

**American College of Radiology
ACR Appropriateness Criteria®
Nontraumatic Chest Wall Pain**

Variant 1: Nontraumatic chest wall pain. No history of malignancy. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
Radiography chest	Usually Appropriate	☼
US chest	May Be Appropriate	○
Radiography rib views	May Be Appropriate	☼☼☼
MRI chest without and with IV contrast	Usually Not Appropriate	○
MRI chest without IV contrast	Usually Not Appropriate	○
Bone scan whole body	Usually Not Appropriate	☼☼☼
CT chest with IV contrast	Usually Not Appropriate	☼☼☼
CT chest without and with IV contrast	Usually Not Appropriate	☼☼☼
CT chest without IV contrast	Usually Not Appropriate	☼☼☼
FDG-PET/CT skull base to mid-thigh	Usually Not Appropriate	☼☼☼☼
WBC scan chest	Usually Not Appropriate	☼☼☼☼

Variant 2: Nontraumatic chest wall pain. Known or suspected malignancy. Secondary evaluation after normal chest radiograph. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
Bone scan whole body	Usually Appropriate	☼☼☼
CT chest with IV contrast	Usually Appropriate	☼☼☼
CT chest without IV contrast	Usually Appropriate	☼☼☼
Radiography rib views	May Be Appropriate	☼☼☼
MRI chest without and with IV contrast	May Be Appropriate	○
MRI chest without IV contrast	May Be Appropriate	○
FDG-PET/CT skull base to mid-thigh	May Be Appropriate	☼☼☼☼
US chest	Usually Not Appropriate	○
CT chest without and with IV contrast	Usually Not Appropriate	☼☼☼
WBC scan chest	Usually Not Appropriate	☼☼☼☼

Variant 3:

Nontraumatic chest wall pain. Suspected infectious or inflammatory condition. Secondary evaluation after normal chest radiograph. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
CT chest with IV contrast	Usually Appropriate	⊕⊕⊕
CT chest without IV contrast	Usually Appropriate	⊕⊕⊕
US chest	May Be Appropriate	○
MRI chest without and with IV contrast	May Be Appropriate	○
MRI chest without IV contrast	May Be Appropriate (Disagreement)	○
Bone scan whole body	May Be Appropriate (Disagreement)	⊕⊕⊕
FDG-PET/CT skull base to mid-thigh	May Be Appropriate	⊕⊕⊕⊕
WBC scan chest	May Be Appropriate	⊕⊕⊕⊕
Radiography rib views	Usually Not Appropriate	⊕⊕⊕
CT chest without and with IV contrast	Usually Not Appropriate	⊕⊕⊕

Variant 4:

Nontraumatic chest wall pain. History of prior chest intervention. Secondary evaluation after normal chest radiograph. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
CT chest with IV contrast	Usually Appropriate	⊕⊕⊕
CT chest without IV contrast	Usually Appropriate	⊕⊕⊕
US chest	May Be Appropriate	○
MRI chest without and with IV contrast	May Be Appropriate	○
MRI chest without IV contrast	May Be Appropriate	○
FDG-PET/CT skull base to mid-thigh	May Be Appropriate	⊕⊕⊕⊕
Radiography rib views	Usually Not Appropriate	⊕⊕⊕
Bone scan whole body	Usually Not Appropriate	⊕⊕⊕
CT chest without and with IV contrast	Usually Not Appropriate	⊕⊕⊕
WBC scan chest	Usually Not Appropriate	⊕⊕⊕⊕

NONTRAUMATIC CHEST WALL PAIN

Expert Panel on Thoracic Imaging: Justin T. Stowell, MD^a; Christopher M. Walker, MD^b; Jonathan H. Chung, MD^c; Tami J. Bang, MD^d; Brett W. Carter, MD^e; Jared D. Christensen, MD, MBA^f; Edwin F. Donnelly, MD, PhD^g; Tarek N. Hanna, MD^h; Stephen B. Hobbs, MDⁱ; Braeden D. Johnson, MD^j; Asha Kandathil, MD^k; Bruce M. Lo, MD, RDMS, MBA^l; Rachna Madan, MBBS^m; Sarah Majercik, MD, MBAⁿ; William H. Moore, MD^o; Jeffrey P. Kanne, MD.^p

Summary of Literature Review

Introduction/Background

Chest pain is a common reason that patients may present for evaluation in both ambulatory and emergency department settings. Of the many causes for undifferentiated chest pain, acute cardiovascular processes (eg, myocardial infarction or aortic dissection) are the most important to distinguish from less life-threatening etiologies. Distinguishing visceral (eg, angina) from musculoskeletal (ie, chest wall) pain is an essential step in the diagnostic approach. An estimated 20% to 40% of the general population may be affected by chest pain in their lifetime [1], and almost half of patients presenting to primary care settings with chest pain were diagnosed with musculoskeletal causes. Patients presenting to ambulatory care settings more often are found to have noncardiovascular causes of chest pain (musculoskeletal, gastrointestinal, and psychopathologic) than those presenting to emergency departments [1,2]. One large series of ambulatory patients described their chest wall symptoms as stinging (53.0%) or pressing (35.1%), retrosternal (52.0%) or left-sided (69.2%), occurring more than once daily (62.9%), with more than half (55.4%) having chronic symptoms lasting >6 months [1].

Chest wall syndrome collectively describes the various entities that can contribute to chest wall pain of musculoskeletal origin and may affect any chest wall structure including bones, cartilage, joints, ligaments, tendons, and muscles, inclusive of the spine. Most (42%) nontraumatic musculoskeletal chest wall pain has been attributed to costochondritis, which, in most cases, is readily diagnosed by physical examination, without need for diagnostic imaging [3]. One prospective study found that musculoskeletal pain was the most common cause for acute chest pain (51.2%) after other causes were excluded [4]. Anterior chest wall pain affects 30% to 60% of those with axial spondyloarthritis and may be the first manifestation of disease in 4% to 6% of patients [5,6]. Sternoclavicular and manubriosternal joints may be involved in up to half of patients [5]. Chest wall surgical site infections are relatively uncommon, but various risk factors (age, malnutrition, diabetes, smoking, obesity, immunosuppression, coexisting infections, and surgical technique) may increase a patient's risk [7]. Poststernotomy pain is relatively frequent after cardiac surgery that may negatively affect performance of activities of daily living and postoperative quality of life [8]. Chest wall pain may be broadly classified as traumatic or nontraumatic. The recommendations for imaging after blunt chest trauma have already been addressed in previous ACR Appropriateness Criteria. Herein, we address imaging utility in the evaluation of nontraumatic chest wall pain.

