

ACR Appropriateness Criteria[®]

Infective Endocarditis

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Abstract

Infective endocarditis can involve a normal, abnormal, or prosthetic cardiac valve. The diagnosis is typically made clinically with persistently positive blood cultures, characteristic signs and symptoms, and echocardiographic evidence of valvular vegetations or valvular complications such as abscess, dehiscence, or new regurgitation. Imaging plays an important role in the initial diagnosis of infective endocarditis, identifying complications, prognostication, and informing the next steps in therapy. This document outlines the initial imaging appropriateness of a patient with suspected infective endocarditis and for additional imaging in a patient with known or suspected infective endocarditis.

The American College of Radiology Appropriateness Criteria are evidence-based guidelines for specific clinical conditions that are reviewed annually by a multidisciplinary expert panel. The guideline development and revision include an extensive analysis of current medical literature from peer reviewed journals and the application of well-established methodologies (RAND/UCLA Appropriateness Method and Grading of Recommendations Assessment, Development, and Evaluation or GRADE) to rate the appropriateness of imaging and treatment procedures for specific clinical scenarios. In those instances where evidence is lacking or equivocal, expert opinion may supplement the available evidence to recommend imaging or treatment.

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The ACR Appropriateness Criteria documents are updated regularly. Please go to the ACR website at www.acr.org/ac to confirm that you are accessing the most current content.

Disclaimer: 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.

Key Words: Appropriateness Criteria, Appropriate Use Criteria, AUC, Infective endocarditis, Native valve endocarditis, Paravalvular abscess, Prosthetic valve endocarditis, Valvular dehiscence, Valvular vegetation

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ACR Appropriateness Criteria® Infective Endocarditis. Variants 1 and 2 and Tables 1 and 2.

Variant 1. Suspected infective endocarditis. Initial imaging		
Procedure	Appropriateness Category	Relative Radiation Level
US echocardiography transthoracic resting	Usually Appropriate	0
Radiography chest	Usually Appropriate	⊕
CT heart function and morphology with IV contrast	Usually Appropriate	⊕⊕⊕⊕
US echocardiography transesophageal	May Be Appropriate (Disagreement)	0
CTA coronary arteries with IV contrast	May Be Appropriate	⊕⊕⊕
CTA chest with IV contrast	May Be Appropriate	⊕⊕⊕
Arteriography coronary	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 heart	Usually Not Appropriate	⊕⊕⊕⊕
Fluoroscopy heart	Usually Not Appropriate	⊕⊕
MRI heart function and morphology without and with IV contrast	Usually Not Appropriate	0
MRI heart function and morphology without IV contrast	Usually Not Appropriate	0
WBC scan heart	Usually Not Appropriate	⊕⊕⊕⊕

Variant 2. Known or suspected infective endocarditis. Additional imaging to direct patient management or treatment		
Procedure	Appropriateness Category	Relative Radiation Level
US echocardiography transesophageal	Usually Appropriate	0
US echocardiography transthoracic resting	Usually Appropriate	0
CT heart function and morphology with IV contrast	Usually Appropriate	⊕⊕⊕⊕
Arteriography coronary	May Be Appropriate	⊕⊕⊕
CT chest with IV contrast	May Be Appropriate	⊕⊕⊕
CT chest without and with IV contrast	May Be Appropriate	⊕⊕⊕
CT chest without IV contrast	May Be Appropriate	⊕⊕⊕
CTA chest with IV contrast	May Be Appropriate	⊕⊕⊕
CTA coronary arteries with IV contrast	May Be Appropriate	⊕⊕⊕
FDG-PET/CT heart	May Be Appropriate	⊕⊕⊕⊕
Fluoroscopy heart	May Be Appropriate (Disagreement)	⊕⊕
MRI heart function and morphology without and with IV contrast	May Be Appropriate	0
MRI heart function and morphology without IV contrast	May Be Appropriate	0
Radiography chest	May Be Appropriate	0
WBC scan heart	May Be Appropriate	⊕⊕⊕⊕

Table 1. 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.

Table 2. Relative radiation level designations

RRL	Adult Effective Dose Estimate Range (mSv)	Pediatric Effective Dose Estimate Range (mSv)
0	0	0
⊕	<0.1	<0.03
⊕⊕	0.1-1	0.03-0.3
⊕⊕⊕	1-10	0.3-3
⊕⊕⊕⊕	10-30	3-10
⊕⊕⊕⊕⊕	30-100	10-30

Note: Relative radiation level (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."

SUMMARY OF LITERATURE REVIEW

Introduction/Background

Infective endocarditis can involve a normal, abnormal, or prosthetic cardiac valve. In recent years, infective endocarditis of normal right-sided valves has become more frequent because of intravenous (IV) injection of illicit drugs, indwelling IV catheters, and implantable cardiac devices [1-3]. In patients with implanted cardiac devices, it has become increasingly important to consider infections of the device leads, device generator, and device pocket [4]. The clinical presentation of endocarditis is heterogeneous, with patients often presenting with acute heart failure due

to severe valve destruction, but many presenting insidiously. The physical examination often reveals a new heart murmur, most commonly due to valvular insufficiency, and evidence of heart failure or a myriad of potential embolic and inflammatory/immune-mediated sequelae. At the first clinical suspicion of infective endocarditis, the workup typically includes serial blood cultures and transthoracic echocardiography (TTE) [5,6].

