Musculoskeletal Imaging in Physical Therapist Practice

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This article presents an overview of current concepts of evidence-based diagnosis using a variety of imaging modalities for a broad spectrum of musculoskeletal conditions and syndromes. There is limited but increasing evidence that physical therapists appropriately use diagnostic studies in clinical practice. Pathology revealed by diagnostic studies must be viewed in the context of the complete examination, as pathology is common in the asymptomatic population. Special diagnostic challenges are presented by patients with areas of referred pain, multiple injuries or multiple areas of pathology, neoplasms, and infections. Plain film radiographs have been overused in the clinical management of many conditions, including low back pain. Clinical decision rules provide simple evidence-based guidelines for the appropriate use of imaging studies. *J Orthop Sports Phys Ther 2005;35:708-721.*

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D iagnostic imaging is an important tool for the differential diagnosis of many musculoskeletal conditions. Physical therapists working in direct access roles are assuming greater diagnostic responsibility. The role of musculoskeletal imaging in physical therapist practice is therefore becoming increasingly important.[127] Availability of diagnostic studies to physical therapists may vary greatly depending upon many factors within the practice setting. US Army physical therapists functioning as direct access providers have long held privileges for ordering imaging studies and laboratory tests considered essential to their diagnostic role.[7,12,43,47,48] Physical therapists who do not have the privilege to order imaging studies, especially with the greater direct access role conferred to physical therapists, should still be familiar with the indications and role of diagnostic radiology. In these situations, physical therapists should establish the proper professional interactions with individuals who can facilitate ordering necessary imaging studies.

The Evidence Regarding the Use of Musculoskeletal Imaging Studies by Physical Therapists

There is limited but increasing evidence that physical therapists appropriately use diagnostic studies in clinical practice. A study comparing the care administered by physical therapists with orthopaedic surgeons in the primary management of musculoskeletal problems determined that the physical therapists were most cost effective, with no difference in patient outcomes except that the patients seen by the physical therapists were more satisfied with their care.[20] Although the physical therapists had equal ability to order the imaging studies, they were less reliant on imaging in their diagnostic strategies. This resulted in cost savings and a reduction in patient exposure to ionizing radiation. Other retrospective studies have similarly found that when physical therapists working in direct access settings have privileges for ordering imaging studies, the utilization of such studies are reduced by up to 50%.[43,47,48] A recent retrospective study compared the clinical diagnostic accuracy of physical therapists, orthopaedic surgeons, and nonorthopaedic providers on patients with musculoskeletal injuries referred for magnetic resonance imaging (MRI) studies.[72] The reference standard for diagnostic accuracy was the radiologist's official reading of each MRI study. No difference was found between the diagnostic accuracy of the physical therapists and the orthopaedic surgeons. The nonorthopaedic physicians were, however, significantly less diagnostically accurate than physical therapists and the orthopaedic surgeons.

Integrating Musculoskeletal Imaging With Physical Therapist Practice

Irrespective of whether a physical therapist can order imaging

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studies in their practice setting, they should be familiar with musculoskeletal imaging indications, limitations, risks, and benefits. At a minimum, physical therapists should be able to suggest the appropriate imaging study according to clinical practice guidelines or other current evidence for diagnosis. The type of imaging that will best reveal the suspected pathology, with the least risk to the patient, at a reasonable price should be recommended. Many providers who refer to physical therapists have a limited knowledge of musculoskeletal diagnosis and the diagnostic indications of musculoskeletal imaging modalities.[30,31,65,72] Therefore, the informed physical therapist may be in a good position to either order diagnostic imaging procedures or to make recommendations according to current practice guidelines and the diagnostic utility of the various procedures.

At times it may be clearly evident from the patient/client history, the review of systems, or the test and measures, that imaging studies are indicated. At other times the need for imaging may only become apparent in the absence of an appropriate response to the physical therapy intervention. Whenever the response to the intervention is not consistent with the prognosis, additional diagnostic testing, including the appropriate imaging study, may be indicated. As in the currently recommended evidence-based diagnostic strategies for acute low back pain (LBP),[8,49] the physical therapist may need to determine the degree of response to physical therapy intervention before making a decision on the need for imaging studies or laboratory tests.

Imaging studies are normally indicated only when positive findings will influence decision making. For example, pubic rami and proximal tibial stress fractures are common training injuries among military recruits.[3,6] When appropriately managed, these injuries will rarely require medical or surgical intervention. Accordingly, if the patient/client history, review of systems, or tests and measures strongly suggest a tibial stress fracture and are not consistent with infection, neoplasm, or other serious pathology, physical therapy intervention may be initiated without diagnostic studies. If the injury responds consistent with the expected prognosis, imaging studies may not be required. Comparatively, stress fractures of the femoral neck, with primary involvement of the superior or primary tension trabeculae, are often treated surgically. A more aggressive approach involving both early diagnostic imaging and surgery may be warranted to prevent the possible catastrophic consequences of a complete femoral neck fracture in a young person. Imaging that reveals a femoral neck stress fracture will alter the physical therapy intervention and may indicate a need for surgery. Surgical stabilization of the fracture is typically based on the area and extent of involvement of the femoral neck.[16,77] Therefore, whenever a physical therapist is suspicious of a femoral neck stress reaction or fracture, imaging that is sensitive for the disorder is promptly indicated.

In other situations, a patient may have clinical findings of a condition where there is evidence for the benefit of treatment such as a surgical procedure. However, if the patient is not willing to undergo the treatment that requires imaging, or if the patient is not a suitable candidate for the treatment, there is again no reason to pursue the imaging study. A good example might be an elderly patient in poor physiological health with an apparent rotator cuff tear by clinical examination. If the patient is not a surgical candidate, advanced imaging, such as an MRI, adds expense to the care of the patient without influencing the treatment or outcome.

The Diagnostic Utility of Musculoskeletal Imaging Procedures

For the physical therapist to be successful in differential diagnosis, it is essential to have a working familiarity of probability-based diagnosis and the diagnostic test properties sensitivity, specificity, positive and negative likelihood ratios, and positive and negative predictive values.[32,90] To appropriately select from among competing diagnostic tests, physical therapists must be able to recognize when the sensitivity is appropriate to screen for a given condition, and to know when the specificity is adequate to confirm the condition.

Plain film radiographs are not sensitive to subtle pathology. Significant changes to the structure of bone must occur before radiographs will reveal it. Therefore the chance of having a false negative for subtle, early-stage pathology, such as stress injuries, metabolic bone disease, infectious processes, nondisplaced fractures, and neoplasms, is high with plain radiographs. There are a number of published case reports of patients who have presented to the emergency department with strong suggestion of hip fractures after a fall.[18,60,78,79] These patients all had negative radiographs and in some cases negative CT scans. In each case the physicians were so strongly convinced that a fracture was present they persisted with special MRI sequences and ultimately revealed the fractures. The strong pretest likelihood of a fracture in these hip fracture cases motivated the physicians to pursue incrementally more sensitive imaging studies despite the negative test results. Learning test properties, such as specificity and sensitivity, with respect to each imaging modality for select pathology greatly assists the physical therapist in recognizing the potential for false negative or false positive test results. MRI has become the standard in

many cases for imaging acute injuries, due to the low potential for false negatives given the appropriate image sequences.[24]

The Relevance of Pathology Revealed in Diagnostic Images

It is important to understand that diagnostic images must be interpreted within the broad context of a comprehensive history and physical examination. There are many examples in the published literature of pathology in the spine and extremities in the asymptomatic population. MRI findings of knee pathology have been reported in asymptomatic collegiate basketball players.[64] Calcific tendonitis and rotator cuff tears have been reported in the shoulders of asymptomatic individuals.[25,26,67] A wide variety of spinal pathology, including disk protrusions, herniations, free fragments, and annular tears have been demonstrated on the MRIs of asymptomatic persons.[37,45,50,81,93,96] The radiologist will often suggest clinical correlation of imaged pathology on the official report. The comprehensive clinical examination will typically provide the appropriate relevance to any pathology identified with an imaging study.