Initial Imaging Definition

Initial imaging is defined as imaging at the beginning of the care episode for the medical condition defined by the variant. More than one procedure can be considered usually appropriate in the initial imaging evaluation when:

- There are procedures that are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care)

OR

^aResearch Author, Mayo Clinic Florida, Jacksonville, Florida. ^bUniversity of Kansas Medical Center, Kansas City, Kansas. ^cPanel Chair, University of Chicago, Chicago, Illinois. ^dUniversity of Colorado School of Medicine, Anschutz Medical Campus, Aurora, Colorado. ^eThe University of Texas MD Anderson Cancer Center, Houston, Texas. ^fDuke University Medical Center, Durham, North Carolina. ^gOhio State University, Columbus, Ohio. ^hEmory University, Atlanta, Georgia. ⁱUniversity of Kentucky, Lexington, Kentucky. ^jSalina Regional Health Center, Salina, Kansas. ^kUT Southwestern Medical Center, Dallas, Texas. ^lSentara Norfolk General/Eastern Virginia Medical School, Norfolk, Virginia; American College of Emergency Physicians. ^mBrigham & Women's Hospital, Boston, Massachusetts. ⁿIntermountain Medical Center, Salt Lake City, Utah; American Association for the Surgery of Trauma. ^oNew York University Langone Medical Center, New York, New York. ^pSpecialty Chair, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin.

The American College of Radiology seeks and encourages collaboration with other organizations on the development of the ACR Appropriateness Criteria through representation of such organizations on expert panels. Participation on the expert panel does not necessarily imply endorsement of the final document by individual contributors or their respective organization.

Reprint requests to: publications@acr.org

- There are complementary procedures (ie, more than one procedure is ordered as a set or simultaneously where each procedure provides unique clinical information to effectively manage the patient's care).

Discussion of Procedures by Variant

Variant 1: Nontraumatic chest wall pain. No history of malignancy. Initial imaging.

Bone Scan Whole Body

Bone scintigraphy using diphosphonate radiotracer has been used to detect a variety of bone diseases that may cause chest wall pain, including fractures, metastases, arthritis, osteomyelitis, osteonecrosis, and costochondritis [9], but is usually not useful as an initial imaging modality. In a retrospective study of 225 patients with atypical chest pain considered to be of low to intermediate Framingham coronary risk, Tc-99m methylene diphosphonate bone scintigraphy showed a focal abnormality in nearly half (49.4%), with most (42.7%) being posttraumatic lesions of the rib, sternum, vertebral bodies, or clavicle; 4.9% costochondritis; and 1.8% neoplastic lesions [9]. Bone scintigraphy was positive in 5/7 (71.4%) patients diagnosed with costochondritis [9]. Overall, bone scintigraphy helped determine a cause for chest pain in 94/225 (41.8%) of patients, but in 15.3% of patients with abnormalities on bone scintigraphy, the true cause for chest pain was considered irrelevant to those findings [9].

CT Chest

Despite its superior sensitivity for detection and characterization of chest wall abnormalities, in the absence of other clinical risk factors like trauma, infection, or malignancy, CT may not be useful as a first-line modality for evaluation of chest wall pain [10]. For diagnosis of cough-induced rib fractures, some authors suggest that chest CT be reserved for patients who require evaluation of other pulmonary diseases [11]. Although not validated in nontraumatic settings, diagnostic accuracy for rib fractures may be improved and reading time decreased when the radiologist incorporates unfolded rib reformatted images [12,13]. Chest CT might also diagnose other causes of chest wall pain, such as mediastinal fat necrosis (also variably referred to in the literature as pericardial, epicardial, and epericardial fat necrosis) [14].

FDG-PET/CT Skull Base to Mid-Thigh

There is no relevant literature to support the use of fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET/CT as initial imaging in the evaluation of chest wall pain in patients with no history of malignancy.

MRI Chest

MRI may be complementary to other modalities in characterization of various processes and to delineate the extent of chest wall or osseous involvement on a case-by-case basis [15].

Radiography Chest

After a thorough history and physical examination, chest radiography may be a useful initial imaging test to evaluate for specific etiologies of chest wall pain (eg, rib fracture, infection, or neoplasm) and to evaluate for other conditions that may simulate chest wall pain, such as spontaneous pneumothorax [16]. However, chest radiographs may be insensitive to detect abnormalities of the rib cartilages, costochondral junctions, costovertebral joints, and chest wall soft tissues. In a series of 183 stable adult outpatients presenting with nontraumatic chest pain imaging with both chest radiography and rib series, rib fractures were detected in only 4.9% of cases [17]. In another study of 1,089 patients presenting to the emergency department who underwent chest radiography for evaluation of nontraumatic chest pain, only 70 (6.4%) were deemed to have findings clinically relevant to emergency department care [18]. In one series of patients with rupture of the costal margin associated with severe coughing fits, all patients had widening of the rib spaces on chest radiographs, whereas 4/9 patients had associated rib fractures [19].

Radiography Rib Views

For focal chest wall pain detected at physical examination, a radiographic rib series may be helpful to assess for rib fracture or other rib lesion [16]. Radio-opaque skin markers placed on the skin have been used by some institutions to assist the radiologist in localization of abnormalities near the patient's site of pain. In one retrospective series of 17 patients who presented with post-tussive chest pain, 14 (82.4%) were diagnosed with rib fractures on rib radiography [11]. Most fractures involved the mid to lower ribs, with the 10th rib being the most commonly affected [11]. Sensitivity for detection of minor traumatic rib fractures was improved with combined use of conventional and inverted grayscale rib series [20]. However, despite being more sensitive for detection of rib fractures than chest radiographs in the setting of minor thoracic trauma, detection of rib fractures on conventional rib series radiographs resulted in no significant change in clinical management between the 2 groups, calling into question their clinical utility [21].

US Chest

Although diagnostic ultrasound (US) of the chest is not typically utilized for the evaluation of chest wall pain, point-of-care US has been shown to be feasible for detection of rib fractures in the setting of minor trauma in emergency settings, with 27/94 (29%) detecting rib fractures after negative chest radiography [22]. Another study showed US to detect costochondral fractures in 68.8% of radiographically occult cases [23]. US of the chest has several diagnostic limitations, including technical difficulties related to posterior location of fractures, and soft-tissue penetration in patients with large breasts [22]. Patient-reported pain during the US examination limited evaluation in only 14% of cases but may be helpful in targeting the examination to the focal abnormality. US has added benefits of dynamic imaging capabilities as well as relative ease [15,24]. Dynamic US detected slipping rib syndrome in 32/36 (89%) and ruled it out in 10/10 (100%) [25].