Although infective endocarditis is typically diagnosed clinically with persistently positive blood cultures in association with characteristic symptoms and physical findings [5,7], and then further evaluated by echocardiography,

blood cultures may be negative in the setting of antibiotic use. Imaging is used to support the diagnosis by demonstrating vegetations of cardiac valves and, in complicated cases, paravalvular abscesses affecting native [8] and prosthetic [9] valves. Imaging is also used to assess the severity of valvular damage, identify complications, recognize the presence and severity of heart failure, and inform the next steps in patient management [7,10].

The term “suspected” in the variant description may imply a combination of symptoms, findings on clinical examination, laboratory results, and those found on imaging performed for other reasons. The term “initial imaging” refers to the imaging step after suspicion has been established. This document has 2 variants. The first variant represents initial imaging; namely, that none of the studies in **Variant 1** have been performed. Recognizing that a small set of variants are unable to fully encompass the diverse set of clinical presentations, whereas the second variant considers patients for whom an initial imaging study has been performed.

Special Imaging Considerations

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) [11]:

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 multi-planar 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 in which each procedure provides unique clinical information to effectively manage the patient’s care).

DISCUSSION OF PROCEDURES BY VARIANT

Variant 1: Suspected infective endocarditis. Initial imaging

Arteriography Coronary. There is limited evidence in the literature for the use of catheterization for assessing patients with suspected infective endocarditis. The primary indication is for presurgical evaluation of the coronary arteries [12].

CT Chest. There is limited evidence in the literature for the use of CT chest to assess patients with suspected infective endocarditis. The primary role of CT chest is in evaluating pulmonary complications of infective endocarditis and can be particularly helpful in right-sided endocarditis for demonstrating septic pulmonary infarcts and abscesses [13,14].

CT Heart Function and Morphology. CT is less accurate than TTE and transesophageal echocardiography (TEE) for identifying valvular vegetation. Consequently, the primary role of CT is in evaluating complications of infective endocarditis such as paravalvular and myocardial abscesses and pseudoaneurysms [15–20]. In depicting aortic valve pseudoaneurysms, one study showed a sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of 100%, 87.5%, 91.7%, and 100%, respectively [18]. The primary weakness of CT is in detecting native aortic valve vegetations <1 cm in size for which the NPV was 55.5%. However, the sensitivity, specificity, PPV, and NPV were all 100% for vegetations >1 cm in size [18]. One study also showed CT to lack sensitivity for detecting valve perforations when compared with TEE [17]. Compared with echocardiography, CT may be superior in both detecting and visualizing the full extent of a paravalvular abscess, pseudoaneurysm, or fistula, particularly in patients with prosthetic valves [7,10,20–23]. CT may be equivalent or superior to echocardiography in identifying vegetations and valve dehiscence in suspected prosthetic valve endocarditis [7,22,24]. CT may also be utilized to assess for abnormalities in the mobility of mechanical heart valves [24].

CTA Chest. There is limited evidence in the literature for the use of CTA chest for assessing patients with suspected infective endocarditis. The primary role of CTA chest is in evaluating complications of infective endocarditis such as septic pulmonary infarcts and abscesses as well as

paravalvular abscess, depending on CTA acquisition technique [13,14].

CTA Coronary Arteries. There is limited evidence in the literature for the use of coronary CTA (CCTA) for assessing patients with suspected infective endocarditis. CCTA has a role in preoperative planning and assessment of coronary artery disease before surgery [15,17], wherein the risks of selective coronary angiography may be considerable. Given the well-established high NPV of CCTA, its use for the presurgical assessment of significant coronary artery disease allows for a noninvasive alternative to cardiac catheterization [15,25,26]. Although the use of CCTA and CT-derived fractional flow reserve has not been studied in a patient population with suspected infective endocarditis, extrapolating from the available literature suggests that selective CT-derived fractional flow reserve in patients found to have coronary artery disease on CCTA may play a role in guiding treatment decisions [27,28].

FDG-PET/CT Heart. There is limited evidence in the literature for the use of fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET/CT in suspected infective endocarditis. One prospective study showed a low sensitivity of 39% for diagnosing infective endocarditis when compared with the modified Duke criteria [29]. Another retrospective study showed a sensitivity of 0% for diagnosing native valve endocarditis when compared with the modified Duke criteria [30].

