

**American College of Radiology  
ACR Appropriateness Criteria®  
Dyspnea-Suspected Cardiac Origin (Ischemia Already Excluded)**

**Variant 1: Dyspnea due to suspected valvular heart disease. Ischemia excluded. Initial imaging.**

Procedure	Appropriateness Category	Relative Radiation Level
US echocardiography transthoracic resting	Usually Appropriate	○
Radiography chest	Usually Appropriate	☼
US echocardiography transesophageal	May Be Appropriate	○
US echocardiography transthoracic stress	May Be Appropriate	○
CT heart function and morphology with IV contrast	May Be Appropriate	☼☼☼☼
MRI heart function and morphology without and with IV contrast	May Be Appropriate	○
MRI heart function and morphology without IV contrast	May Be Appropriate	○
Arteriography coronary with ventriculography	Usually Not Appropriate	☼☼☼
CT coronary calcium	Usually Not Appropriate	☼☼☼
CTA coronary arteries with IV contrast	Usually Not Appropriate	☼☼☼
MRI heart function with stress without and with IV contrast	Usually Not Appropriate	○
MRI heart function with stress without IV contrast	Usually Not Appropriate	○
FDG-PET/CT heart	Usually Not Appropriate	☼☼☼☼
Rb-82 PET/CT heart	Usually Not Appropriate	☼☼☼☼
SPECT or SPECT/CT MPI rest and stress	Usually Not Appropriate	☼☼☼☼

**Variant 2:****Dyspnea due to suspected cardiac arrhythmia. Ischemia excluded. Initial imaging.**

Procedure	Appropriateness Category	Relative Radiation Level
US echocardiography transthoracic resting	Usually Appropriate	○
MRI heart function and morphology without and with IV contrast	Usually Appropriate	○
US echocardiography transesophageal	May Be Appropriate	○
Radiography chest	May Be Appropriate (Disagreement)	⚠
CT heart function and morphology with IV contrast	May Be Appropriate	⚠⚠⚠⚠
MRI heart function and morphology without IV contrast	May Be Appropriate	○
FDG-PET/CT heart	May Be Appropriate	⚠⚠⚠⚠
US echocardiography transthoracic stress	Usually Not Appropriate	○
Arteriography coronary with ventriculography	Usually Not Appropriate	⚠⚠⚠
CT coronary calcium	Usually Not Appropriate	⚠⚠⚠
CTA coronary arteries with IV contrast	Usually Not Appropriate	⚠⚠⚠
MRI heart function with stress without and with IV contrast	Usually Not Appropriate	○
MRI heart function with stress without IV contrast	Usually Not Appropriate	○
Rb-82 PET/CT heart	Usually Not Appropriate	⚠⚠⚠⚠
SPECT or SPECT/CT MPI rest and stress	Usually Not Appropriate	⚠⚠⚠⚠

**Variant 3: Dyspnea due to suspected pericardial disease. Ischemia excluded. Initial imaging.**

Procedure	Appropriateness Category	Relative Radiation Level
US echocardiography transthoracic resting	Usually Appropriate	○
Radiography chest	Usually Appropriate	⦿
CT heart function and morphology with IV contrast	Usually Appropriate	⦿⦿⦿⦿
MRI heart function and morphology without and with IV contrast	Usually Appropriate	○
US echocardiography transesophageal	May Be Appropriate	○
CT chest with IV contrast	May Be Appropriate	⦿⦿⦿
CT chest without IV contrast	May Be Appropriate	⦿⦿⦿
CTA chest with IV contrast	May Be Appropriate	⦿⦿⦿
MRI heart function and morphology without IV contrast	May Be Appropriate	○
FDG-PET/CT heart	May Be Appropriate (Disagreement)	⦿⦿⦿⦿
US echocardiography transthoracic stress	Usually Not Appropriate	○
Arteriography coronary with ventriculography	Usually Not Appropriate	⦿⦿⦿
CT chest without and with IV contrast	Usually Not Appropriate	⦿⦿⦿
CT coronary calcium	Usually Not Appropriate	⦿⦿⦿
CTA coronary arteries with IV contrast	Usually Not Appropriate	⦿⦿⦿
MRI heart function with stress without and with IV contrast	Usually Not Appropriate	○
MRI heart function with stress without IV contrast	Usually Not Appropriate	○
Rb-82 PET/CT heart	Usually Not Appropriate	⦿⦿⦿⦿
SPECT or SPECT/CT MPI rest and stress	Usually Not Appropriate	⦿⦿⦿⦿

## DYSPNEA-SUSPECTED CARDIAC ORIGIN (ISCHEMIA ALREADY EXCLUDED)

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### **Summary of Literature Review**

#### **Introduction/Background**

Dyspnea is the symptom of perceived breathing discomfort, with varied mechanisms and associated sensations [1]. Dyspnea is a complex symptom, with contributions from physiologic, psychological, and environmental factors [2]. Dyspnea is frequently encountered in primary care, accounting for up to 2.5% of family physician visits and 8.4% of emergency department visits [3]. In a systematic review of longitudinal studies, dyspnea showed utility in prediction of mortality and suggested the presence of underlying disease, most commonly pulmonary and/or cardiovascular [4]. Common cardiac causes include myocardial disease, namely, ischemic and nonischemic myocardial disease (see the ACR Appropriateness Criteria<sup>®</sup> topics on “[Nonischemic Myocardial Disease with Clinical Manifestations \(Ischemic Cardiomyopathy Already Excluded\)](#)” [5] and “[Suspected New-Onset and Known Nonacute Heart Failure](#)” [6]), valvular heart disease (VHD), arrhythmia, and pericardial pathology [2]. Patient history indications that may suggest a cardiac etiology include dyspnea on exertion, or even at rest in severe scenarios abnormalities, as well as orthopnea, paroxysmal nocturnal dyspnea, and edema.