WBC Scan Chest

There is no relevant literature to support the use of nuclear medicine white blood cell (WBC) chest scans as initial imaging in the evaluation of chest wall pain in patients with no history of malignancy.

Variant 2: Nontraumatic chest wall pain. Known or suspected malignancy. Secondary evaluation after normal chest radiograph. Next imaging study.

Bone Scan Whole Body

Bone scintigraphy has been shown to have 95% sensitivity for detection of skeletal metastases and defines extent of involvement across the entire skeleton [26]. It may have a role in characterization of primary chest wall neoplasms, especially those that may contain chondroid or osteoid components [26]. Limitations of bone scintigraphy occur in the setting of nonosteoblastic processes such as multiple myeloma that may not be detected by this modality.

CT Chest

More than 50% of chest wall neoplasms are malignant, most commonly from metastases or direct invasion of thoracic tumors [27]. Chest CT is useful for characterizing chest wall neoplasms, defining their extent, and is more sensitive than radiography for detection of subtle osseous and soft-tissue lesions [15,27-30]. Chest CT provides a 3-D evaluation of lesions, precise anatomic localization, and internal tissue content (eg, fat, calcification, soft tissue) [27-29]. For example, chondrosarcoma is the most common primary malignancy of the chest wall, typically originating from the sternum or costochondral cartilages of the anterior chest wall, and may exhibit a “rings and arcs” pattern of mineralization that is well characterized on CT [27-31].

Although uncommon, chest wall metastases usually indicate advanced disease. Osseous metastases may manifest as sclerotic (eg, prostate cancer), mixed lytic and sclerotic (eg, breast cancer), or purely lytic (eg, renal cell carcinoma) and are best characterized at CT [27]. Soft-tissue metastases may be readily detected at CT if they involve the skin or subcutaneous fat. However, intramuscular lesions may have similar attenuation as the skeletal muscle and may be missed, unless there is muscle expansion, invasion of adjacent osseous structures, or enhancement after administration of intravenous (IV) contrast material. CT is also useful for image-guided biopsy of lesions [32].

FDG-PET/CT Skull Base to Mid-Thigh

FDG-PET/CT is valuable in the staging (presurgical planning, detection of distant metastases) and follow-up of patients with primary soft-tissue sarcomas, with maximum standardized uptake value (SUV_{max}) measurements being correlated with greater glucose transporter protein expression and histologic aggressiveness [33]. In one study, FDG-PET/CT was shown to have prognostic value, with greater event-free survival in patients whose tumors measured less than SUV_{max} 10.2 [33]. In addition, FDG-PET/CT may be helpful in directing image-guided needle biopsy to areas of metabolic activity to improve diagnostic accuracy in heterogeneous tumors [32]. Although FDG-PET/CT is sensitive for the detection of FDG-avid tumors, false-positives may result from misinterpretation of various normal physiologic states, including skeletal muscle uptake, brown fat uptake, and some benign lesions, such as infection, inflammation, healing fractures, and fibrous dysplasia. In one large retrospective series, benign nonphysiologic FDG uptake was present in >25% of oncologic FDG-PET/CT, with 55.7% of lesions showing moderate or marked FDG uptake relative to background [34]. Choi et al [35] determined that FDG-PET/CT had poor performance (accuracy 57.2%) in differentiating between benign and metastatic rib lesions, with the best SUV_{max} cutoff to differentiate being low at 2.4. However, predictive value for metastases was improved when FDG-PET activity was combined with CT findings of correlative osteolytic and osteoblastic lesions [35]. FDG-PET/CT may identify CT occult bone metastases, which demonstrate focal FDG uptake without a corresponding lesion on

CT [36]. A large meta-analysis concluded that FDG-PET/CT has a higher diagnostic value than FDG-PET, MRI, and bone scintigraphy for detection of bone metastases in patients with lung cancer, with a pooled sensitivity of 92% (95% confidence interval [CI]: 0.88–0.95), specificity 98% (95% CI: 0.97–0.98), and diagnostic odds ratio of 449.2 (164.0–1230.21) [37].

MRI Chest

Chest MRI is often complementary to CT in comprehensive tissue characterization of chest wall neoplasms, defining their extent, and for planning of therapeutic interventions [15,27-30,38]. The soft-tissue contrast afforded by MRI may allow for tissue characterization of lesions, including differentiation of neoplastic processes from nonneoplastic mimics (eg, infection) [27,30,39]. Chest MRI also has been utilized for determining neurovascular involvement [40]. Some studies have shown added value of respiratory dynamic chest MRI in determination of chest wall invasion, defined as restricted movement of a tumor by the chest wall during breathing maneuvers [41,42]. One study of 61 patients whose static CT or MRI were equivocal for invasion showed respiratory dynamic chest MRI to have 100% sensitivity, 82.9% specificity, and 88.5% accuracy for predicting chest wall invasion with positive and negative predictive values of 74.1% and 100%, respectively [41]. False-positives occurred in the setting of pleural adhesions that restricted movement, but in most cases, they could be differentiated from true invasion at surgery [41].

Radiography Rib Views

For focal chest wall pain in patients with suspected malignancy, a radiographic rib series may be helpful to assess for a rib lesion [16]. However, as for chest radiography, further characterization with CT, MRI, or nuclear medicine studies may be beneficial to detect radiographically occult lesions.

US Chest

Generally, US serves a limited role in the primary evaluation of suspected primary chest wall neoplasms but may serve a role in determining secondary invasion of the chest wall by intrathoracic tumors. In a study of 23 patients who had a chest CT that showed findings suspicious for chest wall invasion by intrathoracic tumors or lung invasion by chest wall tumors, the sensitivity and specificity for chest wall invasion (using absence of a sliding pleura sign) were 88.9% and 100%, respectively, with 100% and 93.3% positive and negative predictive values, respectively [43]. Surgeon-performed US outperformed CT in diagnosis of chest wall invasion, with 90.9% sensitivity and 85.7% specificity versus 61.5% sensitivity and 84.6% specificity for CT [44]. Respective positive and negative predictive values in the same study of 28 patients were 83.3% and 92.3% for US compared with 80% and 68.8% for CT [44]. Another study showed US to have a higher sensitivity than CT for determining chest wall invasion by lung cancer (89% versus 42%, respectively) but had a lower specificity (95% versus 100%, respectively) [45]. However, a study of 131 patients with thoracic masses showed overlap in performance of US and CT for diagnosing chest wall invasion [46]. US may be helpful for image-guided biopsy of superficial lesions [27,32,39,46].