Some recent studies have shown potential clinical value of FDG-PET/CT in infective endocarditis [31]. A prospective study with 72 patients showed that adding abnormal FDG uptake around a prosthetic valve to the modified Duke criteria at admission increased the sensitivity for the diagnosis of prosthetic valve endocarditis from 70% to 97% [32]. Another smaller prospective study showed that adding PET/CT to the modified Duke criteria in patients with an intermediate probability of infective endocarditis and an implantable cardiac device increased diagnostic accuracy [33]. However, when looking at a cohort of patients with native and prosthetic valves, one study showed a relatively low sensitivity of 39% for the diagnosis of infectious endocarditis [29]. Another retrospective study showed a sensitivity of 0% for diagnosing native valve endocarditis when compared with the modified Duke criteria [30].

In patients with congenital heart disease and intravascular or intracardiac prosthetic material, one prospective study showed that the use of PET/CT in addition to the modified Duke criteria, increased the diagnostic accuracy from 61.2% to 85.1% [34].

Fluoroscopy Heart. There are no data to support the use of cardiac fluoroscopy in suspected infective endocarditis.

On rare occasions, cardiac fluoroscopy may be indicated for evaluating mechanical prosthetic cardiac valves afflicted with endocarditis [35]. Valve fluoroscopy is used to detect excess mobility of the mechanical prosthetic valve during the cardiac cycle (a finding highly suggestive of valve dehiscence due to infective endocarditis) or to detect immobility of mechanical prosthetic valve leaflets secondary to infected pannus or thrombus.

WBC Scan Heart. White blood cells (WBCs) may be labeled with either indium-111 (In-111), Tc-99m, or gallium-67 (Ga-67) [36]. There is limited evidence in the literature for the use of WBC scans in suspected infective endocarditis. One center reported a sensitivity of 0% for the detection of valvular vegetations by In-111 WBC in 7 patients with known vegetations seen by TEE [37].

MRI Heart Function and Morphology. There is limited evidence in the literature for the use of MRI of the heart in suspected infective endocarditis. One study showed that MRI was able to detect 14 out of 16 (87.5%) valvular vegetations $> 7 \times 9.5$ mm in patients with suspected infective endocarditis when compared with echocardiography [38]. One vegetation was not visualized because of an artifact from a prosthetic valve.

Radiography Chest. The chest radiograph is used to determine cardiac chamber size and the presence and severity of pulmonary venous hypertension and edema. It is also used to monitor the severity of the hemodynamic consequences of valvular regurgitation caused by infective endocarditis and to assess the response to treatment. In right-sided endocarditis, the chest radiograph may be effective in demonstrating pulmonary infarcts and abscesses as sequelae of septic emboli.

US Echocardiography Transthoracic Resting. TTE resting plays an important role in the evaluation of infective endocarditis and is currently the only imaging criterion included in the modified Duke criterion used for a diagnosis of infective endocarditis [39]. It can demonstrate vegetations on cardiac valves, valvular regurgitation, and paravalvular abscess. It is the most frequently used imaging study for confirming the diagnosis of infective endocarditis. The demonstration of vegetations by echocardiography is 1 of the 2 major modified Duke criteria required for the diagnosis of a definite endocarditis [39,40].

Studies show that criteria for the diagnosis, which include the findings on TTE [40,41], were significantly better than traditional criteria based on clinical and bacteriologic criteria.

Several studies evaluated the diagnostic value of TTE and TEE in relation to the pretest probability of infective

endocarditis based on clinical assessment in pediatric [42] and adult [43] patients. These studies concluded that TTE has a lower yield in patients with low probability of endocarditis. TEE is the procedure of choice for patients with intermediate or high probability of endocarditis.

In right-sided endocarditis, TTE and TEE performed comparably, demonstrating similar numbers of vegetations and frequency of tricuspid regurgitation [1,44].

In left-sided native valve *Staphylococcus aureus* endocarditis, the presence of an intracardiac abscess and left ventricular ejection fraction <40% on echocardiography have been shown to be independent predictors of in-hospital mortality [45]. In this same group of patients, intracardiac abscess and valve perforation on echocardiography have been shown to be independent predictors of 1-year mortality [45].

One large retrospective study has shown that in low- to intermediate-risk patients using a strict negative criterion on TTE beyond the absence or presence of valvular vegetations increases the sensitivity and NPV of TTE (sensitivity: 98% versus 43%; NPV: 97% versus 87%) [46].

US Echocardiography Transesophageal. TEE plays an important role in the evaluation of infective endocarditis [39]. It is used in suspected infective endocarditis to directly identify or exclude valvular vegetations, paravalvular abscess, and valvular regurgitation [47,48]. It is the most sensitive imaging technique for identifying vegetations, the presence of which is the hallmark for a definitive diagnosis of infective endocarditis [40]. Ultrasound (US) diagnosis of infective endocarditis provides better diagnostic accuracy than using clinical criteria alone [41]. TEE has been shown to have up to a 98.6% NPV in suspected infective endocarditis [49]. TEE has better sensitivity than TTE for detecting vegetations [40]. TEE has better sensitivity and accuracy than TTE for identifying paravalvular abscesses [40]. TEE is indicated for suspected infective endocarditis of prosthetic valves; it is significantly more accurate than TTE [40]. Authors of a review in 2010 noted that TEE has sensitivity and specificity of >90% for detecting intracardiac lesions associated with infective endocarditis [40].