Potential Errors in Musculoskeletal Imaging

Imaging studies are subject to the same sources of error as other diagnostic tests. The images from one patient may be mistaken for those of another patient, the wrong extremity may be imaged, obvious injuries may be imaged while other injuries are missed, areas of referred pain rather than the source of the symptoms may be imaged, and the images may be misinterpreted by the radiologist or referring provider.[36,125] Images may also be of poor quality or not reveal all the structures intended for that particular view. The most common reason for missed cervical fractures is technical error resulting in inadequate visualization of the seventh cervical vertebra.[38] Inadequate examination may lead the clinician to erroneous conclusions regarding the region to be imaged or the type of imaging study indicated. A thorough examination tailored to the patient's presentation and a current knowledge of diagnostic standards and evidence-based interventions are essential to accurately determine the need for imaging and the appropriate body region(s) to be studied.

A common error in musculoskeletal imaging is to image an area of referred pain. Although any detailed discussion of referred pain is beyond the scope of this article, there is general consensus that symptoms can be referred remotely from the origin of pathology, that pain can be referred from both somatic and visceral structures, and that palpation tenderness may indeed exist in the area of the referred pain.[2,23,33-35,41,62,66,73] Diagnostic studies of referred-pain locations are likely to reveal only irrelevant pathology or appear normal. Careful planning and execution of the patient/client examination based on the unique presentation of each patient, with full consideration of the possibility of referred pain, will help reduce such examination errors. Consistent examination procedures, such as examining and clearing the cervical or lumber spine for extremity complaints, and examining and clearing the joint and surrounding area proximal to the area of symptoms, will help identify the true source of referred pain. For example, there are a number of case studies[5,13,29,80,122] documenting missed hip pathology in the pediatric population due to the referral of symptoms from the pelvis and hip to the distal thigh and knee. This presentation has resulted in delayed diagnosis and treatment, and increased imaging of the normal structures in the area of the referred pain. Another example of the diagnostic challenges presented with referred pain and irrelevant pathology revealed in diagnostic images is presented in the lumbar and cervical spine. The lower levels of these spinal regions are typical locations for pathology even in asymptomatic persons.[50] Because the upper aspects of these spinal regions are known to refer symptoms distally, the potential exists to mistakenly correlate asymptomatic pathology at lower spinal levels with the pain that is being referred from higher spinal levels.[33-35]

Sometimes the more obvious or more symptomatic area obscures the need for imaging of other injuries or pathology. Common examples include ankle sprains accompanied by foot fractures and lower extremities fractures accompanied by spinal fractures. Careful examination of all possibly involved body regions is required to minimize these diagnostic errors.

Ordering Diagnostic Images

The physical therapist may have the opportunity to select or recommend the type of imaging and the appropriate sequences or views. Therefore it is important for physical therapists to understand the most current diagnostic standards and imaging recommendations for a given condition. Familiarity with evidence-based screening and diagnosis strategies for the most common conditions in any given practice will facilitate proper decision making.

To accurately interpret the imaging study, the radiologist is dependent upon the requesting provider's description of the mechanism of injury and the location of the suspected pathology or areas of symptoms. Radiologists appreciate brief but anatomically correct descriptions from providers that allow them to focus on specific areas and to make judgments on the relevance of identified pathology. Under normal circumstances, the provider ordering the imaging can also request the appropriate priority for

routine, serious, and life-threatening conditions. In some settings, the wait for an MRI or CT scan is significant. While emergency requests will have clear priority, patients with other less serious conditions may have to wait an extended period for the study. This waiting period underscores the need to judiciously use imaging studies according to the best available evidence. Overutilization of imaging unnecessarily delays the care process and increases health care costs.

Interpretation of Diagnostic Images

Many clinicians assume that the most important aspect of diagnostic imaging is recognizing pathology. While recognizing and assessing clinically important pathology may facilitate many aspects of clinical care, the responsibility for interpreting diagnostic images rests primarily with the radiologist. However, skilled physical therapist review of images, combined with information from the patient/client examination or intervention, may help to reveal overlooked pathology or provide relevance to pathology reported on the official reading.[11,36,89,121,125] It is, however, relatively much more important for a physical therapist to recognize the indications for diagnostic imaging, to select the most appropriate imaging study, and to image the appropriate area(s) than it is to interpret the image.

Conventional Radiographs

When appropriate, conventional radiographs represent a cost-effective and highly specific imaging modality useful for demonstrating a wide range of skeletal pathology. Conventional radiographs use ionizing radiation to produce high-resolution analogue images on specialized film. Similar to many other types of images, they can also be digitized for transmission and viewing on computerized systems. Radiographs are useful to distinguish air, bone, calcification, fat, soft tissue, and fluids. Depending upon the intent of the radiographic study, a beam of ionizing radiation is directed at a standardized angle to the area to be imaged. Each substance or tissue will absorb varying amounts of the radiation producing images of relative radiodensity and radiolucency. Air absorbs the least radiation and therefore appears to be the most radiolucent or has the darkest appearance on radiographs. Fat, fluids, soft tissue, muscle, bone, and metal will progressively absorb more ionizing radiation, thereby producing a relatively more white or radiopaque appearance on the radiograph. Typically, radiographs are used to demonstrate bone origin pathology, the relationship of bone structures, or the relationship of foreign objects to skeletal structures. The degree of detail provided for muscle, ligament, or tendon injuries is not

adequate to be diagnostically useful.[27,69] Radiographs demonstrate fine cortical and trabecular detail of bone and characterize certain types of bone reactions associated with benign and malignant neoplasms and infections. Fractures ranging from simple to complex, avulsion fractures, and later-stage stress fractures may be identified with radiographs. The minimal radiographic examination includes 2 views of the imaged body part at right angles to each other. Fractures may appear to be dramatically less complex or less displaced in one view than another. Many facilities have standardized views for providers to choose from when ordering plain radiographs and other imaging procedures. Current knowledge of the diagnostic evidence will facilitate appropriate decision making with respect to the required views. For example, 4 standard-view radiographs (anterior to posterior, lateral, and both obliques) have been demonstrated to be superior to 2 standard-view radiographs (anterior to posterior and lateral view) for detecting knee fractures.[42] Specific injuries may be best demonstrated with specialized views in addition to the standard views.

Ionizing radiation exposure is an important consideration for diagnostic radiology. Shields must be used to protect any body parts that will be exposed to radiation but are not of interest in the examination. The diagnostic imaging literature can be helpful to select appropriate views that limit radiation exposure. For example, radiation exposure to the breasts and thyroid gland as well as the resultant cancer risk can be reduced by simply using posterior-to-anterior rather than anterior-to-posterior views in the monitoring of long-term conditions such as scoliosis.[58,59] Shielding of the breasts is indicated whenever possible.[58,59] Lumbar spine oblique and spot lateral views, and isolated sacroiliac joint view radiographs are rarely indicated due to the high levels of associated gonadal radiation, particularly in female patients.[70,88,92]

Plain radiographs are not considered to be sensitive to the early changes associated with tumors, infections, and some fractures. However, they may be more specific than bone scans and even MRI in differentiating potential etiologies of lesions because of their proven ability to characterize specific calcification patterns and periosteal reactions. Due to the lack of sensitivity of plain radiographs for many subtle pathologies, more sensitive procedures should be considered when the pretest likelihood strongly suggests pathology, despite normal plain films.[27,28]

Plain radiographs should be interpreted in a systematic manner that lessens the tendency to jump to the obvious pathology and thereby miss other perhaps more subtle pathology. One simple and commonly taught method of interpreting plain films is referred to as the ABCs.[19,124] Although there is no evidence that this method is superior to any other for

studying plain films, it is considered to be a useful systematic method. The "A" is used to study the size, number, shape, and alignment of bones. Pathology visualized includes fractures, dislocations, and cortical alterations. The "B" is used as a reminder to study bone density, including general and focal bone density, and trabecular alterations that are indicative of metabolic bone disease, infections, tumors, and arthritic changes. The "C" is a reminder for studying cartilage space, including the width and symmetry of the joint space and the contour and density of the subchondral bone. Degenerative and rheumatoid arthritis are among the more common pathologies producing joint space alterations. The "S" is the reminder to study the soft issue for gross swelling, capsular distension, periosteal elevation, and signs specific to certain areas of the body, such as the appearance or increased visibility of the fat pads of the elbow. For example, there are pads of fat in the olecranon and coronoid fossa at the elbow. On a lateral-view radiograph of the normal elbow, the posterior fat pad is not visible, and the anterior fat pad is slightly visible as a thin area of relative lucency just anterior to the coronoid fossa. Increased visibility of either pad after elbow trauma is strongly associated with an elbow fracture.[76]

Appropriate Use of Radiographs

Overuse of radiologic imaging studies has been a significant economic problem in the United States for many years. Although radiographic studies are inexpensive compared with some of the advanced imaging studies, the economic impact of lower-cost but higher-volume procedures can be substantial.[119] Clinical prediction or decision rules that indicate when there is a need for radiographic studies for specific types of injuries have been developed to help reduce unnecessary imaging studies. In general, clinical decision rules (CDRs) are clinical tools that can quantify the individual contribution of the components of the examination for determining the diagnosis, prognosis, or treatment in a given patient. CDRs formally test, simplify, and increase the accuracy of diagnostic and prognostic assessments. Attempts have been made to categorize a CDR based on the criteria of the method of derivation, the validation of the CDR to ensure that its repeated use leads to the same results, and its predictive value.[39,40,56,57,75,82,84,98-102,104-115] CDRs have been developed primarily for use by emergency department physicians. Most CDRs are developed for maximum sensitivity to avoid missing relevant findings that may indicate the need for further testing or to guide treatment selection. Physical therapists using CDRs to guide their decision-making process should also bear in mind that the rules apply to acute, first-time presentations of significant injuries.