Typical treatment goals include identification of the causative disease process to facilitate therapy, recovery, and improvement of dyspnea symptoms. Initial diagnostic evaluation is centered about careful history taking and physical examination [1]. Physical examination findings in cardiac causes of dyspnea could include murmurs (eg, systolic murmurs in the setting of valve insufficiency) as well as an abnormality in heart rate or rhythm, extra heart sounds (S3 in setting of ventricular dysfunction, pericardial knock associated with constriction), or jugular vein distention and edema in heart failure. A nuanced accounting of relevant physical examination findings and history is beyond the scope of this document. Diagnostic investigation may be supplemented by chest radiography and electrocardiography (ECG) as well as laboratory testing. However, identifying the cause of dyspnea in some cases remains elusive [7], and advanced diagnostic imaging may play a critical role in the care of these patients.

#### **Special Imaging Considerations**

MRI imaging artifacts in patients with implanted electronic devices [8-11] and arrhythmias [12-14] can be mitigated with use of evolving imaging techniques.

Point-of-care scanning with pocket echocardiography has improved time to definitive treatment (83 versus 180 days) and has been associated with improved outcomes, 15% versus 28% hospitalization or death, in a prospective randomized trial involving 253 patients in resource limited areas [15], whereas point-of-care echocardiography scanning with standard equipment obviated the need for formal scans in community patients with asymptomatic murmurs [16], with 100% of abnormalities identified on a point-of-care scan in 175 patients.

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Point-of-care ultrasound (US) is an emerging approach to diagnostic assessment of undifferentiated dyspnea, with varying imaging protocols and findings of efficacy. A meta-analysis of 7 studies, including 1,861 patients with undifferentiated dyspnea, found that B-lines identified on bedside lung US had a pooled sensitivity of 83% (95% confidence interval [CI], 66%–92%), and specificity of 84% (95% CI, 72%–91%) in diagnosis of heart failure [17]. Point-of-care US was shown to be faster than typical clinical evaluation and was more sensitive for diagnosis of heart failure, whereas standard clinical evaluation provided similar accuracy in diagnosis of acute coronary syndrome, pneumonia, pleural effusion, pneumothorax, and dyspnea due to other cause, and better accuracy than US in diagnosis of chronic obstructive pulmonary disease/asthma and pulmonary embolism [18].

For the purposes of distinguishing between CT and CT angiography (CTA), ACR Appropriateness Criteria topics use the definition in the [ACR–NASCI–SIR–SPR Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography \(CTA\)](#) [19]:

*“CTA uses a thin-section CT acquisition that is timed to coincide with peak arterial or venous enhancement. The resultant volumetric dataset is interpreted using primary transverse reconstructions as well as multiplanar reformations and 3-D renderings.”*

All elements are essential: 1) timing, 2) reconstructions/reformats, and 3) 3-D renderings. Standard CTs with contrast also include timing issues and reconstructions/reformats. Only in CTA, however, is 3-D rendering a **required** element. This corresponds to the definitions that the CMS has applied to the Current Procedural Terminology codes.

### 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

- 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: Dyspnea due to suspected valvular heart disease. Ischemia excluded. Initial imaging.

##### Arteriography Coronary with Ventriculography

There is no relevant literature to support the use of arteriography coronary with ventriculography for the evaluation of dyspnea due to suspected VHD, ischemia excluded.

##### CT Coronary Calcium

There is scant literature regarding the use of CT coronary calcium scans in the evaluation of dyspnea due to suspected VHD, ischemia excluded. Presence of mitral annular calcification on CT coronary calcium scans has shown correlation with cardiovascular risk [20]. Coronary artery calcium scanning for the detection and quantification of aortic valve calcium burden may be useful in some instances, for example, in patients with low-gradient aortic stenosis, but is not a first-line imaging examination.

##### CT Heart Function and Morphology

CT plays a predominantly supportive role to echocardiography in the assessment of suspected VHD, utilized when echocardiographic images are suboptimal, or to provide complementary information [21]. CT can aid in differentiating aortic leaflet morphologies, with leaflet fusion length, uneven cusp area, and midline calcification all showing strong association with bicuspid valve ( $P < .05$ ) [22], with the valve type characterized on surface echocardiography often (20%) reclassified after tomographic imaging with MRI, CT, or transesophageal echocardiography (TEE) [23]. CT may provide additional insight in the setting of suspected mechanical prosthetic valve dysfunction [24] and can also provide precise concomitant anatomic delineation of the entire aorta.

CT is increasingly utilized as part of a comprehensive preprocedural preparation for VHD interventions. CT imaging of cardiac and vascular structures plays a critical role in the planning of transcatheter aortic valve

replacement [25], and up to 30.9% and 32.6% of those with suspect clinical and echocardiographic findings posttranscatheter aortic valve replacement or surgical aortic valve repair, respectively [26].