Several studies evaluated the diagnostic value of TTE and TEE in relation to the pretest probability of infective endocarditis based on clinical assessment in pediatric [42] and adult [43] patients. These studies concluded that TTE has a lower yield in patients with low probability of endocarditis. TEE is the procedure of choice for patients with intermediate or high probability of endocarditis. Although TEE has been shown to have significantly higher sensitivity than TTE for identifying vegetations [40], specificities were similar at 91% to 100% for TEE and 91% to 98% for TTE.

In right-sided endocarditis, TTE and TEE performed comparably, demonstrating similar numbers of vegetations and frequency of tricuspid regurgitation [1,44].

The size and other characteristics of vegetations on echocardiography have been shown to be useful in predicting complications such as peripheral embolization [50]. In left-sided native valve *S. aureus* endocarditis, the presence of an intracardiac abscess and left ventricular ejection fraction <40% on echocardiography has been shown to be independent predictors of in-hospital mortality [45]. In this same group of patients, intracardiac abscess and valve perforation on echocardiography have been shown to be independent predictors of 1-year mortality [45].

Variant 2: Known or suspected infective endocarditis. Additional imaging to direct patient management or treatment

Arteriography Coronary. The primary role of catheterization is for the presurgical evaluation of the coronary arteries [7,12]. It may be used to assess the severity of valvular dysfunction and ventricular function, but this use has largely been replaced by echocardiography [12].

CT Chest. The primary role of CT chest is in evaluating complications of infective endocarditis after a diagnosis has been made. Routine CT chest can be helpful in right-sided endocarditis for demonstrating septic pulmonary infarcts and abscesses, osteomyelitis, and for preoperative assessment and surgical planning [25].

CT Heart Function and Morphology. The primary role of CT heart is in evaluating complications of infective endocarditis such as paravalvular and myocardial abscesses and pseudoaneurysms [15-20,51]. In depicting aortic valve pseudoaneurysms, one study showed a sensitivity, specificity, PPV, and NPV of 100%, 87.5%, 91.7%, and 100%, respectively [18]. Compared with echocardiography, CT may be superior in both detecting and visualizing the full extent of a paravalvular abscess, pseudoaneurysm, or fistula, particularly in patients with prosthetic valves [7,10,20-23]. CT may be equivalent or superior to echocardiography in identifying vegetations and valve dehiscence in suspected prosthetic valve endocarditis [7,22,24]. CT may also be utilized to assess for abnormalities in the mobility of mechanical heart valves and to identify causes of mechanical valve dysfunction that are missed on echocardiography and fluoroscopy [24].

CTA Chest. The primary role of CTA chest is in evaluating complications of infective endocarditis such as septic pulmonary infarcts and abscesses, paravalvular abscess depending on CTA

acquisition technique [13,14], and aortic pseudoaneurysms. CTA chest can also be helpful for preoperative assessment of vasculature and surgical planning [25].

CTA Coronary Arteries. CCTA has a role in preoperative planning and assessment of coronary artery disease before surgery [15,17], where the risks of selective coronary angiography may be considerable. Given the well-established high NPV of CCTA, its use for the presurgical assessment of significant coronary artery disease allows for a noninvasive alternative to cardiac catheterization [15,25,26]. Although the use of CCTA and CT-derived fractional flow reserve has not been studied in a patient population with suspected infective endocarditis, extrapolating from the available literature suggests that selective CT-derived fractional flow reserve in patients found to have coronary artery disease on CCTA may play a role in guiding treatment decisions [27,28].

FDG-PET/CT Heart. Some recent studies have shown potential clinical value of FDG-PET/CT in infective endocarditis [31]. One study showed that FDG-PET/CT detected clinically unsuspected sites of extracardiac infection in up to 24% of cases [52]. Several single-center studies have shown promise in identifying cardiovascular implantable electronic device infections using FDG-PET/CT with sensitivities ranging from 60% to 100% and specificities ranging from 86% to 100% [4,53-55]. In cases in which TTE and TEE were normal or equivocal, 2 studies showed that FDG-PET/CT was able to detect periprosthetic abscesses [56,57], which has been shown to occur in nearly 30% of cases [47].

Fluoroscopy Heart. Cardiac fluoroscopy may be indicated for evaluating mechanical prosthetic cardiac valves afflicted with endocarditis [35]. Valve fluoroscopy is used to detect excess mobility of the mechanical prosthetic valve during the cardiac cycle (a finding highly suggestive of valve dehiscence due to infective endocarditis) or to detect immobility of mechanical prosthetic valve leaflets secondary to infected pannus or thrombus.

