conditions, especially trauma and inflammation, are far more common causes of myelopathy.

VII. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [100].

VIII. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance must meet all state and federal requirements. The requirements include, but are not limited to, specifications of maximum static magnetic strength, maximum rate of change of magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels.

IX. 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 (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards).

The quality of a study involves the quality of the images themselves and the interpretation, with technologist and radiologist expertise required for an optimal outcome.

1. Technologist quality

   This section discusses the performance of the examination and measures that might be necessary on the technologist side that is not covered in the specifications section

   MRI is a somewhat user-dependent examination; a technologist's vigilance and knowledge are keys to creating the best examination possible using available equipment and responding to patient-specific imaging challenges. Coil selection, parameter selection, and patient positioning are important in the initial setting up of a study including appropriate scout images to assure correct numeration of the vertebral bodies. Once images are available, the technologist must identify artifacts and understand how to reduce them, as well as assess appropriate coverage. Additional important roles of the technologist are to understand the clinical indication, to act as a check to ensure the study to be performed is appropriate for the given indication, and have a basic knowledge of the anatomical site of potential pathology, and furthermore, to ask for help when uncertain. In addition, identifying unexpected pathology is important to determine whether additional imaging is warranted. The hope is to meet all the patient’s needs on the initial visit, but it is understood that patients may need to be recalled for further imaging.

   Additional sequences may be necessary to distinguish between pathology and artifact (such as potentially abnormal cord signal).

2. Radiologist quality

   The quality of an examination interpretation involves many aspects of interpretation including perception, disease understanding, and an environment that reduces interruption and promotes radiologist concentration. Both aspects require a systematic and rigorous evaluation of a good-quality examination [101].

   Imaging examinations should be interpreted in a systematic and thorough fashion. What ends up in a report is often the preference of the interpreting physician, with some physicians being more detailed than others. Despite the form of a report or its content, the interpreting physician should see all reasonably detectable pathology and report clinically relevant pathology.

A description of alignment, discs, canal and foraminal stenosis, and what is causing each is typical in a report. It may not always be possible to distinguish between disc and osteophyte.

In the spine, one of the most important causes of pain is nerve compression. Identification of compressed or displaced nerves and the location thereof, with an eye on defining the cause of a patient's pain, is some of the most valuable information derived from spine MRI. Identification and descriptions of disc protrusions, extrusions, and sequestrations, though often subtle, are imperative for the MRI reader. Less common causes of pain include spinal cord and soft-tissue (eg, muscle) abnormalities. The facet joints should be evaluated as a source of pain, as should the sacroiliac joints in lumbar MRI.

Incidental imaged extraspinal pathology is important to identify in order to catch potential malignancies or other pertinent pathology early. Liver lesions can potentially be seen on scout images. Congenital vascular abnormalities, aortic aneurysms, and retroperitoneal adenopathy may also be incidentally observed and reported.

Some diseases are particularly difficult to confirm on imaging, such as infection, and repeat studies may be necessary to prove that a finding is or is not clinically relevant.

Specific policies and procedures related to safety should be in place along with documentation that these policies and procedures are updated annually and that they are formulated under the supervision and direction of the supervising MRI physician. Guidelines should be provided that deal with potential hazards associated with MRI examinations to the patients as well as to others in the immediate area. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination.

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [102].

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