CT imaging is increasingly utilized in planning transcatheter interventions for valvular and structural heart disease beyond the aortic valve [27-29] as well as planning, risk stratification, and follow-up of surgical interventions for VHD [26].

Epicardial fat as assessed on CT has shown correlation with mitral annular and aortic leaflet calcification [30], although this is not routinely employed in clinical practice.

### **CTA Coronary Arteries**

There is no relevant literature to support the use of CTA coronary arteries for the evaluation of dyspnea due to suspected VHD, ischemia excluded. Coronary ostia heights relative to aortic annulus are assessed on CTA as part of transcatheter aortic valve planning [25].

### **FDG-PET/CT Heart**

There is no relevant literature to support the use of fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET/CT heart for the evaluation of dyspnea due to suspected VHD, ischemia excluded.

### **MRI Heart Function and Morphology**

MRI plays a complementary role to echocardiography in the assessment of suspected VHD. MRI may be utilized when echocardiographic images are suboptimal or to provide additional quantitative flow information with use of phase-contrast velocity encoded sequences. MRI offers multiplanar capacity in demonstration of leaflet morphology and motion and is less dependent upon patient anatomy than echocardiography. However, MRI requires multiple cardiac cycles for data collection, and imaging may be compromised in cases of arrhythmia, whereas echocardiography offers real-time valve morphologic assessment and is more mobile. MRI often shows lower peak velocities than Doppler US; however, mean flow is more accurately analyzed with phase-contrast techniques that account for variation in flow across a vessel diameter. MRI may be preferred over echocardiography in the assessment of the pulmonary valve and can be used to grade mitral, pulmonic, or aortic regurgitation if there is clinical uncertainty after echocardiography [21]. The assessment of regurgitant volume, left ventricular (LV) volume, and myocardial fibrosis may play an eventual role in risk prognosis in VHD. MRI quantified aortic insufficiency has shown correlation with surgical repair, with 85% of patients having regurgitant fraction >33% progressing to surgery, typically in <3 years [31]. Discordance between echocardiographic and MRI assessment of mitral insufficiency has been reported ( $r = 0.6$ ), with MRI predicting postsurgical LV remodeling more accurately ( $r = 0.85$ ,  $P < .0001$ ) than echocardiography ( $r = 0.32$ ;  $P = .1$ ) in a prospective multicenter trial [32]. MRI provides high inter- and intrareader reproducibility [33] with semiautomated flow measurement in the ascending aorta and main pulmonary artery.

MRI may provide additional insight in the setting of suspected bioprosthetic valve dysfunction and suboptimal or clinically discordant transthoracic echocardiography (TTE) [24], with safe imaging possible across a broad range of prostheses at 1.5T, with most safe at 3.0T [34]. MRI can also aid in differentiation between aortic valvular as well as sub- and supra-annular stenosis, delineate leaflet morphology, with the valve type characterized on surface echocardiography often (20%) reclassified after tomographic imaging with MRI, CT, or TEE [23], and provide complementary assessment of the degree of stenosis by planimetry [35]. More advanced analysis of bulk flow patterns and energetics (including 4-D flow), myocardial strain, and tissue mapping on MRI are predominantly experimental at this point but may eventually provide more routine clinical insight to native and postsurgical valve function [36-39], with the potential to obtain concomitant cardiovascular morphologic information [40]. MRI can aid in anatomic delineation as well as identification of diffuse myocardial fibrosis in patients with mitral valve prolapse. In a retrospective study of patients with mitral valve prolapse, postcontrast T1-weighted times were significantly shorter in those patients with complex ventricular arrhythmia (324 versus 354 ms,  $P = .03$ ) [41]. In a group of patients with mitral annular disjunction, papillary muscle fibrosis was more often noted in those patients with severe arrhythmia events (36% versus 9%,  $P = .03$ ) [42]. A systematic review of 19 studies showed strong correlation between late gadolinium enhancement (LGE) in papillary muscle (odds ratio [OR] 4.09, 95% CI, 1.28–13.05) and longitudinal mitral annular disjunction distance (OR 1.16, 95% CI, 1.02–1.33) with ventricular arrhythmia [43].

Although CT and echocardiography are most commonly used for planning and follow-up of structural and VHD interventions, MRI is playing an increasing role in this expanding field [35], capitalizing on the good spatial and temporal resolution, large field of view, and inherent tissue characterization available with MRI.

### **MRI Heart Function with Stress**

There is no relevant literature to support the use of MRI heart function with stress for the evaluation of dyspnea due to suspected VHD, ischemia excluded.

### **Radiography Chest**

Chest radiography can provide information on heart failure in the setting of VHD. Diagnosis of specific valve abnormalities is limited, but radiographs may aid in identification of characteristic cardiac chamber and great vessel changes [44] as well as marked calcification of aortic root or mitral annulus.

### **Rb-82 PET/CT Heart**

There is no relevant literature to support the use of Rb-82 PET/CT heart for the evaluation of dyspnea due to suspected VHD, ischemia excluded.

### **SPECT or SPECT/CT MPI Rest and Stress**

There is no relevant literature to support the use of single-photon emission computed tomography (SPECT) or SPECT/CT myocardial perfusion imaging (MPI) for the evaluation of dyspnea due to suspected VHD, ischemia excluded.