TABLE 1. Ottawa knee rules for radiography (97% sensitive and 27% specific for knee fractures). Seaberg 1998.

Indications for Radiography If Any Are Present
Patient is older than 55 y
Tenderness at the head of the fibula
Isolated tenderness of the patella
Inability to flex the knee to 90°
Inability to weight bear 4 steps both immediately after the injury and in the emergency department

Exclusion Criteria
Age less than 18 years
Isolated superficial skin injuries
Injuries more than 7 days old
Recent injuries being re-evaluated
Patients with altered levels of consciousness
Paraplegia or multiple injuries

TABLE 2. Ottawa ankle rules for radiography (100% sensitive and 40% specific for ankle fractures). Stiell et al 1993.[102]

Indications for Radiography If Any of the Following Are Present
Bone tenderness at the posterior edge or tip of the lateral malleolus
Bone tenderness at the posterior edge or tip of the medial malleolus
Inability to bear weight both immediately and in the emergency department

The Ottawa knee rules for radiography (Table 1) include 5 indication criteria.[106,112-114] If any of the 5 criteria are present, radiographs are required. Similarly, the rules use 6 criteria to describe situations where the rules cannot be applied. The Ottawa knee rules are 97% sensitive and 27% specific for knee fractures.[112,114] The Ottawa ankle rules for radiography (Table 2) and the Ottawa foot rules for radiography (Table 3) each use 3 inclusion criteria.[61,98,99,103,104,110] The Ottawa ankle rules are 100% sensitive and 40% specific. The Canadian cervical spine rules (Table 4) use high-risk and low-risk factors. If any high-risk factors are present, radiographs are indicated. If no high-risk factors are present and the low-risk factors describe the mechanism of injury and patient presentation, simple active range of motion testing is considered safe. If cervical range of motion is less than 45° in either direction, radiographs are indicated. The Canadian cervical spine rules are 100% sensitive and 43% specific for cervical fractures. A clinical decision rule based on establishing pretest probability using clinical signs and symptoms with the diagnostic standard of Doppler ultrasound and invasive venography has been developed for the diagnosis of lower-extremity deep vein thrombosis.[123] This CDR has been validated[87,126] and studies suggest that the diagnostic accuracy for deep vein thrombosis in orthopaedic outpatients

could be improved for both physical therapists and orthopaedic surgeons by implementing the CDR.[85,86]

Tomography

Tomography is a type of body section radiography that allows for visualization of lesions down to 1 mm or lesions that might be obscured by overlying structures when imaged with plain radiographs.[44] Tomography utilizes relatively higher doses of ionizing radiation, but it is confined to a smaller area and produces images that typically have superior resolution to that of plain radiographs.[69]

Conventional tomograms and computed tomography (CT scans) are the 2 general types of tomography. To produce plain radiographs, the beam of ionizing radiation and the film cassette are prepositioned and the film and the body part remain stationary while exposed to the radiation. In conventional tomograms, the tube producing the radiographic image and the radiographic film move simultaneously, resulting in an image from a single plane of focus within a specific area of interest. Sequential images are taken in parallel planes until the desired area has been adequately imaged. The radiographer can adjust the thickness of the slices through the imaged area. When compared to plain radiographs, conventional tomography provides increased capability to demonstrate the details of subtle pathology, including fracture lines, fracture healing, small tumors, and cystic and sclerotic lesions of bone. Tomograms and radiographs may be interpreted together to facilitate comparison.[44]

A CT scan or CT is another radiologic modality utilizing a source of ionizing radiation, radiation detectors, and a computer for data processing. A CT system includes an X-ray tube within a circular scanning gantry, a patient table, an X-ray generator, and a computerized data-processing unit. The patient is positioned on a table and then moved inside the scanning gantry. The X-ray tube is rotated 360° around the patient, while the computer collects the data and formulates an axial image through the area of interest. The thin axial image is called a slice.[44] Multiple X-ray beams projected at different angles and levels produce a series of computer-generated cross-sectional images or slices of the body. The computer determines the relative impedance of the body tissues to the X rays and subsequently assigns relative density values to each point in the body. Images are constructed of relative shades of gray. Bone and soft tissue differences are the most striking. The ability to differentiate between types of soft tissue, such as tendons and ligaments, is limited, while the cortical and trabecular definition of bone is excellent. CT is well suited to examine the spine and the extremities and may be combined with arthrography for joint injuries.

CT is generally considered to be the less complex and expensive alternative to MRI. The main variable in CT is the thickness of the slice. Slices as thin as 1 mm may be required to produce good reformations. Disadvantages of CT include higher radiation doses and higher cost when compared to conventional radiography.[69] When radiographs are normal and the patient/client examination strongly suggests fracture, CT may represent the next diagnostic step to rule out a fracture. Recent advances in MRI capability are challenging the traditional diagnostic advantages of CT for bone pathology, although CT is still preferred for the details of cortical bone. The combination of CT and MRI may be used for evaluating combinations of bone and soft tissue injuries. MRI is considered more useful for disc herniations, but the reconstruction of thin axial images from the spinal segment into images in the sagittal, coronal, or oblique planes may allow CT to provide additional details of spinal osteophytes and spinal fractures.

TABLE 3. Ottawa foot rules for radiography. Stiell et al 1993.[102]

Indications for Radiography
If Any of the Following Are Present

Bone tenderness at the base of the fifth metatarsal
Bone tenderness at the navicular
Inability to bear weight immediately and in the emergency department

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TABLE 4. Canadian cervical spine rules (100% sensitivity and 43% specificity for identifying important cervical injuries). Stiell et al 2001.[108]

The 3 questions of the Canadian cervical spine rules are provided below. If (1) there are high-risk factors or (2) it is safe to assess range of motion but the patient rotates less than 45° to either side, radiographs are indicated.

Are there any high-risk factors present that mandates radiography?
• Age >65 y
• Dangerous mechanism of injury*
• Paresthesias in the extremities?

Are there low-risk factors that allow safe assessment of range of motion?
• Simple rear-end motor vehicle accident
• Normal sitting posture in emergency department
• Ambulatory at any time since injury
• Delayed onset of neck pain and absence of midline tenderness

Is the patient able to actively rotate the neck 45° to the right and to the left? Was a dangerous mechanism involved?

* Dangerous mechanism
• Fall from ≥1 m or 5 stairs
• Axial load to head (eg, diving)
• High-speed motor vehicle accident (>100 km/h), rollover, ejection
• Motorized recreational vehicles
• Bicycle collision

These fractures range from stress fractures of the pars interarticularis to complex burst fractures of the vertebral bodies.