WBC Scan Heart. WBCs may be labeled with either In-111, Tc-99m, or Ga-67 [36]. This may be used for identifying and localizing infected vegetations and paravalvular abscesses [39,58]. When echocardiography is inconclusive in suspected prosthetic valve endocarditis, a WBC scan has been shown to have a lower sensitivity than FDG-PET/CT (64% versus 93%, respectively) but a higher specificity (100% versus 71%, respectively) for the diagnosis of endocarditis [39,59].

MRI Heart Function and Morphology. MRI may have a role in evaluating complications of endocarditis such as

paravalvular and myocardial abscesses, pseudoaneurysms, fistulas, and endothelial inflammation before morphological changes develop [60,61]. It is less accurate than TTE and TEE for identifying valvular vegetations [38] but may serve as an additional study to evaluate for native valve vegetations when echocardiography is inconclusive or nondiagnostic. MRI can be helpful to quantify valvular regurgitation—a feature that may be used to help determine prognosis and guide management—in cases where echocardiography is suboptimal, shows discordance between anatomic and Doppler findings, or in cases with eccentric jets, which can be harder to accurately quantify by echocardiography [62].

Radiography Chest. The chest radiograph is used to determine cardiac chamber size and the presence and severity of pulmonary venous hypertension and edema. It is also used to monitor the severity of the hemodynamic consequences of valvular regurgitation caused by infective endocarditis and to assess the response to treatment. In right-sided endocarditis, the chest radiograph may be effective in demonstrating pulmonary infarcts and abscesses as sequelae of septic emboli.

US Echocardiography Transthoracic Resting. After the diagnosis of infective endocarditis is made, echocardiography can be used to make an informed decision for surgical treatment and play an important role in prognostication. Echocardiography is an excellent tool to evaluate for heart failure, which is a strong indication for valve surgery in several clinical scenarios [39].

The size and other characteristics of vegetations on echocardiography have been shown to be useful in predicting complications such as peripheral embolization [50]. Vegetation's increase or failure to decrease in size on serial echocardiograms during antibiotic therapy has been shown to be predictive of a prolonged or complicated course of infective endocarditis [40,44,63]. However, the usefulness of repeated TTE for altering patient management decreases with the number of repetitions [64]. Other echocardiographic findings that can guide prognosis include periannular complications, severe valvular regurgitation, low ejection fraction, pulmonary hypertension, severe prosthetic valve dysfunction, and premature mitral valve closure (a sign of elevated diastolic pressures) [7].

In left-sided native valve *Staphylococcus aureus* endocarditis, the presence of an intracardiac abscess and left ventricular ejection fraction <40% on echocardiography have been shown to be independent predictors of in-hospital mortality [45]. In this same group of patients, intracardiac abscess and valve perforation on echocardiography have been shown to be independent predictors of 1-year mortality [45].

US Echocardiography Transesophageal. After the diagnosis of infective endocarditis is made, echocardiography can be used to make an informed decision for surgical treatment and play an important role in prognostication. Echocardiography is an excellent tool to evaluate for heart failure, which is a strong indication for valve surgery in several clinical scenarios [39].

The size and other characteristics of vegetations on echocardiography have been shown to be useful in predicting complications such as peripheral embolization [50]. Vegetation's increase or failure to decrease in size on serial echocardiograms during antibiotic therapy has been shown to be predictive of a prolonged or complicated course of infective endocarditis [40,44,63]. Other echocardiographic findings that can guide prognosis include periannular complications, severe valvular regurgitation, low ejection fraction, pulmonary hypertension, severe prosthetic valve dysfunction, and premature mitral valve closure (a sign of elevated diastolic pressures) [7].

In left-sided native valve *S. aureus* endocarditis, the presence of an intracardiac abscess and left ventricular ejection fraction <40% on echocardiography have been shown to be independent predictors of in-hospital mortality [45]. In this same group of patients, intracardiac abscess and valve perforation on echocardiography have been shown to be independent predictors of 1-year mortality [45].

SUMMARY OF RECOMMENDATIONS

- **Variant 1:** US echocardiography transthoracic resting, radiography chest, or CT heart function and morphology with IV contrast is usually appropriate for the initial imaging of suspected infective endocarditis. Radiography chest should be performed in addition to US echocardiography transthoracic resting or CT heart function and morphology with IV contrast. The panel did not agree on recommending US echocardiography transesophageal for the initial imaging of suspected infective endocarditis. There is insufficient medical literature to conclude whether or not these patients would benefit from US echocardiography transesophageal for this clinical scenario. US echocardiography transesophageal in this patient population is controversial but may be appropriate.
- **Variant 2:** US echocardiography transesophageal, US echocardiography transthoracic resting, or CT heart function and morphology with IV contrast is usually appropriate for additional imaging to direct patient management or treatment of known or suspected infective endocarditis. 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 fluoroscopy heart for additional imaging to direct patient management or treatment of known or suspected infective endocarditis. There is insufficient medical literature to conclude whether or not these patients would benefit from fluoroscopy heart for this clinical scenario. Fluoroscopy 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 rating round tabulations for each recommendation.