WBC Scan Chest

There is no relevant literature to support the use of nuclear medicine WBC scans as initial imaging in the evaluation of chest wall pain in patients with known or suspected malignancy.

Variant 3: Nontraumatic chest wall pain. Suspected infectious or inflammatory condition. Secondary evaluation after normal chest radiograph. Next imaging study.

Bone Scan Whole Body

Nuclear medicine studies, including bone scans and radiolabeled WBC scans, are especially helpful in localization of infectious or inflammatory conditions of the bones, joints, and costal cartilages, especially in the setting of negative radiographs and CT and in patients with metallic implants [47,48]. Bone scintigraphy is useful in screening the entire body for occult infectious or inflammatory disease, especially for patients with fever of unknown origin [26].

Bone scans were 100% sensitive for the detection of sternoclavicular joint inflammation among 40 patients who presented with anterior chest wall pain as an early indicator of spondyloarthritis [49]. Patients with synovitis, acne, pustulosis, hyperostosis, and osteitis (SAPHO) syndrome—a chronic, relapsing condition that often involves the sternoclavicular joints—frequently present with anterior chest wall pain that corresponds to radiotracer uptake about these joints that may be found on bone scintigraphy [6,50]. Bone scintigraphy may be useful for the evaluation of patients with undifferentiated costochondral pain and swelling and is a highly sensitive indicator of osseocartilaginous disease [51]. However, its specificity for differentiating inflammatory processes, such as Tietze syndrome, from other bone tumors is insufficient [51].

CT Chest

CT is superior to US and radiography in determination of disease extent, including characterization of deep compartments and intrathoracic involvement. Osseous involvement, including cortical erosion, fragmentation, and sequestra, are readily depicted on CT. Gas formation within necrotic tissues or in the setting of serious infections, such as necrotizing fasciitis, is easily depicted on CT [48,52]. Chronic chest wall infections (eg, empyema necessitans, actinomycosis, Aspergillus) are well characterized with CT [52]. Administration of IV contrast may help to characterize and define fluid collections and soft-tissue sinus tract formation. Advantages of CT include rapid image acquisition, isotropic data, and high spatial resolution. Limitations include decreased sensitivity related to streak artifacts around metallic hardware. CT may be utilized for image-guided drainage procedures or during percutaneous biopsy.

CT has shown equivocal sensitivity for detection of lesions in patients with underlying spondyloarthritis who presented with anterior chest wall pain [53]. Patients with asbestos-related pleural disease findings at chest CT also reported chest pain, especially diffuse pleural thickening (50%–68%) and rounded atelectasis (70%–83%) [54]. CT is complementary to bone scans for diagnosis of SAPHO syndrome showing osseous sclerosis (77.3%), erosions (44%), and hyperostosis (41%), frequently involving the upper chest wall and sternocostoclavicular joints [50]. CT showed higher sensitivity (92.3% versus 84.6%) and specificity (64.3% versus 35.7%) for differentiating primary chest wall tumors from Tietze syndrome as an etiology of costochondral junction pain and swelling in 27 patients [51].

FDG-PET/CT Skull Base to Mid-Thigh

Various infectious and inflammatory conditions that utilize glucose may manifest with FDG avidity on FDG-PET/CT. In a retrospective study of 1,134 consecutive oncologic FDG-PET/CT scans, infectious and inflammatory conditions accounted for 73.3% of benign causes of FDG avidity [34]. This has justified the expanded clinical utility of FDG-PET/CT, and the Society of Nuclear Medicine and Molecular Imaging (SNMMI) and European Association of Nuclear Medicine (EANM) have issued consensus guidelines on the appropriate use of FDG imaging for diagnosis of suspected infectious and inflammatory conditions [55]. In their guidelines, a summary of the literature indicates that FDG-PET/CT has high sensitivity (94.6%), specificity (91.5%), and accuracy (94.5%) for diagnosis of peripheral bone osteomyelitis (excluding diabetic foot and postoperative osteomyelitis indications) [55]. FDG-PET/CT has also shown favorable diagnostic performance for other major indications that include spondylodiscitis, fever of unknown origin, metastatic infection in high-risk patients with bacteremia, and vasculitis [55,56]. A recent meta-analysis of 23 studies and 1,927 patients with fever and inflammation of unknown origin showed FDG-PET/CT to have a sensitivity of 84% (95% CI, 0.79–0.89), specificity of 63% (95% CI, 0.49–0.75), positive likelihood ratio of 2.3 (95% CI, 1.5–3.4), negative likelihood ratio of 0.25 (95% CI, 0.16–0.38), and diagnostic odds ratio of 9.0 (95% CI, 4.0–20) [57].

MRI Chest

MRI is highly effective at detecting and characterizing infectious and inflammatory disorders of the chest wall soft tissues and osseous structures, maintaining a high negative predictive value in excluding disease in the setting of normal imaging findings [48,58]. Fluid-sensitive sequences, especially those with applied fat signal suppression, detect early edema and readily define extent of soft tissue and osseous involvement that may not be apparent on CT [52]. Administration of gadolinium-based contrast material further characterizes areas of hyperemia and defines fluid collections and soft-tissue sinus tract formation. Unlike CT, gas formation is not as well appreciated on MRI but may be seen as signal void, especially on gradient-echo sequences [48]. MRI may be useful for defining infectious involvement of skin and fascial layers, muscle, bursae, and tendons. If clinical suspicion for potentially life-threatening necrotizing fasciitis is high, detection of hyperintense signal within chest wall deep fascial compartments on fluid-sensitive MRI sequences is highly suggestive of the disease, and the absence of these findings essentially exclude the disease [48,58]. MRI also serves a role in surgical planning prior to debridement procedures, distinguishing viable from nonviable tissue based on tissue signal and enhancement characteristics [48]. MRI may be helpful in the differentiation of chest wall infection from tumor.

Anterior chest wall pain is a common complaint among patients who have underlying spondyloarthritis, but the diagnosis may be delayed for many years [53]. MRI was 62.5% sensitive in determining sternoclavicular and sternocostal involvement by inflammatory spondyloarthritis in patients who presented with anterior chest wall pain as an early manifestation of their disease and was able to provide specific information regarding disease activity and severity beyond that provided by bone scintigraphy [49]. Another study showed higher sensitivity of MRI for detection of disease activity (bone marrow edema, erosions, and fat infiltration) than other serologic and clinical

parameters, and especially involvement of the manubriosternal joint [59]. Other systemic inflammatory conditions can also be suggested by MRI with abnormal signal intensity of skeletal muscle (whether from edema or fatty atrophy), such as immune-mediated myositis and other neurodegenerative diseases [48].