MRI

Primarily due to the ability to image both bone and soft tissue structures with excellent resolution in 3 dimensions, MRI is rapidly becoming the imaging modality of choice for a wide spectrum of musculoskeletal pathology.[91] MRI scans use magnetic fields from large and powerful magnets to produce computer-generated axial, sagittal, and cross-sectional images of the body.[11]

MRI uses the magnetic properties of the body's tissues rather than ionizing radiation to produce an image. Patients positioned in the MRI scanner are exposed to a strong magnetic field and radiofrequency (RF) pulses that produce measurable changes in the body's atoms. MRIs depend on the intrinsic spin of atoms (typically hydrogen) with an odd number of neutrons or protons, which produces a magnetic moment. The atomic nuclei of tissues placed within the field align to the direction of the magnetic field. The atoms are subjected to the additional influence of RF pulses from the magnetic coils and the atomic response is registered. The RF pulses cause the nuclei to absorb energy and produce resonance that is characteristic for the type of tissue. Upon removal of the RF pulse, the energy absorbed is released as an electrical signal from which digital images are derived. The signal intensity refers to the strength of the radio wave that a tissue emits following removal of the RF pulse. The strength of the radio wave produces either bright high-signal-intensity or dark-low-signal-intensity images. Signal intensity in a specific tissue will depend both upon the T1 and T2 relaxation times, and the relative concentration of hydrogen ions.[44]

The longitudinal or T1 relaxation refers to the return of protons to equilibrium following the application and removal of the RF pulse. The transverse or T2 relaxation time describes the associated loss of coherence or phase between individual protons immediately following the application of the RF pulse. Tissue contrast is enhanced, as required by varying the RF pulse sequences, to increase the differences in T1 and T2 relaxation. MRIs are subsequently referred to as T1 or T2 weighted.

On T1-weighted images subacute hemorrhage and fat have characteristic bright signal intensity. Due to the typical high fat content, bone appears bright in a T1-weighted MRI. Abscesses or cysts that contain high levels of proteinaceous material will have a medium to bright appearance, while other soft tissues will have characteristic low signal intensity.[51] T1-weighted images are thought to be particularly well suited to reveal the details of anatomy as they clearly delineate the architecture of a variety of soft tissue structures.

By comparison, fluids are demonstrated as high-signal-intensity images in T2-weighted MRIs. The "2" in H_2O can be used to help remember that fluids and fluid-containing structures, such as bursae, inflamed tendons, tumors, and abscesses will have a bright appearance in T2-weighted images.[51] T2-weighted images, overall, reveal less detail in soft tissue structures and are therefore less suited for the study of fine anatomic features. Proton-density–weighted images combine the properties of T1- and T2-weighted images and produce good anatomic detail with little tissue contrast.

The high signal intensity of fat in certain MRI sequences can overwhelm the appearance of pathology and will need to be suppressed by one of several mechanisms to adequately reveal signal differences between fat and fluid. Fast spin echo (FSE) T2-weighted images produce particularly bright fat images. Fat suppression or saturation produces a dull appearance to fat for a better contrast with the bright signals from fluids. Inversion recovery (STIR) is another technique that reduces the signal from fat while increasing the signal from fluid and edema.[51]

Patient movement in MRI is an important factor that can dramatically decrease image quality. Voluntary and involuntary patient movements, respiratory movements of the ribcage, or peristaltic movements of the bowel can all reduce the quality of the acquired images. Slices that are too thin or that are acquired too close to each other can produce interference and also decrease image quality.

FSE acquisition of images can reduce the required acquisition time, thus lessening the potential for patient movement. To produce a spin echo effect, a second RF pulse is rapidly applied producing a spin echo effect or echo of the original signal. Spin echo pulse sequences include T1-, T2-, and proton-density–weighted images. FSE proton density MRIs reveal anatomic detail, while FSE T2-weighted MRIs with fat saturation are well suited to reveal marrow pathology. They are also selected for patients with metal hardware.

There are both absolute and relative contraindications for MRI procedures. Any implants or objects of ferromagnetic metal that could become dislodged due to the strong magnetic fields utilized in MRI are absolute contraindications for the procedure. Examples include cerebral aneurysm clips, pacemakers, shrapnel, unstable orthopaedic hardware, and the undetected metal slivers a machinist may have lodged in the eye. The most important detail is to determine if the metal object or device in question is ferromagnetic. MRIs may be obtained in the presence of orthopaedic hardware that is firmly implanted with the possibility of some local signal interference. A relative contraindication of MRI includes intolerance of the procedure by claustrophobic patients and the

inability of the patients to be motionless during the procedure. The relative high cost of the procedure is a limiting factor.

MRI produces high-quality images of large joint components, such as fibrocartilage, ligaments, capsules, and synovium, as well as small joints and fine soft tissue structures. The use of the appropriate coils and pulse sequences provides the ability to produce the appropriate detail. The standard MRI of joints includes images in 3 orthogonal planes, one of which suppresses the characteristic bright signal of fat for improved contrast. A FSE or gradient echo sequence should be included in each joint study to evaluate articular cartilage. Adding intra-articular contrast to an MRI study increases the sensitivity to diagnose rotator cuff tears, labral lesions, or articular cartilage injuries. Compared to the gold standard of arthroscopy for the evaluation of anterior cruciate ligament injuries, MRI has a diagnostic accuracy of more than 90%.[119] MRI is useful to diagnose muscle and tendon tears and is thought to be superior to ultrasonography for monitoring the stages of healing.[17]

MRI has been proven superior to CT for delineating combinations of multiple soft tissue and osseous insults.[27] MRI is also considered more useful than CT to demonstrate abnormalities of bone marrow. Benign tumors may be distinguished from malignant spinal lesions, and the extent of tumors and the relationship of the tumor to neighboring tissues may be distinguished with specific types of MR sequences.[27] MRI has been suggested as the gold standard for detecting bone stress injuries.[1,53] The sensitivity of MRI for stress fractures has been reported to be as high as 100%, with a specificity of 86%, and an overall accuracy of 95%.[1,52,53,83,128] The highest sensitivity and observer agreement for stress fractures are reported with STIR and T2-weighted MRI sequences.[1]

Scintigraphy

Scintigraphy or bone scans reveal the uptake of a radiopharmaceutical substance (radio-labeled phosphate) into areas of reactive bone. Hours prior to a bone scan, the radiopharmaceutical substance is injected into a patient. The skeletal system is subsequently scanned by a detector to reveal areas of increased radionuclide uptake. All normal bone has some degree of metabolic activity and will therefore ultimately incorporate some of the radiopharmaceutical substance. The most metabolically active areas, such as bone attempting to heal after a fracture or responding to a neoplasm or infection, will typically have recognizably increased uptake at those areas. Areas of bone with the most uptake will appear as dark or "hot" areas on the scan.

Bone scans are primarily used to scan for the presence and distribution of lesions.[27] Patients that are diagnosed with cancer may subsequently undergo a bone scan to help screen for metastasis to skeletal structures. Bone scans are sensitive but not specific, as many pathologies produce similar appearances on bone scan. Bone scans are considered to be sensitive for changes in bone associated with fractures (including stress fractures), infections, and tumors.[69] One notable exception to the sensitivity of a bone scan occurs with multiple myeloma, a malignant neoplasm of plasma cells.[4] Musculoskeletal manifestations of multiple myeloma include diffuse osteopenia and multiple lucent areas of bone that eventually result in painful pathological fractures. The lucent areas represent "cold lesions" that may not be metabolically active enough to cause increased uptake of the radiopharmaceutical on a bone scan. An elevated erythrocyte sedimentation rate (a nonspecific indicator of inflammation) plus the appearance of osteopenia on plain radiographs elevates the clinical suspicion of myelomatosis, thereby requiring full medical evaluation, including additional laboratory tests and potentially a biopsy.

Bone scans are commonly utilized by physical therapists in the US Army to detect stress fractures among training soldiers. Although radiographs may eventually reveal stress fractures, their lack of sensitivity limits their diagnostic use. Complete and displaced femoral neck fractures and subsequent avascular necrosis of the femoral head can result from an unrecognized or improperly treated femoral neck stress fracture. In a training soldier or athlete with a high pretest probability of a femoral neck stress fracture, who has normal radiographs and/or a normal bone scan, an MRI with T2 and STIR sequences is warranted. The radionuclide bone scan will also reveal old and well-healed fractures, degenerative joint disease, open growth plates, and the sacroiliac joints as areas of increased radiopharmaceutical uptake. The patient/client examination, including the history, will help differentiate these types of findings for relevance to the current presentation.

Ultrasound

Ultrasound imaging is a fast and inexpensive tool that is capable of producing excellent images of the musculoskeletal system without the use of ionizing radiation. It is highly sensitive to the identification of fine soft tissue changes. Although primarily used for research purposes at this time, some physical therapists currently use ultrasound to image real-time muscle contractions, tendon gliding, and to assess muscle size in clinical practice. Valuable rehabilitation information on a broad spectrum of soft tissue injuries and conditions could be provided to the physical therapist through ultrasound images.