### **US Echocardiography Transesophageal**

TEE is useful in the assessment of suspected VHD with suboptimal or clinically discordant TTE results [24] and is critical in perioperative assessment of VHD. Novel developments in automated 3-D assessment shows promise in delineation of mitral valve anatomy, with good correlation between 3-D and 2-D assessment noted for all parameters—intercommissural diameter ( $r = 0.84$ ,  $P < .01$ ), mitral annular area ( $r = 0.94$ ,  $P > .01$ ), anterior leaflet length ( $r = 0.83$ ,  $P < .01$ ), and posterior leaflet length ( $r = 0.67$ ,  $P < .01$ ) [45]—where assessment of pulmonary vein flow can give insight to prosthetic mitral valve thrombosis [46]. En-face 3-D TEE imaging of leaflet is feasible but led to nonsignificant underestimation when compared with measurements obtained from 2-D TEE views in a series of patients undergoing elective cardiac surgery or intervention [47].

### **US Echocardiography Transthoracic Resting**

TTE is the primary modality for diagnosis, assessment, and follow-up of native and prosthetic VHD [21,48], providing insights to anatomy, mechanism of disease, and hemodynamic impact. Evaluation of leaflet morphology is typically obtained first by echocardiography, with proposed schemes to distinguish unicuspid from bicuspid or tricuspid aortic valves [49], although there is reported a common (20%) reclassification of leaflet morphology as determined on surface echocardiography after MRI, CT, or TEE imaging [23], or internal review of echocardiography images [50]. Bicuspid leaflet morphology as identified on echocardiography can predict valvular function and aortic dilation [51], with a prospective group of 852 patients with bicuspid valve having aortic regurgitation (23%) related to valve prolapse (OR: 5.16,  $P < .0001$ ), and aortic stenosis (22%) associated with fused right and noncusps, (OR: 2.09,  $P < .001$ ), and the presence of raphe (OR: 2.75,  $P < 0.001$ ). Gradation of valve abnormality (eg, mild, moderate, or severe aortic stenosis) is predominantly obtained by echocardiography. Echocardiographic assessment of early bioprosthetic valve failure can be addressed systematically with correlation to surgical changes [52]. Patient prosthesis mismatch has been associated with raised transprosthetic pressure after mitral valve replacement, although only when calculated by the continuity equation ( $P = .021$ ) [53]. Doppler parameters may be useful in estimating LV filling pressure in patients with mitral annular calcification [54]; in a group of 50 patients with mitral annular calcification, the ratio of early-to-late diastolic filling velocity (mitral E/A) showed the best correlation, ( $r = 0.66$ ;  $P < .001$ ), whereas the ratio of early diastolic filling velocity-to-mitral annulus velocity (E/e') demonstrated weak correlation ( $r = 0.42$ ;  $P = .003$ ).

Large-scale screening of populations revealed newly identified VHD in 51% of 2,500 patients >65 years of age, although this was commonly mild [55], with cardiac auscultation by general practitioners showing modest sensitivity and specificity (44% and 69% , respectively) in asymptomatic patients, even in the setting of significant disease [56]. TTE 3-D techniques may improve assessment of mitral or aortic valve dysfunction, with a systematic review showing the strongest evidence for estimating the mitral valve area in patients with rheumatic mitral valve stenosis and the vena contracta area in patients with mitral insufficiency [57]. Echocardiography has provided mechanistic clarification to tricuspid valve insufficiency induced by device leads; notably, when the lead tip was in the interventricular septum or if the lead was shown to be impinging on a leaflet, the device lead was more likely to impede leaflet mobility ( $P < .05$ ), and interfering leads were associated with more significant tricuspid regurgitation than noninterfering leads ( $P < .05$ ) [58]. Echocardiographic assessment of the left atrium may improve insights to aortic and mitral valve dysfunction [59].



Novel strain imaging applications have shown promise in characterizing LV changes in patients with aortic stenosis and aortic insufficiency [60]. Volume loop characteristics (area under receiver operating characteristic curve [AUC] = 0.99, 1.00, and 1.00; all  $P < .01$ ) showed improved discrimination relative to peak strain (AUC = 0.75, 0.89, and 0.76;  $P = .06$ ,  $<.01$ , and  $.08$ , respectively) and LV ejection fraction (AUC = 0.56, 0.69 and 0.69; all  $P > .05$ ) to distinguish aortic valve stenosis versus control, aortic valve regurgitation versus control, and aortic valve stenosis versus aortic valve regurgitation groups, respectively. Strain imaging has also shown promise in providing improved insight to aortopathy and aortic elasticity in patients with a bicuspid valve [61].

### **US Echocardiography Transthoracic Stress**

TTE stress may be useful in further characterization of mitral and aortic stenosis, for example, in setting of discrepant resting echocardiographic gradation of stenosis and patient symptoms [21,24], as well as evaluating symptoms and exercise capacity of patients. Stress echocardiography may be useful in determining eligibility for competitive sports [62], with exercise-induced changes to ventricular response and valvular lesion, as well as changes to right ventricular (RV) systolic pressure potentially aiding in decision making.