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

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 2). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document [65].

REFERENCES

1. Akinosoglou K, Apostolakis E, Marangos M, Pasvol G. Native valve right sided infective endocarditis. *Eur J Intern Med* 2013;24:510-9.
2. Cecchi E, Imazio M, Tidu M, et al. Infective endocarditis in drug addicts: role of HIV infection and the diagnostic accuracy of Duke criteria. *J Cardiovasc Med (Hagerstown)* 2007;8:169-75.
3. Lee MR, Chang SA, Choi SH, et al. Clinical features of right-sided infective endocarditis occurring in non-drug users. *J Korean Med Sci* 2014;29:776-81.

4. Erba PA, Pizzi MN, Roque A, et al. Multimodality imaging in infective endocarditis: an imaging team within the endocarditis team. *Circulation* 2019;140:1753-65.
5. Haldar SM, O'Gara PT. Infective endocarditis: diagnosis and management. *Nat Clin Pract Cardiovasc Med* 2006;3:310-7.
6. Kiefer TL, Bashore TM. Infective endocarditis: a comprehensive overview. *Rev Cardiovasc Med* 2012;13:e105-20.
7. Habib G, Lancellotti P, Antunes MJ, et al. 2015 ESC Guidelines for the management of infective endocarditis: The Task Force for the Management of Infective Endocarditis of the European Society of Cardiology (ESC). Endorsed by: European Association for Cardio-Thoracic Surgery (EACTS), the European Association of Nuclear Medicine (EANM). *Eur Heart J* 2015;36:3075-128.
8. Anguera I, Miro JM, Evangelista A, et al. Periannular complications in infective endocarditis involving native aortic valves. *Am J Cardiol* 2006;98:1254-60.
9. Anguera I, Miro JM, San Roman JA, et al. Periannular complications in infective endocarditis involving prosthetic aortic valves. *Am J Cardiol* 2006;98:1261-8.
10. Gomes A, Glaudemans A, Touw DJ, et al. Diagnostic value of imaging in infective endocarditis: a systematic review. *Lancet Infect Dis* 2017;17:e1-14.
11. American College of Radiology. ACR-NASCI-SIR-SPR practice parameter for the performance and interpretation of body computed tomography angiography (CTA). Available at: <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/body-cta.pdf>. Accessed September 30, 2020.
12. Kung VW, Jarral OA, Shipolini AR, McCormack DJ. Is it safe to perform coronary angiography during acute endocarditis? *Interact Cardiovasc Thorac Surg* 2011;13:158-67.
13. Bruun NE, Habib G, Thuny F, Sogaard P. Cardiac imaging in infective endocarditis. *Eur Heart J* 2014;35:624-32.
14. Colen TW, Gunn M, Cook E, Dubinsky T. Radiologic manifestations of extra-cardiac complications of infective endocarditis. *Eur Radiol* 2008;18:2433-45.
15. Fagman E, Flinck A, Snygg-Martin U, Olaison L, Bech-Hanssen O, Svensson G. Surgical decision-making in aortic prosthetic valve endocarditis: the influence of electrocardiogram-gated computed tomography. *Eur J Cardiothorac Surg* 2016;50:1165-71.
16. Fagman E, Perrotta S, Bech-Hanssen O, et al. ECG-gated computed tomography: a new role for patients with suspected aortic prosthetic valve endocarditis. *Eur Radiol* 2012;22:2407-14.
17. Feuchtnr GM, Stolzmann P, Dichtl W, et al. Multislice computed tomography in infective endocarditis: comparison with transesophageal echocardiography and intraoperative findings. *J Am Coll Cardiol* 2009;53:436-44.
18. Gahide G, Bommart S, Demaria R, et al. Preoperative evaluation in aortic endocarditis: findings on cardiac CT. *AJR Am J Roentgenol* 2010;194:574-8.
19. Koo HJ, Yang DH, Kang JW, et al. Demonstration of infective endocarditis by cardiac CT and transoesophageal echocardiography: comparison with intra-operative findings. *Eur Heart J Cardiovasc Imaging* 2018;19:199-207.
20. Kim IC, Chang S, Hong GR, et al. Comparison of cardiac computed tomography with transesophageal echocardiography for identifying vegetation and intracardiac complications in patients with infective endocarditis in the era of 3-dimensional images. *Circ Cardiovasc Imaging* 2018;11:e006986.
21. Cahill TJ, Baddour LM, Habib G, et al. Challenges in infective endocarditis. *J Am Coll Cardiol* 2017;69:325-44.