Images in ultrasonography are created by the use of sound waves that are produced by a sound head

and directed into the area of interest. The sound waves are sent into the tissues under the sound head through a water-soluble coupling medium and the sound waves are imaged as they return. Differences in signal return provide the ability to distinguish among structures and the integrity of a given structure. Ultrasound is thought to produce better images of more superficial structures, making it more useful in thin patients. Substances that reflect sound, like bone and metal, cannot be adequately imaged for diagnostic purposes. Ultrasound is an excellent modality for imaging the rotator cuff of the shoulder, but it is typically unable to image some aspects of the glenoid labrum. Ultrasound has also proven useful in the evaluation of a traumatic hemarthrosis of the knee, while certain structures, such as the menisci, articular cartilage, and cruciate ligaments, can be difficult to image and distinguish.[119] Early changes associated with rheumatoid arthritis, such as synovitis, capsular swelling of the metacarpophalangeal and talocrural joints, and bone erosion, are better demonstrated with ultrasound examination than clinical examination or conventional radiography.[63,118] Ultrasound has a demonstrated role in the diagnosis of acute muscle and tendon injuries.[17] The use of ultrasound for monitoring healing processes, such as ruptured Achilles tendons or torn hamstring muscles, has not been well defined.[71]

Ultrasound appears to be well suited for physical therapist use because of the direct operator interaction with the patient. The operator is in essence performing a physical examination and palpating deeply with the aid of the ultrasound, guided by a working knowledge of anatomy and the patient description of their symptom location. Operator skill and experience has been reported to be a large factor in the diagnostic utility of ultrasound images, accounting for the disparity of reported sensitivity for musculoskeletal pathology.[15,46,120] Power Doppler ultrasound produces detailed images of intramuscular and intratendinous structures and can demonstrate hyperemia in the rotator cuff and biceps tendon, as well as other soft tissue shoulder pathology. Depending on a number of factors, including operator skill and experience, power Doppler ultrasound may be as sensitive as MRI and is particularly useful in distinguishing chronic tendonitis from acute tendonitis and rotator cuff tears.[15,46,120]

Imaging Studies for LBP

Due to the high volume of patients with LBP seen in physical therapist practice and the frequent inappropriate use of lumbar spine imaging studies, current evidence-based guidelines for LBP imaging deserve special attention.[97] Lower back radiographs have been described as the single most overprescribed diagnostic imaging procedure, resulting in increased cost, excessive gonadal radiation exposure,

and irrelevant findings that lead to inappropriate diagnoses and treatment.[97] Only 1 of 2500 plain radiographs detects something not suspected on the medical history and examination that has an impact on patient care.[97]

In 1994, the Agency on Health Care Policy and Research (AHCPR) published guidelines[8-10] to help standardize the management of acute LBP. The AHCPR guidelines on the management of acute LBP are now officially archived, but they have been reviewed and determined to still be appropriate for the management of acute LBP.[49,74,97,117] Primary care provider education regarding the evidence for the management of LBP has been shown to reduce imaging studies, specialty referrals, and surgery.[9,11,54] Consistent with the original ACHPR guidelines, in the absence of red flags, routine testing, such as laboratory tests, radiographs, and other imaging studies are not recommended during the first month of acute LBP management.[8,22,49] Red flags or key findings suggestive of serious pathology include general health changes, history of a primary cancer, unexplained weight loss, fevers and chills, recent history of infection, loss of bowel or bladder control, saddle paresthesias, rigid paraspinous or iliopsoas muscular spasm, severe pain, atypical location of symptoms, and extreme limitation of movement. The presence of these red flags, increase the probability of serious underlying spinal conditions such as a fracture, tumor, infection, or cauda equina syndrome.

A thorough patient/client examination should identify most patients with LBP who require imaging studies. Application of evidence-based screening strategies can determine the possibility of certain conditions and thereby reduce the need for imaging studies. For example, when the patient is younger than 50 years of age, without a history of a primary cancer or unexplained loss of weight, and the patient is improving over time or responding to conservative therapy, cancer can be ruled out in patients with LBP with 100% sensitivity.[22,49] Equally sensitive combinations of questions for spinal infections and fractures have not been determined. The sensitivity of fever for spinal infections ranges from 27% to 83%, depending on which spinal structures are infected.[22,49] Immunocompromised status, intravenous drug use, recent urinary tract infections, pelvic inflammatory conditions, and surgery are associated with increased risk for spinal infection.

The presence of a possible red flag will require clinical judgment to determine if plain radiographs or laboratory tests are required at the initial visit.[49] Definitive red flags identified at the initial visit require anterior-posterior and lateral view radiographs, and simple laboratory studies such as an erythrocyte sedimentation rate (ESR) and possibly a complete blood cell count (CBC). In patients with a history of a malignant process, metastatic disease

must be ruled out as a cause of LBP. The lumbar spine is the most common site for secondary deposits to musculoskeletal tissues from primary cancers of other systems. For acute LBP in patients with a history of a primary cancer, the screening strategy of radiographs and ESR applies. The combination of radiographs and an ESR has been shown to be a very sensitive method to screen for occult neoplasms and other systemic disease, such as infection. Deyo and Diehl[21] reported on 1975 screened patients with back pain and all cases of occult neoplasms had either an abnormal film or an elevated ESR.

When imaging and laboratory studies are required due to the absence of improvement with intervention or the presence of red flags, the initial radiographs should be limited to anterior-to-posterior and lateral views. The additional diagnostic value of coned lateral views and oblique radiographs are generally not worth the additional radiation exposure, particularly to female patients. Oblique lumbar radiographs, usually done to screen for spondylolysis, double the X-ray dose to the patient and rarely add useful clinical information in adults. Although oblique radiographs do provide visualization of the pars interarticularis in the case of suspected spondylolisthesis, MRI or CT more accurately guides decision making for a suspected acute pars fracture.[14] Flexion/extension films are useful to identify spondylolisthesis with associated instability, although clinical judgment is required to determine the appropriate candidates for this imaging and the potential clinical relevance of any findings.[55,68,116]

Advanced imaging studies, such as bone scans, MRI, and CT, should be reserved for patients with LBP who are likely surgical candidates, patients whose symptoms do not respond over a longer period of time, patients whose symptoms are not consistent with typical musculoskeletal presentations, and patients with abnormal screening findings.[94,95] In patients with a strong pretest likelihood of spinal pathology, normal radiographs and an elevated ESR, advanced imaging studies are indicated. Bone scans are more sensitive than plain films for detecting either infections or neoplasms of the spine. MRI provides greater anatomic detail, with increased sensitivity and specificity at about twice the cost of a bone scan. The sensitivity of bone scans for neoplasms ranges from 74% to 98%; the sensitivity of MRIs ranges from 83% to 93%.[49]

MRI is an appropriate study to provide anatomic detail of a herniated disc before surgery for patients who are limited by sciatica for more than 4 weeks and show physiologic evidence of neurologic dysfunction. Careful clinical correlation is required for any imaged pathology, as anatomic abnormalities of the lumbar spine, including degenerative changes and abnormal discs, are commonly found in the asymptomatic population and these findings increase in frequency with older patients.[50,96]

The screening strategy is dependent upon the sensitivity of the ESR for infectious processes, as plain films have the least sensitivity for spinal infections. Radiographic abnormalities may not appear in spinal radiographs for 2 to 8 weeks.[44] MRI has been found to be as equally sensitive to spinal infections as CT myelography, with 96% sensitivity and 92% specificity. Additionally, MRI provides better imaging of the vertebral bodies, intervertebral disks, and paravertebral tissues. T1-weighted MRI is superior to CT myelography for providing details of the anatomic limits of the abscess, the degree of cord compression, and paraspinal and vertebral involvement.[49,94,97]

Nonspinal conditions, such as vascular, abdominal, urinary, or pelvic pathology, are capable of referring symptoms to the lower back. Suspected pathology within these systems may indicate a need for additional screening questions, tests, and measures, such as abdominal and pelvic region palpation, and laboratory tests and/or imaging procedures such as ultrasound or CT.

CONCLUSIONS

In conclusion, musculoskeletal imaging represents an increasingly important diagnostic tool for physical therapists, regardless of whether the physical therapist can presently order the studies or simply use the results in the differential diagnosis decision-making process. The evidence suggests that physical therapists can use their strong knowledge of anatomy and experience in musculoskeletal examination to appropriately decide when to order imaging studies, thereby reducing imaging rates, with no adverse outcome to the patient. For optimal diagnostic efficiency and accuracy, it is essential to understand probability-based diagnosis and to stay current with the evidence related to the diagnostic properties of the various imaging modalities for common conditions physical therapists are likely to encounter in clinical practice.