### **Variant 2: Dyspnea due to suspected cardiac arrhythmia. Ischemia excluded. Initial imaging.**

#### **Arteriography Coronary with Ventriculography**

There is no relevant literature to support the use of arteriography coronary with ventriculography for the evaluation of dyspnea due to suspected cardiac arrhythmia, ischemia excluded.

#### **CT Coronary Calcium**

There is no relevant literature to support the use of CT coronary calcium for the evaluation of dyspnea due to suspected cardiac arrhythmia, ischemia excluded.

#### **CT Heart Function and Morphology**

Cardiac CT can provide precise anatomic and morphologic information in a range of pathologies that may lead to cardiac dysrhythmia and, in some cases, can lend insight to tissue characterization. A scoring system combining CT-derived morphologic and tissue characterization in 77 patients with diagnosed or suspected arrhythmogenic RV cardiomyopathy/dysplasia (ARVC/D) yielded a sensitivity of 77.8%, a specificity of 96.0%, a positive predictive value of 91.3%, a negative predictive value of 88.9%, and an accuracy of 89.6% [63]. Automated quantitation of fat in the RV free wall on CT imaging using a fat extent threshold of 8.5% was used to diagnose ARVC/D with 94% sensitivity (95% CI, 82%–98%) and 92% specificity (95% CI, 83%–96%) [64]. Quantitation of fat is not regularly performed in a clinical setting, but qualitative assessment of extensive fatty change in conjunction with RV dilation and dysfunction as demonstrated on 4-D cine imaging may be useful. Epicardial fat distribution on CT imaging has also been investigated for diagnosis of ARVC/D, with the optimal cutoff LV epicardial adipose tissue index (normalized to mediastinal adipose tissue) of 0.24, with a sensitivity and specificity of 91% and 71%, respectively [65]. Wall thinning, hypoperfusion, and delayed enhancement can identify scars [66]. Myocardial scars depicted by CT have been compared with electrical features from electroanatomic mapping, with overall segmental concordance good ( $\kappa = 0.536$ ), suggesting at least a potential role of CT integration in ventricular tachycardia and radiofrequency catheter ablation procedures [67].

CT can provide a precise regional anatomic survey for pre- and intraprocedural guidance of catheter ablation [66], with potential ablation targets notably located within 1 cm of critical structures such as coronary arteries and phrenic nerve in 35 (80%) and 18 (37%) patients, respectively [68]. CT also provides robust anatomic delineation of pulmonary vein and left atrial appendage anatomy [28] for both planning and follow-up of pulmonary vein ablation as well as left atrial appendage occlusion for atrial fibrillation treatment. Measured attenuation of epicardial fat has shown to be a predictor of electrophysiologic properties of the adjacent left atrium in patients with atrial fibrillation [69].

#### **CTA Coronary Arteries**

There is no relevant literature to support the use of CTA coronary arteries for the evaluation of dyspnea due to suspected cardiac arrhythmia, ischemia excluded.

#### **FDG-PET/CT Heart**

Patients may benefit from PET imaging for scar identification and for prediction of ventricular arrhythmia and sudden cardiac death. Full thickness myocardial scarring has shown strong association with major arrhythmic events after accounting for age, sex, cardiovascular risk factors, beta-blocker therapy, and resting LV ejection fraction



(adjusted hazard ratio per 10% increase in scars, 1.48 [95% CI, 1.22–1.80];  $P < .001$ ) in patients with low LV ejection fraction (<35%) [70].

### **MRI Heart Function and Morphology**

Ventricular arrhythmias are the primary cause of sudden cardiac death, and the presence and characterization of myocardial scars on MRI can help predict the likelihood of ventricular arrhythmia or sudden cardiac death in patients with nonischemic myocardial disease [66]. In a review of 15 studies, with a total of 2,747 patients, in patients with a myocardial scar, the risk for adverse cardiac events was more than 3-fold higher, and the risk for arrhythmic events 5-fold higher compared to patients without a myocardial scar [71]. Life threatening arrhythmic events rate was significantly higher in hypertrophic cardiomyopathy patients with significant LGE than in those without (3.0%/year versus 0.5%/year,  $P = .011$ ); furthermore, in these patients, the annual events rate was noted to be significantly higher in patients with T2-weighted high signal than in those without (5.8%/year versus 0.9%/year,  $P = .008$ ) [72]. In a systematic review of patients with known sarcoidosis and suspected cardiac involvement, the combined end point of death or ventricular arrhythmia occurred in 64 patients with scarring versus 18 patients without scarring on LGE imaging on MRI (annualized incidence, 8.8% versus 0.6%; relative risk 6.20 [95% CI, 2.47–15.6];  $P < .001$ ) [73]. Across a wide spectrum of patients with dilated cardiomyopathy captured in a systematic review and meta-analysis of 29 studies, LGE on MRI was strongly and independently associated with ventricular arrhythmia or sudden cardiac death [74]. In a meta-analysis of 19 studies of patients with ischemic and nonischemic cardiomyopathy, LGE showed a pooled OR for arrhythmic event of 5.62 (95% CI, 4.20–7.51), with no significant differences between ischemic cardiomyopathy and nonischemic cardiomyopathy patients [75]. In an investigation of 59 patients with cardiac sarcoidosis, multivariate regression analysis showed the extent of LGE to be the sole independent predictor of outcome events on cardiac MRI, with a hazard ratio of 2.2 per tertile (95% CI, 1.07–4.59), with extent of LGE >22% (third tertile) had positive and negative predictive values for serious cardiac events of 75% and 76%, respectively [76].