22. Habets J, Tanis W, van Herwerden LA, et al. Cardiac computed tomography angiography results in diagnostic and therapeutic change in prosthetic heart valve endocarditis. *Int J Cardiovasc Imaging* 2014;30:377-87.
23. Nishimura RA, Otto CM, Bonow RO, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol* 2014;63:2438-88.
24. Symersky P, Budde RP, de Mol BA, Prokop M. Comparison of multidetector-row computed tomography to echocardiography and fluoroscopy for evaluation of patients with mechanical prosthetic valve obstruction. *Am J Cardiol* 2009;104:1128-34.
25. Akhtar NJ, Markowitz AH, Gilkeson RC. Multidetector computed tomography in the preoperative assessment of cardiac surgery patients. *Radiol Clin North Am* 2010;48:117-39.
26. Rybicki FJ, Sheth T, Chen FY. Cardiac surgical imaging. In: Cohn L, ed. *Cardiac surgery in the adult*. 3rd ed. New York, NY: McGraw-Hill; 2008:179-98.
27. Fairbairn TA, Nieman K, Akasaka T, et al. Real-world clinical utility and impact on clinical decision-making of coronary computed tomography angiography-derived fractional flow reserve: lessons from the ADVANCE Registry. *Eur Heart J* 2018;39:3701-11.
28. Collet C, Onuma Y, Andreini D, et al. Coronary computed tomography angiography for heart team decision-making in multivessel coronary artery disease. *Eur Heart J* 2018;39:3689-98.
29. Kouijzer IJ, Vos FJ, Janssen MJ, van Dijk AP, Oyen WJ, Bleeker-Rovers CP. The value of 18F-FDG PET/CT in diagnosing infectious endocarditis. *Eur J Nucl Med Mol Imaging* 2013;40:1102-7.
30. Ricciardi A, Sordillo P, Ceccarelli L, et al. 18-Fluoro-2-deoxyglucose positron emission tomography-computed tomography: an additional tool in the diagnosis of prosthetic valve endocarditis. *Int J Infect Dis* 2014;28:219-24.
31. Swart LE, Gomes A, Scholtens AM, et al. Improving the diagnostic performance of (18)F-fluorodeoxyglucose positron-emission tomography/computed tomography in prosthetic heart valve endocarditis. *Circulation* 2018;138:1412-27.
32. Saby L, Laas O, Habib G, et al. Positron emission tomography/computed tomography for diagnosis of prosthetic valve endocarditis: increased valvular 18F-fluorodeoxyglucose uptake as a novel major criterion. *J Am Coll Cardiol* 2013;61:2374-82.
33. Graziosi M, Nanni C, Lorenzini M, et al. Role of (1)(8)F-FDG PET/CT in the diagnosis of infective endocarditis in patients with an implanted cardiac device: a prospective study. *Eur J Nucl Med Mol Imaging* 2014;41:1617-23.
34. Pizzi MN, Dos-Subira L, Roque A, et al. (18)F-FDG-PET/CT angiography in the diagnosis of infective endocarditis and cardiac device infection in adult patients with congenital heart disease and prosthetic material. *Int J Cardiol* 2017;248:396-402.
35. Horstkotte D, Korfer R, Loogen F, Rosin H, Bircks W. Prosthetic valve endocarditis: clinical findings and management. *Eur Heart J* 1984;5(Suppl C):117-22.
36. Tsopelas C. Radiotracers used for the scintigraphic detection of infection and inflammation. *ScientificWorldJournal* 2015;2015:676719.
37. McDermott BP, Mohan S, Thermidor M, Parchuri S, Poulouse J, Cunha BA. The lack of diagnostic value of the indium scan in acute bacterial endocarditis. *Am J Med* 2004;117:621-3.
38. Dursun M, Yilmaz S, Yilmaz E, et al. The utility of cardiac MRI in diagnosis of infective endocarditis: preliminary results. *Diagn Interv Radiol* 2015;21:28-33.
39. Baddour LM, Wilson WR, Bayer AS, et al. Infective endocarditis in adults: diagnosis, antimicrobial therapy, and management of complications: a scientific statement for healthcare professionals from the American Heart Association. *Circulation* 2015;132:1435-86.
40. Habib G, Badano L, Tribouilloy C, et al. Recommendations for the practice of echocardiography in infective endocarditis. *Eur J Echocardiogr* 2010;11:202-19.
41. Durak DT, Lukes AS, Bright DK. New criteria for diagnosis of infective endocarditis: utilization of specific echocardiographic findings. *Duke Endocarditis Service. Am J Med* 1994;96:200-9.
42. Aly AM, Simpson PM, Humes RA. The role of transthoracic echocardiography in the diagnosis of infective endocarditis in children. *Arch Pediatr Adolesc Med* 1999;153:950-4.