Radiography Rib Views

There is no relevant literature to support the use of radiography rib views beyond chest radiography in the primary evaluation of chest wall pain in patients with suspected chest wall infectious or inflammatory conditions.

US Chest

US is a useful modality for targeted evaluation of soft tissue, osseous, and joints of the chest wall and for characterization and potential drainage of abscesses and joint effusions but has limited capability of determining extent of disease [48].

WBC Scan Chest

Indium-111–tagged WBC scans and Tc-99m–tagged WBC scans are useful in screening for occult infectious or inflammatory disease, which can then be localized with a single-photon emission CT (SPECT)/CT scan. Because WBCs accumulate in both infections and normal bone marrow, a Tc-99m sulfur colloid scan may have to be performed to delineate osteomyelitis from normal marrow [60]. The SNMMI/EANM guidelines do not indicate a distinct advantage of FDG-PET/CT over conventional scintigraphic techniques in the evaluation of suspected infectious or inflammatory disorders [55]. However, disadvantages of conventional WBC scans include various technical factors, such as the need to tag and manipulate potentially infected blood products and unstable labeling [56,61]. In addition, compared with FDG-PET/CT, conventional planar WBC scans result in lower-resolution images that contribute to lower sensitivity and accuracy of diagnosis, especially of smoldering low-grade infections and problems involving the central skeleton [56,61].

Variant 4: Nontraumatic chest wall pain. History of prior chest intervention. Secondary evaluation after normal chest radiograph. Next imaging study.

Bone Scan Whole Body

A single case report described bone scan findings of heterogeneous radiotracer uptake in ribs that were within the areas of the chest wall that received >30 Gy after a chest CT revealed no abnormality [62]. In a case report of a patient with chest pain 11 months after chest wall radiation for breast cancer, a bone scan showed evidence of costochondritis but no metastases after initial negative CT and were both later positive after the patient developed rib fractures [63].

Bone scan or radiolabeled WBC scan plays a role in the evaluation of sternal osteomyelitis, especially in patients who have equivocal CT findings, maintaining a high negative predictive value for osteomyelitis [64].

CT Chest

In a study of 177 patients who received stereotactic radiation therapy for lung cancer, chest CT identified rib fractures in 23.2% on an average of 21 months (range 4–58 months) after completion of therapy [65]. Findings of chest wall edema (25.4%), osseous cortical thinning (20.3%), and osteosclerosis (14.7%) usually preceded rib fractures, and most tumors were within 16 mm of the chest wall [65,66]. Chest wall pain was reported in 18 of 177 (10.8%) patients, 14 (77.8%) of whom had rib fractures [65].

CT has variable performance in the diagnosis of sternal wound infections after cardiac surgery. Most patients may present with clinical signs and symptoms of sternal infection, precluding the need for imaging. However, CT may be useful for diagnosis in patients in whom the diagnosis is suspected but who lack overt clinical signs and symptoms [64,67]. In a study of 40 patients, the sensitivity and specificity of CT for diagnosis of mediastinitis was best beyond 17 days after surgery (100% and 90%, respectively), with 100% sensitivity and only 33% specificity in the first 17 postoperative days [68,69].

Noninfectious poststernotomy chest pain may affect more than half of patients after sternotomy and was inversely correlated with the degree of osseous healing (complete versus incomplete) [8]. Sternal nonunion and sternal dehiscence may be characterized at CT, with sternal gap >3 mm correlating with significantly higher chest pain intensity compared with those with minor dehiscence and those with normal sternal healing, as determined by chest CT [8,64,70]. Chest CT with 3-D reconstructions was useful in assessing the degree of healing and residual chest wall deformities in 46 patients randomized to either operative or nonoperative management of flail chest [71]. CT is commonly used in the pre- and postoperative evaluation of patients who underwent chest wall reconstruction for rib fractures and chest wall tumors [72,73]. Rarely, desmoid-type fibromatosis can occur at prior thoracotomy sites

and may mimic chest wall recurrence. CT in combination with FDG-PET/CT is useful for detecting and characterizing these lesions and for image-guided biopsy [74].

FDG-PET/CT Skull Base to Mid-Thigh

Investigators have shown a positive dose-dependent relationship in chest wall FDG-PET/CT uptake predictive of patients who later developed chest wall complications (pain and rib fractures) after stereotactic body radiation therapy for lung cancer [75]. False-positive diagnoses can occur in cases in which there is myositis-related FDG uptake in the chest wall musculature in patients who have undergone prior radiation [76]. Furthermore, FDG-PET/CT is valuable in determining depth of infection, involvement of costal cartilages, and for preoperative planning of debridement procedures in patients with deep sternal wound infections after sternotomy procedures [77]. The sensitivity and specificity of FDG-PET/CT for sternal wound infections was 91% and 97%, respectively, with SUV_{max} showing value in patients who are imaged >6 months after surgery [78].

MRI Chest

Chest MRI is valuable in the evaluation of patients after treatment of chest wall neoplasms and is superior to chest CT for detection of sites of residual or recurrent tumor after chest radiation or resection, especially using T1-weighted fat-suppressed sequences after administration of gadolinium-based contrast material [27]. MRI may also be used to determine the etiology of rib fractures in patients with known malignancy [63]. MRI has been also used in follow-up and response evaluation of patients with chest wall and breast desmoid tumors that developed after mastectomy and silicone implant augmentation [79].

Chest MRI may be a valuable tool in the early detection of sternal wound infections, given its high spatial resolution and soft-tissue contrast, but is limited by susceptibility artifacts related to sternotomy wires and other cardiac implants [69].

Radiography Rib Views

There is no relevant literature to support the use of radiography rib views beyond chest radiography in the primary evaluation of chest wall pain in patients with prior chest wall intervention.

US Chest

Apart from targeted evaluation of the chest wall soft tissues for hematoma or abscess evaluation or treatment after chest wall surgery, US has a limited role. One study utilized sternal US to assess for sternal nonunion with dynamic compression and cortical sliding as a cause for poststernotomy chest pain [70].

WBC Scan Chest

There is sparse literature to support the use of WBC scans in the primary evaluation of patients who present with chest wall pain after previous intervention. Quirce et al [80,81] compared the diagnostic performance of planar and SPECT WBC scans among 41 patients with suspected sternal infections after sternotomy, showing superior performance of SPECT over planar imaging for detection of infections at both 4 and 20 hours after injection and for differentiating superficial from deeper infections.