Morphologic analysis of fibrotic scarring in nonischemic dilated cardiomyopathy has shown promise in prediction of electrophysiologic impact [77]. In a group of patients with systemic sclerosis, extracellular volume as measured on MRI corresponded with a risk for significant arrhythmia [78]. In a group of cardiac resynchronization therapy patients, an algorithm based on scar mass as quantitated by MRI identified 148 patients (68.2%) without implantable cardioverter-defibrillator therapy/sudden cardiac death during follow-up with a 100% negative predictive value [79], and appropriate implantable cardioverter-defibrillator therapy can be predicted in ischemic cardiomyopathy patients with primary prevention implantable cardioverter-defibrillator by quantifying the LGE border zone [80]. Concomitant assessment for structural heart disease and LV function can also be obtained.

MRI can provide tissue-specific direction for targeted treatment of both ventricular and atrial arrhythmic foci [81,82].

Morphologic and functional criteria as assessed by MRI are useful in cases of suspected ARVC/D [83].

### **MRI Heart Function with Stress**

There is no relevant literature to support the use of MRI heart function with stress for the evaluation of dyspnea due to suspected cardiac arrhythmia, ischemia excluded.

### **Radiography Chest**

There is no relevant literature to support the use of radiography for the evaluation of dyspnea due to suspected arrhythmia, ischemia excluded. Radiography may demonstrate cardiac silhouette enlargement as well as pulmonary vascular cephalization or edema as may be seen in setting of cardiac arrhythmia.

### **Rb-82 PET/CT Heart**

There is no relevant literature to support the use of Rb-82 PET/CT heart for the evaluation of dyspnea due to suspected cardiac arrhythmia, ischemia excluded.

### **SPECT or SPECT/CT MPI Rest and Stress**

There is scant literature regarding the use of SPECT or SPECT/CT MPI in the assessment of suspected arrhythmia. MPI can elucidate remodeling in patients who are postcardiac resynchronization therapy, with differential incidence of ventricular arrhythmia [84], and gated SPECT imaging phase analysis has shown potential in differentiating degrees of mechanical dyssynchrony [85].

### **US Echocardiography Transesophageal**

There is scant literature regarding the use of TEE in the assessment of suspected arrhythmia. Left atrial appendage size (left atrial appendage end-diastolic volume [ $P = .002$ ; OR 1.6] and morphology [cauliflower shape ( $P = .001$ ; OR, 10.2)]) are predictive of thromboembolic events in patients with nonvalvular atrial fibrillation [86].

### **US Echocardiography Transthoracic Resting**

Echocardiography is an important noninvasive imaging technique in the diagnosis and prognosis of patients with arrhythmias, providing insight into associated myocardial, valvular, and structural disorders. Morphologic and functional criteria are useful in RV assessment in cases of suspected ARVC/D [83]. Assessment of LV function by speckle-tracking strain assessment has shown utility in prediction of ventricular arrhythmia in patients post-LV assist devices placement [87], and ejection fraction as assessed by echocardiography has shown predictive value in ventricular arrhythmia as well as in all-cause mortality in heart failure patients with implantable cardioverter-defibrillators [88].

Use of speckle-tracking strain analysis has also shown incremental prognostic value to typical clinical and ECG criteria for cardiac resynchronization therapy using cutoff values of  $-9\%$  for global circumferential and longitudinal strain [89], whereas another group of cardiac resynchronization patients with global longitudinal strain better than  $-8.3\%$  showed event-free survival benefit (log rank,  $P < .001$ ) [90]. Strain analysis with speckle tracking has also shown utility in risk assessment of malignant arrhythmias in Chagas disease (OR, 0.72; 95% CI, 0.54–0.96;  $P = .026$ ) [91], in early detection of LV systolic dysfunction in setting of frequent ventricular extrasystoles, with global LV longitudinal strain decreased in patients with frequent ventricular extrasystoles ( $-18.4 \pm 3.4$  and  $-21.8 \pm 2.4$ ;  $P < .001$ ) [92], as well as predicting outcomes in dyssynchrony patients, using either tissue Doppler imaging longitudinal velocity delay  $\geq 80$  ms or speckle-tracking radial strain delay  $\geq 130$  ms [93].

Although epicardial fat is rarely noted on clinical reports, associations have been noted between epicardial fat thickness as measured on echocardiography and dysrhythmia [94], in the prediction of successful electrical cardioversion and atrial fibrillation recurrence [95,96], and in the ablation of premature ventricular contractions [97].

Measurement of left atrial volume has shown to be a predictor of persistent atrial fibrillation after mitral valve surgery, with indexed volume  $>39$  mL/m<sup>2</sup> having a sensitivity of 79% (AUC: 0.762, SE: 0.051,  $P < .001$ ) [98].

### **US Echocardiography Transthoracic Stress**

There is no relevant literature to support the use of TTE stress for the evaluation of dyspnea due to suspected arrhythmia, ischemia excluded.

### **Variant 3: Dyspnea due to suspected pericardial disease. Ischemia excluded. Initial imaging.**

#### **Arteriography Coronary with Ventriculography**

There is no relevant literature to support the use of arteriography coronary with ventriculography for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded. This is distinguished from right heart catheterization.