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REFERENCES

1. Ahovuo JA, Kiuru MJ, Kinnunen JJ, Haapamaki V, Pihlajamaki HK. MR imaging of fatigue stress injuries to bones: intra- and interobserver agreement. *Magn Reson Imaging.* 2002;20:401-406.
2. Albarran J, Durham B, Gowers J, Dwight J, Chappell G. Is the radiation of chest pain a useful indicator of myocardial infarction? A prospective study of 541 patients. *Accid Emerg Nurs.* 2002;10:2-9.

3. Almeida SA, Williams KM, Shaffer RA, Brodine SK. Epidemiological patterns of musculoskeletal injuries and physical training. *Med Sci Sports Exerc.* 1999;31:1176-1182.

4. Angtuaco EJ, Fassas AB, Walker R, Sethi R, Barlogie B. Multiple myeloma: clinical review and diagnostic imaging. *Radiology.* 2004;231:11-23.

5. Ankarath S, Ng AB, Giannoudis PV, Scott BW. Delay in diagnosis of slipped upper femoral epiphysis. *J R Soc Med.* 2002;95:356-358.

6. Armstrong DW, 3rd, Rue JP, Wilckens JH, Frassica FJ. Stress fracture injury in young military men and women. *Bone.* 2004;35:806-816.

7. Benson CJ, Schreck RC, Underwood FB, Greathouse DG. The role of Army physical therapists as nonphysician health care providers who prescribe certain medications: observations and experiences. *Phys Ther.* 1995;75:380-386.

8. Bigos S, Bowyer O, Braen G, et al. Acute low back problems in adults. Clinical practice guideline no. 14. AHCPR publication no. 95-0642. Rockville, MD: Agency for Health Care Policy and Research, Public Health Service, US Department of Health and Human Services; 1994.

9. Bigos SJ. Perils, pitfalls, and accomplishments of guidelines for treatment of back problems. *Neurol Clin.* 1999;17:179-192.

10. Bigos SJ, Davis GE. Scientific application of sports medicine principles for acute low back problems. The Agency for Health Care Policy and Research Low Back Guideline Panel (AHCPR, Guideline #14). *J Orthop Sports Phys Ther.* 1996;24:192-207.

11. Brealey S. Measuring the effects of image interpretation: an evaluative framework. *Clin Radiol.* 2001;56:341-347.

12. Bryan JM, Bursch G, Greathouse DG. The future of physical therapy. *Rehab Manag.* 1998;11:48-50, 52, 54.

13. Calmbach WL, Hutchens M. Evaluation of patients presenting with knee pain: Part II. Differential diagnosis. *Am Fam Physician.* 2003;68:917-922.

14. Campbell RS, Grainger AJ, Hide IG, Papastefanou S, Greenough CG. Juvenile spondylolysis: a comparative analysis of CT, SPECT and MRI. *Skeletal Radiol.* 2005;34:63-73.

15. Chang CY, Wang SF, Chiou HJ, Ma HL, Sun YC, Wu HD. Comparison of shoulder ultrasound and MR imaging in diagnosing full-thickness rotator cuff tears. *Clin Imaging.* 2002;26:50-54.

16. Clough TM. Femoral neck stress fracture: the importance of clinical suspicion and early review. *Br J Sports Med.* 2002;36:308-309.

17. Connell DA, Schneider-Kolsky ME, Hoving JL, et al. Longitudinal study comparing sonographic and MRI assessments of acute and healing hamstring injuries. *AJR Am J Roentgenol.* 2004;183:975-984.

18. Craig JG, Moed BR, Eyler WR, van Holsbeeck M. Fractures of the greater trochanter: intertrochanteric extension shown by MR imaging. *Skeletal Radiol.* 2000;29:572-576.

19. Daffner RH. Evaluation of cervical vertebral injuries. *Semin Roentgenol.* 1992;27:239-253.

20. Daker-White G, Carr AJ, Harvey I, et al. A randomised controlled trial. Shifting boundaries of doctors and physiotherapists in orthopaedic outpatient departments. *J Epidemiol Community Health.* 1999;53:643-650.

21. Deyo RA, Diehl AK. Cancer as a cause of back pain: frequency, clinical presentation, and diagnostic strategies. *J Gen Intern Med.* 1988;3:230-238.

22. Deyo RA, Rainville J, Kent DL. What can the history and physical examination tell us about low back pain? *JAMA.* 1992;268:760-765.

23. Doran FS. The sites to which pain is referred from the common bile-duct in man and its implication for the theory of referred pain. *Br J Surg.* 1967;54:599-606.

24. Dorsay TA, Major NM, Helms CA. Cost-effectiveness of immediate MR imaging versus traditional follow-up for revealing radiographically occult scaphoid fractures. *AJR Am J Roentgenol.* 2001;177:1257-1263.

25. Ebenbichler GR, Erdogmus CB, Resch KL, et al. Ultrasound therapy for calcific tendinitis of the shoulder. *N Engl J Med.* 1999;340:1533-1538.

26. Ebenbichler GR, Resch KL, Graninger WB. Resolution of calcium deposits after therapeutic ultrasound of the shoulder. *J Rheumatol.* 1997;24:235-236.

27. Feldman F. Musculoskeletal radiology: then and now. *Radiology.* 2000;216:309-316.

28. Feldman F, Staron R, Zwass A, Rubin S, Haramati N. MR imaging: its role in detecting occult fractures. *Skeletal Radiol.* 1994;23:439-444.

29. Flatman JG. Hip diseases with referred pain to the knee. *JAMA.* 1975;234:967-968.

30. Freedman KB, Bernstein J. The adequacy of medical school education in musculoskeletal medicine. *J Bone Joint Surg Am.* 1998;80:1421-1427.

31. Freedman KB, Bernstein J. Educational deficiencies in musculoskeletal medicine. *J Bone Joint Surg Am.* 2002;84-A:604-608.

32. Fritz JM, Wainner RS. Examining diagnostic tests: an evidence-based perspective. *Phys Ther.* 2001;81:1546-1564.

33. Fukui S, Ohseto K, Shiotani M. Patterns of pain induced by distending the thoracic zygapophyseal joints. *Reg Anesth.* 1997;22:332-336.

34. Fukui S, Ohseto K, Shiotani M, Ohno K, Karasawa H, Naganuma Y. Distribution of referred pain from the lumbar zygapophyseal joints and dorsal rami. *Clin J Pain.* 1997;13:303-307.

35. Fukui S, Ohseto K, Shiotani M, et al. Referred pain distribution of the cervical zygapophyseal joints and cervical dorsal rami. *Pain.* 1996;68:79-83.

36. Goddard P, Leslie A, Jones A, Wakeley C, Kabala J. Error in radiology. *Br J Radiol.* 2001;74:949-951.

37. Gore DR. Roentgenographic findings in the cervical spine in asymptomatic persons: a ten-year follow-up. *Spine.* 2001;26:2463-2466.

38. Graber MA, Kathol M. Cervical spine radiographs in the trauma patient. *Am Fam Physician.* 1999;59:331-342.

39. Graham ID, Stiell IG, Laupacis A, et al. Awareness and use of the Ottawa ankle and knee rules in 5 countries: can publication alone be enough to change practice? *Ann Emerg Med.* 2001;37:259-266.

40. Graham ID, Stiell IG, Laupacis A, O'Connor AM, Wells GA. Emergency physicians' attitudes toward and use of clinical decision rules for radiography. *Acad Emerg Med.* 1998;5:134-140.

41. Graven-Nielsen T, Arendt-Nielsen L. Peripheral and central sensitization in musculoskeletal pain disorders: an experimental approach. *Curr Rheumatol Rep.* 2002;4:313-321.

42. Gray SD, Kaplan PA, Dussault RG, et al. Acute knee trauma: how many plain film views are necessary for the initial examination? *Skeletal Radiol.* 1997;26:298-302.

43. Greathouse DG, Schreck RC, Benson CJ. The United States Army physical therapy experience: evaluation and treatment of patients with neuromusculoskeletal disorders. *J Orthop Sports Phys Ther.* 1994;19:261-266.