Summary of Recommendations

- **Variation 1:** Radiography chest is usually appropriate for the initial imaging of patients with nontraumatic chest wall pain with no history of malignancy.
- **Variation 2:** Bone scan whole body and CT chest with IV contrast or CT chest without IV contrast are usually appropriate as the next imaging study for patients with nontraumatic chest wall pain with known or suspected malignancy and secondary evaluation after a normal chest radiograph. CT chest with IV contrast and CT chest without IV contrast are essentially equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care). However, bone scan whole body is considered complementary to these procedures and may be performed in addition to CT chest.
- **Variation 3:** CT chest with IV contrast or CT chest without IV contrast is usually appropriate as the next imaging study for patients with nontraumatic chest wall pain with suspected infectious or inflammatory condition as a secondary evaluation after a normal chest radiograph. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care). The panel did not agree on recommending MRI chest without IV contrast or bone scan whole body for this clinical scenario. There is insufficient medical literature to conclude whether or not these patients would benefit from

MRI chest without IV contrast or bone scan whole body. These procedures in this patient population are controversial but may be appropriate.

- **Variation 4:** CT chest with IV contrast or CT chest without IV contrast is usually appropriate as the next imaging study for patients with nontraumatic chest wall pain who have a history of prior chest intervention as a secondary evaluation after a normal chest radiograph. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient’s care).

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at <https://acsearch.acr.org/list>. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents go to www.acr.org/ac.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel’s recommendation. “May be appropriate” is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® [Radiation Dose Assessment Introduction](#) document [82].

Relative Radiation Level Designations		
Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
○	0 mSv	0 mSv
⊕	<0.1 mSv	<0.03 mSv
⊕⊕	0.1-1 mSv	0.03-0.3 mSv
⊕⊕⊕	1-10 mSv	0.3-3 mSv
⊕⊕⊕⊕	10-30 mSv	3-10 mSv
⊕⊕⊕⊕⊕	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as “Varies.”

References

1. Bosner S, Becker A, Hani MA, et al. Chest wall syndrome in primary care patients with chest pain: presentation, associated features and diagnosis. *Fam Pract* 2010;27:363-9.
2. Buntinx F, Knockaert D, Bruyninckx R, et al. Chest pain in general practice or in the hospital emergency department: is it the same? *Fam Pract* 2001;18:586-9.
3. Stockkendahl MJ, Christensen HW. Chest pain in focal musculoskeletal disorders. *Med Clin North Am* 2010;94:259-73.
4. Grani C, Senn O, Bischof M, et al. Diagnostic performance of reproducible chest wall tenderness to rule out acute coronary syndrome in acute chest pain: a prospective diagnostic study. *BMJ Open* 2015;5:e007442.
5. Danve A. Thoracic Manifestations of Ankylosing Spondylitis, Inflammatory Bowel Disease, and Relapsing Polychondritis. *Clin Chest Med* 2019;40:599-608.
6. Wendling D, Prati C, Demattei C, Loeuille D, Richette P, Dougados M. Anterior chest wall pain in recent inflammatory back pain suggestive of spondyloarthritis. data from the DESIR cohort. *J Rheumatol* 2013;40:1148-52.
7. Schipper P, Tieu BH. Acute Chest Wall Infections: Surgical Site Infections, Necrotizing Soft Tissue Infections, and Sternoclavicular Joint Infection. *Thorac Surg Clin* 2017;27:73-86.
8. Papadopoulos N, Hacibaramoglu M, Kati C, Muller D, Floter J, Moritz A. Chronic poststernotomy pain after cardiac surgery: correlation of computed tomography findings on sternal healing with postoperative chest pain. *Thorac Cardiovasc Surg* 2013;61:202-8.
9. Lee JW, Lee SW, Chang SH, Lee SM. Clinical role of bone scintigraphy in low-to-intermediate Framingham risk patients with atypical chest pain. *Nucl Med Commun* 2018;39:411-16.
10. Henry TS, Donnelly EF, Boiselle PM, et al. ACR Appropriateness Criteria® Rib Fractures. *J Am Coll Radiol* 2019;16:S227-S34.
11. Sano A, Tashiro K, Fukuda T. Cough-induced rib fractures. *Asian Cardiovasc Thorac Ann* 2015;23:958-60.
12. Bier G, Schabel C, Othman A, et al. Enhanced reading time efficiency by use of automatically unfolded CT rib reformations in acute trauma. *Eur J Radiol* 2015;84:2173-80.
13. Ringl H, Lazar M, Topker M, et al. The ribs unfolded - a CT visualization algorithm for fast detection of rib fractures: effect on sensitivity and specificity in trauma patients. *Eur Radiol* 2015;25:1865-74.
14. Giassi Kde S, Costa AN, Bachion GH, et al. Epipericardial fat necrosis: an underdiagnosed condition. *Br J Radiol* 2014;87:20140118.
15. Kienzl D, Prosch H, Topker M, Herold C. Imaging of non-cardiac, non-traumatic causes of acute chest pain. *Eur J Radiol* 2012;81:3669-74.
16. Ayloo A, Cvengros T, Marella S. Evaluation and treatment of musculoskeletal chest pain. *Prim Care* 2013;40:863-87, viii.
17. Zhang L, McMahon CJ, Shah S, Wu JS, Eisenberg RL, Kung JW. Clinical and Radiologic Predictive Factors of Rib Fractures in Outpatients With Chest Pain. *Curr Probl Diagn Radiol* 2018;47:94-97.
18. Newsom C, Jeanmonod R, Woolley W, et al. Prospective Validation and Refinement of a Decision Rule to Obtain Chest X-ray in Patients With Nontraumatic Chest Pain in the Emergency Department. *Acad Emerg Med* 2018;25:650-56.