43. Harris KM, Li DY, L'Ecuyer P, et al. The prospective role of transesophageal echocardiography in the diagnosis and management of patients with suspected infective endocarditis. *Echocardiography* 2003;20:57-62.
44. San Roman JA, Vilacosta I, Lopez J, et al. Role of transthoracic and transesophageal echocardiography in right-sided endocarditis: one echocardiographic modality does not fit all. *J Am Soc Echocardiogr* 2012;25:807-14.
45. Lauridsen TK, Park L, Tong SY, et al. Echocardiographic findings predict in-hospital and 1-year mortality in left-sided native valve *Staphylococcus aureus* endocarditis: analysis from the International Collaboration on Endocarditis-Pro prospective Echo Cohort Study. *Circ Cardiovasc Imaging* 2015;8:e003397.
46. Sivak JA, Vora AN, Navar AM, et al. An approach to improve the negative predictive value and clinical utility of transthoracic echocardiography in suspected native valve infective endocarditis. *J Am Soc Echocardiogr* 2016;29:315-22.
47. Hill EE, Herijgers P, Claus P, Vanderschueren S, Peetermans WE, Herregods MC. Abscess in infective endocarditis: the value of transesophageal echocardiography and outcome: a 5-year study. *Am Heart J* 2007;154:923-8.
48. Incani A, Hair C, Purnell P, et al. *Staphylococcus aureus* bacteraemia: evaluation of the role of transoesophageal echocardiography in identifying clinically unsuspected endocarditis. *Eur J Clin Microbiol Infect Dis* 2013;32:1003-8.
49. Law A, Honos G, Huynh T. Negative predictive value of multiplane transesophageal echocardiography in the diagnosis of infective endocarditis. *Eur J Echocardiogr* 2004;5:416-21.
50. Hubert S, Thuny F, Resseguier N, et al. Prediction of symptomatic embolism in infective endocarditis: construction and validation of a risk calculator in a multicenter cohort. *J Am Coll Cardiol* 2013;62:1384-92.
51. Koneru S, Huang SS, Oldan J, et al. Role of preoperative cardiac CT in the evaluation of infective endocarditis: comparison with transesophageal echocardiography and surgical findings. *Cardiovasc Diagn Ther* 2018;8:439-49.
52. Bonfiglioli R, Nanni C, Morigi JJ, et al. (1)(8)F-FDG PET/CT diagnosis of unexpected extracardiac septic embolisms in patients with suspected cardiac endocarditis. *Eur J Nucl Med Mol Imaging* 2013;40:1190-6.
53. Bensimhon L, Lavergne T, Hugonnet F, et al. Whole body [(18) F] fluorodeoxyglucose positron emission tomography imaging for the diagnosis of pacemaker or implantable cardioverter defibrillator infection: a preliminary prospective study. *Clin Microbiol Infect* 2011;17:836-44.
54. Ploux S, Riviere A, Amraoui S, et al. Positron emission tomography in patients with suspected pacing system infections may play a critical role in difficult cases. *Heart Rhythm* 2011;8:1478-81.
55. Sarrazin JF, Philippon F, Tessier M, et al. Usefulness of fluorine-18 positron emission tomography/computed tomography for identification of cardiovascular implantable electronic device infections. *J Am Coll Cardiol* 2012;59:1616-25.
56. Vind SH, Hess S. Possible role of PET/CT in infective endocarditis. *J Nucl Cardiol* 2010;17:516-9.
57. Yen RF, Chen YC, Wu YW, Pan MH, Chang SC. Using 18-fluoro-2-deoxyglucose positron emission tomography in detecting infectious endocarditis/endoarteritis: a preliminary report. *Acad Radiol* 2004;11:316-21.
58. Hyafil F, Rouzet F, Lepage L, et al. Role of radiolabelled leucocyte scintigraphy in patients with a suspicion of prosthetic valve endocarditis and inconclusive echocardiography. *Eur Heart J Cardiovasc Imaging* 2013;14:586-94.
59. Rouzet F, Chequer R, Benali K, et al. Respective performance of 18F-FDG PET and radiolabeled leucocyte scintigraphy for the diagnosis of prosthetic valve endocarditis. *J Nucl Med* 2014;55:1980-5.
60. Harris KM, Ang E, Lesser JR, Sonnesyn SW. Cardiac magnetic resonance imaging for detection of an abscess associated with prosthetic valve endocarditis: a case report. *Heart Surg Forum* 2007;10:E186-7.
61. Wong D, Rubinshtein R, Keynan Y. Alternative cardiac imaging modalities to echocardiography for the diagnosis of infective endocarditis. *Am J Cardiol* 2016;118:1410-8.
62. Zoghbi WA, Adams D, Bonow RO, et al. Recommendations for noninvasive evaluation of native valvular regurgitation: a report from the American Society of Echocardiography developed in collaboration with the Society for Cardiovascular Magnetic Resonance. *J Am Soc Echocardiogr* 2017;30:303-71.
63. Thuny F, Di Salvo G, Belliard O, et al. Risk of embolism and death in infective endocarditis: prognostic value of echocardiography: a prospective multicenter study. *Circulation* 2005;112:69-75.
64. Vieira ML, Grinberg M, Pomerantzeff PM, Andrade JL, Mansur AJ. Repeated echocardiographic examinations of patients with suspected infective endocarditis. *Heart* 2004;90:1020-4.
65. 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 September 30, 2020.