#### **CT Chest Without IV Contrast**

There is scant evidence to support the use of CT chest without intravenous (IV) contrast for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded. The presence of bilateral pleural effusions detected on chest CT in patients with acute pericarditis is associated with increased risk of in-hospital cardiac tamponade (OR = 7.52, 95% CI, 2.16–26.21) and not associated with pericarditis recurrence in the long term, typically considered the most problematic complication of pericarditis [99].

#### **CT Chest Without and With IV Contrast**

There is no relevant literature to support the use of CT chest without and with IV contrast for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded.

#### **CT Chest With IV Contrast**

There is no relevant literature to support the use of CT chest with IV contrast for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded. Although this procedure is not a first-line imaging test, it may provide information on pericardial changes such as effusion, thickening, or enhancement.

### **CT Coronary Calcium**

There is no relevant literature to support the use of CT coronary calcium for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded.

### **CT Heart Function and Morphology**

CT is useful in depiction of abnormal pericardial thickening as well as in defining the extent of pericardial calcification [100]. CT can be considered for assessing size, location, and density of pericardial effusion, which may not be fully demonstrated by echocardiography, and can be used for planning before pericardiocentesis or pericardial cardiectomy. In cases of suspected pericardial masses or tumors, CT can be used for assessment of size and location, involvement or invasion of adjacent structures, and extracardiac findings such as lymphadenopathy [101].

CT provides limited and indirect hemodynamic information, such as enlargement of the atria and venae cavae in cases of pericardial constriction. Functional evaluation using CT is possible using retrospective ECG-gated examination, although the utility of such techniques are challenged by breath-held acquisition, suboptimal temporal resolution compared to echocardiography, and MRI as well as the potential increased artifact case of tachycardia or unstable heart rhythm [100,102].

Epicardial fat volume quantitation by CT has shown some association with the outcome of patients with a first episode of acute pericarditis and a potential prognostic implication [103], although this has limited clinical application to date.

### **CTA Chest**

There is no relevant literature to support the use of CTA chest for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded. Although this procedure is not a first-line imaging test, it may provide information on pericardial changes such as effusion, thickening, or enhancement.

### **CTA Coronary Arteries**

There is no relevant literature to support the use of CTA coronary arteries for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded.

### **FDG-PET/CT Heart**

There is limited literature regarding the use of FDG-PET/CT in the assessment of suspected pericardial disease, ischemia excluded. The presence of pericardial inflammation as stratified by standardized uptake values can predict reversibility of transient constrictive pericarditis with medical treatment. Using pericardial maximized standardized uptake value of 3.0 as a cutoff value, sensitivity, specificity, positive predictive value, and negative predictive value of FDG-PET/CT for predicting response to medical treatment were 100%, 71%, 82%, and 100%, respectively, in a small group (n = 16) of prospectively recruited patients with constrictive pericarditis [104]. FDG-PET/CT may be helpful in making a presumptive diagnosis of malignancy, especially in nondiagnostic pericardial effusion with relatively high-risk pericardiocentesis, or may guide selection of an optimal biopsy site with a potential high yield of disease. However, infectious processes such as tuberculosis can show increased FDG uptake mimicking malignancy, which limits FDG-PET/CT utility in differentiation between benign and malignant pericardial disease [105].

### **MRI Heart Function and Morphology**

MRI is typically an adjuvant test when echocardiographic data are ambiguous or inconclusive for constriction [102]. MRI can provide reliable depiction of pericardial thickening, typically with dark blood imaging, with prognostic value for patients eventually progressing to surgical resection. Furthermore, cardiac MR, real-time cine imaging with free breathing can suggest constrictive pathophysiology where the septum shifts toward the left ventricle during early inspiration. A model combining pericardial thickness and relative interventricular septal excursion provided the best overall performance in prediction of constrictive pericarditis in a surgical series of patients (C statistic, 0.98, 100% sensitivity, 90% specificity) [106], although shallow breaths or vigorous inspiration may result in false negative or false positive results, respectively [107].

LGE can reveal the presence and severity of pericardial inflammation [102], with histologic changes corresponding to MRI appearance. MRI may define the extent of associated myocarditis when there is a concern of myocardial involvement and echocardiography is inconclusive [107]. MRI can provide incremental value to evaluate the presence and severity of active pericardial inflammation in patients with constrictive pericarditis [107]. Pericardial delayed hyperenhancement quantitative assessment on cardiac MRI can be a helpful prognostic tool in the care of

patients with recurrent pericarditis, with the potential for image-guided treatment modulation. In one series, patients without MRI follow-up had a larger number of steroid pulse therapies and a higher overall total amount of steroids administered compared with patients followed with MRI ( $P = .003$  and  $P = .001$ , respectively), with recurrence and pericardiocentesis rates also lower in those patients receiving MRI ( $P < .0001$ ) [108]. Quantitative pericardial delayed hyperenhancement has shown improved discrimination for clinical remission compared with other clinical variables (hazard ratio: 0.77; 95% CI, 0.64–0.93;  $P = .008$ ), was independently associated with clinical remission [109], and is useful in the follow-up of patients with suspected chronic or remitting pericarditis. LGE can be present in end-stage pericarditis reflecting fibrosis with no or limited active inflammation, although this tends to be minimal in amount. MRI may also provide insight to pericardial edema using non-IV contrast-enhanced sequences (T2-weighted short-tau inverted recovery fast spin-echo sequences), although the presence of pericardial effusion may confound analysis of inflammatory change.