19. Mary Parks R, Jadoon M, Duffy J. Nontraumatic rupture of the costal margin: a single-center experience. *Asian Cardiovasc Thorac Ann* 2019;27:105-09.
20. Park JB, Cho YS, Choi HJ. Diagnostic accuracy of the inverted grayscale rib series for detection of rib fracture in minor chest trauma. *Am J Emerg Med* 2015;33:548-52.
21. Hoffstetter P, Dornia C, Wagner M, et al. Clinical significance of conventional rib series in patients with minor thoracic trauma. *Rofo* 2014;186:876-80.
22. Lalande E, Guimont C, Emond M, et al. Feasibility of emergency department point-of-care ultrasound for rib fracture diagnosis in minor thoracic injury. *CJEM* 2017;19:213-19.
23. Lee WS, Kim YH, Chee HK, Lee SA. Ultrasonographic evaluation of costal cartilage fractures unnoticed by the conventional radiographic study and multidetector computed tomography. *Eur J Trauma Emerg Surg* 2012;38:37-42.
24. Rudas M, Orde S, Nalos M. Bedside lung ultrasound in the care of the critically ill. *Crit Care Resusc* 2017;19:327-36.
25. Van Tassel D, McMahon LE, Riemann M, Wong K, Barnes CE. Dynamic ultrasound in the evaluation of patients with suspected slipping rib syndrome. *Skeletal Radiol* 2019;48:741-51.
26. Krumme JW, Lauer MF, Stowell JT, Beteselassie NM, Kotwal SY. Bone Scintigraphy: A Review of Technical Aspects and Applications in Orthopedic Surgery. *Orthopedics* 2019;42:e14-e24.
27. Carter BW, Benveniste MF, Betancourt SL, et al. Imaging Evaluation of Malignant Chest Wall Neoplasms. *Radiographics* 2016;36:1285-306.
28. Dillman JR, Pernicano PG, McHugh JB, et al. Cross-sectional imaging of primary thoracic sarcomas with histopathologic correlation: a review for the radiologist. *Curr Probl Diagn Radiol* 2010;39:17-29.
29. Mullan CP, Madan R, Trotman-Dickenson B, Qian X, Jacobson FL, Hunsaker A. Radiology of chest wall masses. *AJR Am J Roentgenol* 2011;197:W460-70.
30. Nam SJ, Kim S, Lim BJ, et al. Imaging of primary chest wall tumors with radiologic-pathologic correlation. *Radiographics* 2011;31:749-70.
31. Al-Refaie RE, Amer S, Ismail MF, Al-Shabrawy M, Al-Gamal G, Mokbel E. Chondrosarcoma of the chest wall: single-center experience. *Asian Cardiovasc Thorac Ann* 2014;22:829-34.
32. Kachroo P, Pak PS, Sandha HS, et al. Chest wall sarcomas are accurately diagnosed by image-guided core needle biopsy. *J Thorac Oncol* 2012;7:151-6.
33. Nishiyama Y, Tateishi U, Kawai A, et al. Prediction of treatment outcomes in patients with chest wall sarcoma: evaluation with PET/CT. *Jpn J Clin Oncol* 2012;42:912-8.
34. Metser U, Miller E, Lerman H, Even-Sapir E. Benign nonphysiologic lesions with increased 18F-FDG uptake on PET/CT: characterization and incidence. *AJR Am J Roentgenol* 2007;189:1203-10.
35. Choi HS, Yoo Ie R, Park HL, Choi EK, Kim SH, Lee WH. Role of (1)(8)F-FDG PET/CT in differentiation of a benign lesion and metastasis on the ribs of cancer patients. *Clin Imaging* 2014;38:109-14.
36. Al-Muqbel KM. Bone Marrow Metastasis Is an Early Stage of Bone Metastasis in Breast Cancer Detected Clinically by F18-FDG-PET/CT Imaging. *Biomed Res Int* 2017;2017:9852632.
37. Qu X, Huang X, Yan W, Wu L, Dai K. A meta-analysis of (1)(8)FDG-PET-CT, (1)(8)FDG-PET, MRI and bone scintigraphy for diagnosis of bone metastases in patients with lung cancer. *Eur J Radiol* 2012;81:1007-15.
38. Bueno J, Lichtenberger JP, 3rd, Rauch G, Carter BW. MR Imaging of Primary Chest Wall Neoplasms. *Top Magn Reson Imaging* 2018;27:83-93.
39. Souza FF, de Angelo M, O'Regan K, Jagannathan J, Krajewski K, Ramaiya N. Malignant primary chest wall neoplasms: a pictorial review of imaging findings. *Clin Imaging* 2013;37:8-17.
40. Bagheri R, Haghi SZ, Kalantari MR, et al. Primary malignant chest wall tumors: analysis of 40 patients. *J Cardiothorac Surg* 2014;9:106.
41. Akata S, Kajiwarana N, Park J, et al. Evaluation of chest wall invasion by lung cancer using respiratory dynamic MRI. *J Med Imaging Radiat Oncol* 2008;52:36-9.
42. Shiotani S, Sugimura K, Sugihara M, et al. Diagnosis of chest wall invasion by lung cancer: useful criteria for exclusion of the possibility of chest wall invasion with MR imaging. *Radiat Med* 2000;18:283-90.
43. Caroli G, Dell'Amore A, Cassanelli N, et al. Accuracy of transthoracic ultrasound for the prediction of chest wall infiltration by lung cancer and of lung infiltration by chest wall tumours. *Heart Lung Circ* 2015;24:1020-6.
44. Tahiri M, Khereba M, Thiffault V, et al. Preoperative assessment of chest wall invasion in non-small cell lung cancer using surgeon-performed ultrasound. *Ann Thorac Surg* 2014;98:984-9.