44. Greenspan A. *Orthopaedic Radiology: A Practical Approach.* Philadelphia, PA: Lippincott, Williams and Wilkins; 2000.

45. Harrison DE, Bula JM, Gore DR. Roentgenographic findings in the cervical spine in asymptomatic persons: A 10-year follow-up. *Spine.* 2002;27:1249-1250.

46. Iannotti JP, Ciccone J, Buss DD, et al. Accuracy of office-based ultrasonography of the shoulder for the diagnosis of rotator cuff tears. *J Bone Joint Surg Am.* 2005;87:1305-1311.

47. James JJ, Abshier JD. The primary evaluation of musculoskeletal disorders by the physical therapist. *Mil Med.* 1981;146:496-499.

48. James JJ, Stuart RB. Expanded role for the physical therapist. Screening musculoskeletal disorders. *Phys Ther.* 1975;55:121-131.

49. Jarvik JG, Deyo RA. Diagnostic evaluation of low back pain with emphasis on imaging. *Ann Intern Med.* 2002;137:586-597.

50. Jensen MC, Brant-Zawadzki MN, Obuchowski N, Modic MT, Malkasian D, Ross JS. Magnetic resonance imaging of the lumbar spine in people without back pain. *N Engl J Med.* 1994;331:69-73.

51. Kaplan PA, Dussault RG, Helms CA, Anderson MW. *Musculoskeletal MRI.* Philadelphia, PA: W.B. Saunders Company; 2001.

52. Kiuru MJ, Mantysaari MJ, Pihlajamaki HK, Ahovuo JA. Evaluation of stress-related anterior lower leg pain with magnetic resonance imaging and intracompartmental pressure measurement. *Mil Med.* 2003;168:48-52.

53. Kiuru MJ, Pihlajamaki HK, Hietanen HJ, Ahovuo JA. MR imaging, bone scintigraphy, and radiography in bone stress injuries of the pelvis and the lower extremity. *Acta Radiol.* 2002;43:207-212.

54. Klein BJ, Radecki RT, Foris MP, Feil EI, Hickey ME. Bridging the gap between science and practice in managing low back pain. A comprehensive spine care system in a health maintenance organization setting. *Spine.* 2000;25:738-740.

55. Krupski W, Majcher P, Fatyga M, Zlomaniec J. The value of spatial reconstructions with computed tomography (3D CT) in recognising the fissure of vertebral arch. *Ann Univ Mariae Curie Sklodowska [Med].* 2002;57:463-470.

56. Laupacis A, Sekar N, Stiell IG. Clinical prediction rules. A review and suggested modifications of methodological standards. *JAMA.* 1997;277:488-494.

57. Laupacis A, Stiell I, Stewart D, Anis A. Using the Ottawa Ankle Rules. *Ann Emerg Med.* 1996;28:730-731.

58. Levy AR, Goldberg MS, Hanley JA, Mayo NE, Poitras B. Projecting the lifetime risk of cancer from exposure to diagnostic ionizing radiation for adolescent idiopathic scoliosis. *Health Phys.* 1994;66:621-633.

59. Levy AR, Goldberg MS, Mayo NE, Hanley JA, Poitras B. Reducing the lifetime risk of cancer from spinal radiographs among people with adolescent idiopathic scoliosis. *Spine.* 1996;21:1540-1547; discussion 1548.

60. Linklater J, Potter HG. Emergent musculoskeletal magnetic resonance imaging. *Top Magn Reson Imaging.* 1998;9:238-260.

61. Lucchesi GM, Jackson RE, Peacock WF, Cerasani C, Swor RA. Sensitivity of the Ottawa rules. *Ann Emerg Med.* 1995;26:1-5.

62. Lundeberg T, Ekholm J. Pain--from periphery to brain. *Disabil Rehabil.* 2002;24:402-406.

63. Luukkainen RK, Saltyshev M, Koski JM, Huhtala HS. Relationship between clinically detected joint swelling and effusion diagnosed by ultrasonography in metatar- sophalangeal and talocrural joints in patients with rheumatoid arthritis. *Clin Exp Rheumatol.* 2003;21:632-634.

64. Major NM, Helms CA. MR imaging of the knee: findings in asymptomatic collegiate basketball players. *AJR Am J Roentgenol.* 2002;179:641-644.

65. Matzkin E, Smith EL, Freccero D, Richardson AB. Adequacy of education in musculoskeletal medicine. *J Bone Joint Surg Am.* 2005;87:310-314.

66. Mennell JM. Differential diagnosis of visceral from somatic back pain. *J Occup Med.* 1966;8:477-480.

67. Milgrom C, Schaffler M, Gilbert S, van Holsbeeck M. Rotator-cuff changes in asymptomatic adults. The effect of age, hand dominance and gender. *J Bone Joint Surg Br.* 1995;77:296-298.

68. Miller SF, Congeni J, Swanson K. Long-term functional and anatomical follow-up of early detected spondylolysis in young athletes. *Am J Sports Med.* 2004;32:928-933.

69. Mintz DN. Imaging of sports injuries. *Phys Med Rehabil Clin N Am.* 2000;11:435-469.

70. Moilanen A, Kokko ML, Pitkanen M. Gonadal dose reduction in lumbar spine radiography. *Skeletal Radiol.* 1983;9:153-156.

71. Moller M, Kalebo P, Tidebrant G, Movin T, Karlsson J. The ultrasonographic appearance of the ruptured Achilles tendon during healing: a longitudinal evaluation of surgical and nonsurgical treatment, with comparisons to MRI appearance. *Knee Surg Sports Traumatol Arthrosc.* 2002;10:49-56.

72. Moore JH, Goss DL, Baxter RE, et al. Clinical diagnostic accuracy and magnetic resonance imaging of patients referred by physical therapists, orthopaedic surgeons, and nonorthopaedic providers. *J Orthop Sports Phys Ther.* 2005;35:67-71.

73. Mork AA, Haufe SM, Yancey WB. Sometimes (what seems to be) a heart attack is (really) a pain in the neck. *J Am Board Fam Pract.* 2004;17:74-77.

74. Negrini S, Politano E, Carabalona R, Mambrini A. General practitioners' management of low back pain: impact of clinical guidelines in a non-English-speaking country. *Spine.* 2001;26:2727-2733; discussion 2734.

75. Nichol G, Stiell IG, Wells GA, Juergensen LS, Laupacis A. An economic analysis of the Ottawa knee rule. *Ann Emerg Med.* 1999;34:438-447.

76. O'Dwyer H, O'Sullivan P, Fitzgerald D, Lee MJ, McGrath F, Logan PM. The fat pad sign following elbow trauma in adults: its usefulness and reliability in suspecting occult fracture. *J Comput Assist Tomogr.* 2004;28:562-565.

77. Ohashi K, Brandser EA, el-Khoury GY. Role of MR imaging in acute injuries to the appendicular skeleton. *Radiol Clin North Am.* 1997;35:591-613.

78. Oka M, Monu JU. Prevalence and patterns of occult hip fractures and mimics revealed by MRI. *AJR Am J Roentgenol.* 2004;182:283-288.

79. Pandey R, McNally E, Ali A, Bulstrode C. The role of MRI in the diagnosis of occult hip fractures. *Injury.* 1998;29:61-63.

80. Pellecchia GL, Lugo-Larcheveque N, Deluca PA. Differential diagnosis in physical therapy evaluation of thigh pain in an adolescent boy. *J Orthop Sports Phys Ther.* 1996;23:51-55.

81. Petren-Mallmin M, Linder J. MRI cervical spine findings in asymptomatic fighter pilots. *Aviat Space Environ Med.* 1999;70:1183-1188.

82. Plint AC, Bulloch B, Osmond MH, et al. Validation of the Ottawa Ankle Rules in children with ankle injuries. *Acad Emerg Med.* 1999;6:1005-1009.

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83. Reeder MT, Dick BH, Atkins JK, Pribis AB, Martinez JM. Stress fractures. Current concepts of diagnosis and treatment. *Sports Med.* 1996;22:198-212.

84. Richman PB, McCuskey CF, Nashed A, et al. Performance of two clinical decision rules for knee radiography. *J Emerg Med.* 1997;15:459-463.

85. Riddle DL, Hillner BE, Wells PS, Johnson RE. Improving the diagnostic process for deep vein thrombosis in orthopaedic outpatients. *Clin Orthop Relat Res.* 2005;258-266.