MRI is useful for assessing pericardial masses and tumors, particularly for accurate localization and sizing and tissue characterization [101,110], and to delineate potential extension to adjacent thoracic anatomic structures.

### **MRI Heart Function with Stress**

There is no relevant literature to support the use of MRI heart function with stress for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded.

### **Radiography Chest**

Chest radiograph may show suggestive findings of pericardial effusion, pericardial calcifications, pericardial cyst, and pericardial defect/absence, although this generally has a lower diagnostic potential to delineate pericardial abnormalities compared with echocardiography, CT, and MRI.

### **Rb-82 PET/CT Heart**

There is no relevant literature to support the use of Rb-82 PET/CT heart for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded.

### **SPECT or SPECT/CT MPI Rest and Stress**

There is no relevant literature to support the use of SPECT or SPECT/CT MPI rest and stress for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded.

### **US Echocardiography Transesophageal**

TEE can be considered in assessing pericardial disease in a patients with suspected complicated acute pericarditis, constrictive pericarditis, or pericardial masses if TTE images are of poor quality [102].

### **US Echocardiography Transthoracic Resting**

TTE is safe and typically considered the first-line imaging modality in almost all types of pericardial diseases [100,102]. Most acute pericarditis cases are uncomplicated, and echocardiography is the first and only imaging test necessary, with diagnosis based on characteristic chest pain and ECG changes. Echocardiography is performed primarily for risk stratification and may identify a pericardial effusion, evidence of pericardial tamponade, wall motion abnormalities, or features of pericardial constriction [102]. Only a minority of patients will develop complicated pericarditis. Echocardiography can provide insight to hemodynamic changes including tamponade and constrictive pathophysiology, although this has a limited role in assessing the presence of active pericardial inflammation [107].

Echocardiography can detect pericardial masses/nodules and is useful in assessing associated hemodynamic effects of tumor or effusion [110].

### **US Echocardiography Transthoracic Stress**

There is no relevant literature to support the use of TTE stress for the evaluation of dyspnea due to suspected pericardial disease, ischemia excluded. Stress echocardiography has shown some promise in demonstrating exercise-induced changes in patients with suspected diastolic dysfunction. E/e' values postexercise have served as a surrogate for elevated LV filling pressures, and exercise-induced pulmonary hypertension has also been noted [111]. Further validation of this technique, increased standardization of imaging protocols, as well as integration of this information into clinical pathways all could potentially elevate this emerging practice to more widespread adoption.

## Summary of Recommendations

- **Variant 1:** US echocardiography transthoracic resting and radiography chest are usually appropriate for the initial imaging of adults with dyspnea due to suspected VHD with ischemia excluded. These procedures are complementary, with echocardiography providing specific anatomic and hemodynamic insight to valve function, while radiography can provide broad characterization of a range of potential causes of dyspnea and, less commonly, can provide insight to particular valve abnormalities.
- **Variant 2:** US echocardiography transthoracic resting or MRI heart function and morphology without and with IV contrast is usually appropriate for the initial imaging of adults with dyspnea due to suspected cardiac arrhythmia with ischemia excluded. Echocardiography and MRI both provide insight into associated myocardial, valvular, and structural disorders. MRI can delineate areas of myocardial scar or infiltrative processes. Echocardiography can also characterize myocardial abnormality, for example, with speckle tracking, although this is less established than MRI techniques. 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 radiography chest for the initial imaging of adults with dyspnea due to suspected cardiac arrhythmia with ischemia excluded. Radiography is unlikely to reveal the etiology of arrhythmia but can provide broad characterization of a range of potential causes of dyspnea. There is insufficient medical literature to conclude whether or not these patients would benefit from radiography chest for this clinical scenario. Radiography chest in this patient population is controversial but may be appropriate.
- **Variant 3:** US echocardiography transthoracic resting or radiography chest or CT heart function and morphology with IV contrast or MRI heart function and morphology without and with IV contrast is usually appropriate for the initial imaging of adults with dyspnea due to suspected pericardial disease with ischemia excluded. Echocardiography allows morphologic and hemodynamic assessment of pericardial abnormalities, although pericardial depiction is usually incomplete. CT provides complete anatomic depiction of the pericardium including calcification, although physiologic assessment is limited. MRI provides morphologic and hemodynamic evaluation of the pericardium, and inflammation can be evaluated with a variety of techniques; however calcific change is not reliably imaged. 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 FDG-PET/CT heart for the initial imaging of adults with dyspnea due to suspected pericardial disease with ischemia excluded. Inflammatory change or neoplastic involvement of the pericardium may be delineated with FDG-PET/CT imaging. There is insufficient medical literature to conclude whether or not these patients would benefit from FDG-PET/CT heart for this clinical scenario. FDG-PET/CT heart in this patient population is controversial but may be appropriate.

## 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](http://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 [112].

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."

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- American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Thoracic Surgeons. *J Am Soc Echocardiogr* 2018;31:381-404.
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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.