45. Bandi V, Lunn W, Ernst A, Eberhardt R, Hoffmann H, Herth FJ. Ultrasound vs. CT in detecting chest wall invasion by tumor: a prospective study. *Chest* 2008;133:881-6.
46. Chira R, Chira A, Mircea PA. Intrathoracic tumors in contact with the chest wall--ultrasonographic and computed tomography comparative evaluation. *Med Ultrason* 2012;14:115-9.
47. Koc ZP, Balci TA, Ozyurtkan MO. The role of the three phase bone scintigraphy in the management of the patients with costochondral pain. *Mol Imaging Radionucl Ther* 2013;22:90-3.
48. Pattamapasong N, Sivasomboon C, Settakorn J, Pruksakorn D, Muttarak M. Pitfalls in imaging of musculoskeletal infections. *Semin Musculoskelet Radiol* 2014;18:86-100.
49. Ramonda R, Lorenzin M, Lo Nigro A, et al. Anterior chest wall involvement in early stages of spondyloarthritis: advanced diagnostic tools. *J Rheumatol* 2012;39:1844-9.
50. Salles M, Olive A, Perez-Andres R, et al. The SAPHO syndrome: a clinical and imaging study. *Clin Rheumatol* 2011;30:245-9.
51. Kaplan T, Gunal N, Gulbahar G, et al. Painful Chest Wall Swellings: Tietze Syndrome or Chest Wall Tumor? *Thorac Cardiovasc Surg* 2016;64:239-44.
52. Bergeron EJ, Meguid RA, Mitchell JD. Chronic Infections of the Chest Wall. *Thorac Surg Clin* 2017;27:87-97.
53. Elhai M, Paternotte S, Burki V, et al. Clinical characteristics of anterior chest wall pain in spondyloarthritis: an analysis of 275 patients. *Joint Bone Spine* 2012;79:476-81.
54. Allen RK, Cramond T, Lennon D, Waterhouse M. A retrospective study of chest pain in benign asbestos pleural disease. *Pain Med* 2011;12:1303-8.
55. Jamar F, Buscombe J, Chiti A, et al. EANM/SNMMI guideline for 18F-FDG use in inflammation and infection. *J Nucl Med* 2013;54:647-58.
56. Vaidyanathan S, Patel CN, Scarsbrook AF, Chowdhury FU. FDG PET/CT in infection and inflammation--current and emerging clinical applications. *Clin Radiol* 2015;70:787-800.
57. Kan Y, Wang W, Liu J, Yang J, Wang Z. Contribution of 18F-FDG PET/CT in a case-mix of fever of unknown origin and inflammation of unknown origin: a meta-analysis. *Acta Radiol* 2019;60:716-25.
58. Shimizu T, Tokuda Y. Necrotizing fasciitis. *Intern Med* 2010;49:1051-7.
59. Weber U, Lambert RG, Rufibach K, et al. Anterior chest wall inflammation by whole-body magnetic resonance imaging in patients with spondyloarthritis: lack of association between clinical and imaging findings in a cross-sectional study. *Arthritis Res Ther* 2012;14:R3.
60. Palestro CJ. Radionuclide imaging of osteomyelitis. *Semin Nucl Med* 2015;45:32-46.
61. Kouijzer IJE, Mulders-Manders CM, Bleeker-Rovers CP, Oyen WJG. Fever of Unknown Origin: the Value of FDG-PET/CT. *Semin Nucl Med* 2018;48:100-07.
62. Lloyd S, Decker RH, Evans SB. Bone scan findings of chest wall pain syndrome after stereotactic body radiation therapy: implications for the pathophysiology of the syndrome. *J Thorac Dis* 2013;5:E41-4.
63. Nicholls L, Gorayski P, Harvey J. Osteoradionecrosis of the Ribs following Breast Radiotherapy. *Case Rep Oncol* 2015;8:332-8.
64. Hota P, Dass C, Erkmén C, Donuru A, Kumaran M. Poststernotomy Complications: A Multimodal Review of Normal and Abnormal Postoperative Imaging Findings. *AJR Am J Roentgenol* 2018;211:1194-205.
65. Nambu A, Onishi H, Aoki S, et al. Rib fracture after stereotactic radiotherapy on follow-up thin-section computed tomography in 177 primary lung cancer patients. *Radiat Oncol* 2011;6:137.
66. Thibault I, Chiang A, Erler D, et al. Predictors of Chest Wall Toxicity after Lung Stereotactic Ablative Radiotherapy. *Clin Oncol (R Coll Radiol)* 2016;28:28-35.
67. Gaudreau G, Costache V, Houde C, et al. Recurrent sternal infection following treatment with negative pressure wound therapy and titanium transverse plate fixation. *Eur J Cardiothorac Surg* 2010;37:888-92.
68. Exarhos DN, Malagari K, Tsatalou EG, et al. Acute mediastinitis: spectrum of computed tomography findings. *Eur Radiol* 2005;15:1569-74.
69. Sharif M, Wong CHM, Harky A. Sternal Wound Infections, Risk Factors and Management - How Far Are We? A Literature Review. *Heart Lung Circ* 2019;28:835-43.
70. Hautalahti J, Rinta-Kiikka I, Tarkka M, Laurikka J. Symptoms of Sternal Nonunion Late after Cardiac Surgery. *Thorac Cardiovasc Surg* 2017;65:325-31.
71. Marasco SF, Davies AR, Cooper J, et al. Prospective randomized controlled trial of operative rib fixation in traumatic flail chest. *J Am Coll Surg* 2013;216:924-32.
72. Bille A, Okiror L, Karenovics W, Routledge T. Experience with titanium devices for rib fixation and coverage of chest wall defects. *Interact Cardiovasc Thorac Surg* 2012;15:588-95.

73. Wang L, Huang L, Li X, et al. Three-Dimensional Printing PEEK Implant: A Novel Choice for the Reconstruction of Chest Wall Defect. *Ann Thorac Surg* 2019;107:921-28.
74. Mori T, Yamada T, Ohba Y, et al. A case of desmoid-type fibromatosis arising after thoracotomy for lung cancer with a review of the english and Japanese literature. *Ann Thorac Cardiovasc Surg* 2014;20 Suppl:465-9.
75. Algan O, Confer M, Algan S, et al. Quantitative evaluation of correlation of dose and FDG-PET uptake value with clinical chest wall complications in patients with lung cancer treated with stereotactic body radiation therapy. *J Xray Sci Technol* 2015;23:727-36.
76. Tomita H, Kita T, Hayashi K, Kosuda S. Radiation-induced myositis mimicking chest wall tumor invasion in two patients with lung cancer: a PET/CT study. *Clin Nucl Med* 2012;37:168-9.
77. Zhang R, Feng Z, Zhang Y, Tan H, Wang J, Qi F. Diagnostic value of fluorine-18 deoxyglucose positron emission tomography/computed tomography in deep sternal wound infection. *J Plast Reconstr Aesthet Surg* 2018;71:1768-76.
78. Hariri H, Tan S, Martineau P, et al. Utility of FDG-PET/CT for the Detection and Characterization of Sternal Wound Infection Following Sternotomy. *Nucl Med Mol Imaging* 2019;53:253-62.
79. Grubstein A, Rapson Y, Zer A, et al. MRI diagnosis and follow-up of chest wall and breast desmoid tumours in patients with a history of oncologic breast surgery and silicone implants: A pictorial report. *J Med Imaging Radiat Oncol* 2019;63:47-53.
80. Quirce R, Carril JM, Gutierrez-Mendiguchia C, Serrano J, Rabasa JM, Bernal JM. Assessment of the diagnostic capacity of planar scintigraphy and SPECT with 99mTc-HMPAO-labelled leukocytes in superficial and deep sternal infections after median sternotomy. *Nucl Med Commun* 2002;23:453-9.
81. Bessette PR, Hanson MJ, Czarnecki DJ, Yuille DL, Rankin JJ. Evaluation of postoperative osteomyelitis of the sternum comparing CT and dual Tc-99m MDP bone and In-111 WBC SPECT. *Clin Nucl Med* 1993;18:197-202.
82. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: <https://www.acr.org/-/media/ACR/Files/Appropriateness-Criteria/RadiationDoseAssessmentIntro.pdf>. Accessed March 26, 2021.

The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.