86. Riddle DL, Hillner BE, Wells PS, Johnson RE, Hoffman HJ, Zuelzer WA. Diagnosis of lower-extremity deep vein thrombosis in outpatients with musculoskeletal disorders: a national survey study of physical therapists. *Phys Ther.* 2004;84:717-728.

87. Riddle DL, Hoppener MR, Kraaijenhagen RA, Anderson J, Wells PS. Preliminary validation of clinical assessment for deep vein thrombosis in orthopaedic outpatients. *Clin Orthop Relat Res.* 2005;252-257.

88. Robbins SE, Morse MH. Is the acquisition of a separate view of the sacroiliac joints in the prone position justified in patients with back pain? *Clin Radiol.* 1996;51:637-638.

89. Robinson PJ. Radiology's Achilles' heel: error and variation in the interpretation of the Rontgen image. *Br J Radiol.* 1997;70:1085-1098.

90. Sackett DL, Straus SE, Richardson WS, Rosenberg W, Haynes RB. *Evidence-Based Medicine: How to Practice and Teach EBM.* New York, NY: Churchill Livingstone; 2000.

91. Sartoris D. *Musculoskeletal Imaging: The Requisites.* Philadelphia, PA: Mosby; 1996.

92. Scavone JG, Latshaw RF, Weidner WA. Anteroposterior and lateral radiographs: an adequate lumbar spine examination. *AJR Am J Roentgenol.* 1981;136:715-717.

93. Siivola SM, Levoska S, Tervonen O, Ilkko E, Vanharanta H, Keinanen-Kiukaanniemi S. MRI changes of cervical spine in asymptomatic and symptomatic young adults. *Eur Spine J.* 2002;11:358-363.

94. Smith AS, Blaser SI. Infectious and inflammatory processes of the spine. *Radiol Clin North Am.* 1991;29: 809-827.

95. Smith AS, Blaser SI. MR of infectious and inflammatory diseases of the spine. *Crit Rev Diagn Imaging.* 1991;32:165-189.

96. Stadnik TW, Lee RR, Coen HL, Neirynck EC, Buisseret TS, Osteaux MJ. Annular tears and disk herniation: prevalence and contrast enhancement on MR images in the absence of low back pain or sciatica. *Radiology.* 1998;206:49-55.

97. Staiger TO, Paauw DS, Deyo RA, Jarvik JG. Imaging studies for acute low back pain. When and when not to order them. *Postgrad Med.* 1999;105:161-162, 165-166, 171-162.

98. Stiell I. Ottawa ankle rules. *Can Fam Physician.* 1996;42:478-480.

99. Stiell I, Wells G, Laupacis A, et al. Multicentre trial to introduce the Ottawa ankle rules for use of radiography in acute ankle injuries. Multicentre Ankle Rule Study Group. *BMJ.* 1995;311:594-597.

100. Stiell IG. Clinical decision rules in the emergency department. *Cmaj.* 2000;163:1465-1466.

101. 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;349:2510-2518.

102. Stiell IG, Greenberg GH, McKnight RD, et al. Decision rules for the use of radiography in acute ankle injuries. Refinement and prospective validation. *JAMA.* 1993;269:1127-1132.

103. Stiell IG, Greenberg GH, McKnight RD, Nair RC, McDowell I, Worthington JR. A study to develop clinical decision rules for the use of radiography in acute ankle injuries. *Ann Emerg Med.* 1992;21:384-390.

104. Stiell IG, Greenberg GH, McKnight RD, Wells GA. Ottawa ankle rules for radiography of acute injuries. *N Z Med J.* 1995;108:111.

105. Stiell IG, Greenberg GH, McKnight RD, Wells GA. The "real" Ottawa ankle rules. *Ann Emerg Med.* 1996;27:103-104.

106. Stiell IG, Greenberg GH, Wells GA, et al. Prospective validation of a decision rule for the use of radiography in acute knee injuries. *JAMA.* 1996;275:611-615.

107. Stiell IG, Greenberg GH, Wells GA, et al. Derivation of a decision rule for the use of radiography in acute knee injuries. *Ann Emerg Med.* 1995;26:405-413.

108. Stiell IG, Lesiuk H, Wells GA, et al. Canadian CT head rule study for patients with minor head injury: methodology for phase II (validation and economic analysis). *Ann Emerg Med.* 2001;38:317-322.

109. Stiell IG, Lesiuk H, Wells GA, et al. The Canadian CT Head Rule Study for patients with minor head injury: rationale, objectives, and methodology for phase I (derivation). *Ann Emerg Med.* 2001;38:160-169.

110. Stiell IG, McKnight RD, Greenberg GH, et al. Implementation of the Ottawa ankle rules. *JAMA.* 1994;271:827-832.

111. Stiell IG, Wells GA. Methodologic standards for the development of clinical decision rules in emergency medicine. *Ann Emerg Med.* 1999;33:437-447.

112. Stiell IG, Wells GA, Hoag RH, et al. Implementation of the Ottawa Knee Rule for the use of radiography in acute knee injuries. *JAMA.* 1997;278:2075-2079.

113. Stiell IG, Wells GA, McDowell I, et al. Use of radiography in acute knee injuries: need for clinical decision rules. *Acad Emerg Med.* 1995;2:966-973.

114. Stiell IG, Wells GA, McKnight RD. Validating the "real" Ottawa Knee Rule. *Ann Emerg Med.* 1999;33: 241-243.

115. Stiell IG, Wells GA, Vandemheen KL, et al. The Canadian C-spine rule for radiography in alert and stable trauma patients. *JAMA.* 2001;286:1841-1848.

116. Stillerman CB, Schneider JH, Gruen JP. Evaluation and management of spondylolysis and spondylolisthesis. *Clin Neurosurg.* 1993;40:384-415.

117. Suarez-Almazor ME, Belseck E, Russell AS, Mackel JV. Use of lumbar radiographs for the early diagnosis of low back pain. Proposed guidelines would increase utilization. *JAMA.* 1997;277:1782-1786.

118. Szkudlarek M, Narvestad E, Klarlund M, Court-Payen M, Thomsen HS, Ostergaard M. Ultrasonography of the metatarsophalangeal joints in rheumatoid arthritis: comparison with magnetic resonance imaging, conventional radiography, and clinical examination. *Arthritis Rheum.* 2004;50:2103-2112.

119. Tandeter HB, Shvartzman P. Acute knee injuries: use of decision rules for selective radiograph ordering. *Am Fam Physician.* 1999;60:2599-2608.

120. Teefey SA, Rubin DA, Middleton WD, Hildebolt CF, Leibold RA, Yamaguchi K. Detection and quantification of rotator cuff tears. Comparison of ultrasonographic, magnetic resonance imaging, and arthroscopic findings in seventy-one consecutive cases. *J Bone Joint Surg Am.* 2004;86-A:708-716.

121. Tehranzadeh J, Andrews C, Wong E. Lumbar spine imaging. Normal variants, imaging pitfalls, and artifacts. *Radiol Clin North Am.* 2000;38:1207-1253, v-vi.

122. Tippett SR. Referred knee pain in a young athlete: a case study. *J Orthop Sports Phys Ther.* 1994;19:117-120.

123. Wells PS, Anderson DR, Bormanis J, et al. Value of assessment of pretest probability of deep-vein thrombosis in clinical management. *Lancet.* 1997;350:1795-1798.

124. Williams CF, Bernstein TW, Jelenko C, 3rd. Essentiality of the lateral cervical spine radiograph. *Ann Emerg Med.* 1981;10:198-204.

125. Williams SM, Connelly DJ, Wadsworth S, Wilson DJ. Radiological review of accident and emergency radiographs: a 1-year audit. *Clin Radiol.* 2000;55:861-865.

126. Wolf SJ, McCubbin TR, Feldhaus KM, Faragher JP, Adcock DM. Prospective validation of Wells Criteria in the evaluation of patients with suspected pulmonary embolism. *Ann Emerg Med.* 2004;44:503-510.

127. Zimny NJ. Diagnostic classification and orthopaedic physical therapy practice: what we can learn from medicine. *J Orthop Sports Phys Ther.* 2004;34:105-109; discussion 110-105.

128. Zwas ST, Elkanovitch R, Frank G. Interpretation and classification of bone scintigraphic findings in stress fractures. *J Nucl Med.* 1987;28:452-457.

CLINICAL COMMENTARY