2013 ACCF/ACR/ASE/ASNC/SCCT/SCMR Appropriate Utilization of Cardiovascular Imaging in Heart Failure: A Joint Report of the American College of Radiology Appropriateness Criteria Committee and the American College of Cardiology Foundation Appropriate Use Criteria Task Force

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Clinical Scenario 1 – Evaluation for Newly Suspected or Potential Heart Failure

Relevant Imaging Parameters

Anatomy

A. Chamber Anatomy Abnormalities (dimension/wall thickness/geometry)
F. Pericardial Abnormalities (including fluid/constriction/ calcification)

Function

G. Global Ventricular Systolic Dysfunction (including reduced ejection fraction)
H. Global Ventricular Diastolic Dysfunction (including reduced early ventricular filling or restriction to filling)
I. Valve Dysfunction (stenosis/regurgitation/other abnormalities)

Myocardial Status

M. Regional Ventricular Systolic Dysfunction (including wall thickening and wall motion)

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
Symptoms of Heart Failure • Shortness of Breath OR • Decreased Exercise Tolerance OR • Symptoms of Fluid Retention OR Findings of Heart Failure • Abnormal CXR (e.g., enlarged silhouette, pulmonary venous hypertension) OR • Abnormal	Chamber Anatomy Abnormalities		Echo	Class I Guideline recommendation for clinical assessment of patients presenting with HF include Echo during initial evaluation to assess LV size and LV wall thickness, along with LVEF and valve function.	(1),(2)
				Multi-center studies have demonstrated the value of Echo measures of LV structure (e.g., dimensions/geometry, wall thickness/mass) and LA size (e.g. area, volume index) as important indicators of subclinical HF and independent markers of subsequent HF events.	(3), (4)
				Multi-center studies have demonstrated that Echo measurements of LV mass and LA volume independently predict development of HF in patients with stable coronary artery disease.	(5)
				LA size independently predicts prognosis in patients with suspected HF referred from the community.	(6)[1]
				LA size (volume index) in patients with suspected HF and LVEF predicts LV diastolic dysfunction	(6)
				Echo assessment of RV dilatation independently predicts mortality in patients with new-onset dyspnea.	(7)
				LA size may provide prognostic value in patients with in dilated cardiomyopathy	(8)
			CMR	In a large epidemiologic study, body size-adjusted LV mass was found to predict incident HF.	(9)[2]
				In patients with new onset heart failure and LV systolic dysfunction, CMR is	(10)

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
biomarker(s) OR Signs of Heart Failure • Evidence of Impaired Perfusion OR • Evidence of Volume Expansion				an accurate method to exclude an ischemic etiology	
			CCT	CCT appearance of the myocardium differs in cardiomyopathy compared to normals.	(11)
			SPECT		NC
			PET		NC
			Cath		NC
Symptoms of Heart Failure • Shortness of Breath OR • Decreased Exercise Tolerance OR • Symptoms of Fluid Retention OR Findings of Heart Failure • Abnormal CXR (e.g. enlarged silhouette, pulmonary venous hypertension) OR • Abnormal biomarker(s) OR	Pericardial Abnormalities		Echo	A variety of Echo parameters can be used to differentiate constrictive pericarditis from restrictive cardiomyopathy in symptomatic patients.	(12)
			CMR	Abnormal diastolic septal motion identified on CMR is helpful to differentiate constrictive pericarditis from restrictive cardiomyopathy	(13)
				Assessment of ventricular function and pericardial anatomy by CMR can be helpful in the diagnosis of pericardial constriction	(14)
			CCT	Assessment of diastolic filling on CT can differentiate normals from those with constrictive pericarditis	(15)
			SPECT		NC
			PET		NC
			Cath	Invasive hemodynamic criteria for diagnosis of constrictive pericarditis	(16)
	Global or Regional Ventricular Systolic Dysfunction		Echo	Class I Guideline recommendation for clinical assessment of patients presenting with HF include Echo during initial evaluation to assess LVEF, along with LV size, LV wall thickness, and valve function.	(2)
				Multi-center studies have shown the ability of Echo to identify measures of subclinical systolic dysfunction (e.g. reduced fractional shortening) that predict subsequent HF.	(17)
				Multi-center studies have demonstrated that Echo measures of systolic function (e.g. LVOT VTI) independently predict development of HF in patients with stable coronary artery disease.	(5)
				Echo assessment of LV systolic function in patients with suspected HF resulted in improved disease classification by general practitioners; this knowledge of LV function changed management in up to two-thirds of these patients.	(18)
				Contractile reserve on Echo predicts prognosis	(19)

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
Signs of Heart Failure • Evidence of Impaired Perfusion OR • Evidence of Volume Expansion				Echo assessment of LVEF independently predicts mortality in patients with new-onset dyspnea.	(7)
			CMR	In asymptomatic patients, increased LV mass and decreased myocardial perfusion, are related to delayed myocardial contraction and greater dyssynchrony on CMR	(20)
			CCT	CCT can be used to evaluate LV segmental wall motion showing good agreement with Echo, except for the right coronary artery segments	(21)
			SPECT	Coronary artery disease extent on SPECT predicts occult LV systolic dysfunction	(22)
			PET		NC
			Cath	Patients with mild generalized LV impairment in the absence of coronary artery disease on Cath have good long-term prognosis compared to those with moderate dysfunction.	(23)
	Global Ventricular Diastolic Dysfunction		Echo	Multi-center studies have shown the ability of Echo to identify subclinical abnormalities of diastolic filling that predict subsequent HF	(17)
				Multi-center studies have demonstrated that Echo measurements of diastolic dysfunction independently predict development of HF in patients with stable coronary artery disease.	(5)
				Peak velocity of early diastolic mitral annular velocity (Ea) on Echo can differentiate restrictive cardiomyopathy from constriction with 89% sensitivity and 100% specificity.	(24)
				Although experiences are conflicting, diastolic dysfunction identified by Echo may occur in up to 25% of populations and is a marker of increased mortality.	(25) (26, 27)
				Echo measures of diastolic function correlate with Brain Naturietic Peptides	(7)
				Single center studies have shown the ability of measures of diastolic function to predict outcome in patients with symptoms of heart failure	(28)
				Echo Doppler parameters are important components of the algorithm for diagnosis of HF with preserved LVEF	(29)
			CMR	LV hypertrophy is associated with regional diastolic dysfunction on CMR in patients without clinical cardiac disease and preserved systolic function.	(30)
			CCT		NC
			SPECT	Coronary artery disease extent on SPECT predicts occult LV systolic dysfunction	(31)
			PET		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
			Cath		NC
	Valve Dysfunction		Echo	Class I Guideline recommendation for clinical assessment of patients presenting with HF include Echo during initial evaluation to assess valve function, along with LVEF, LV size, LV wall thickness.	(2)
				Multicenter studies have demonstrated that Echo measurements of mitral regurgitation severity independently predict development of HF in patients with stable coronary artery disease.	(5) (32)
			CCT	CT can identify mitral valve anatomic abnormalities responsible for functional mitral regurgitation that accompanies HF.	(33)
			CMR		NC
	Myocardial blood flow		SPECT	Multi center study demonstrates the value of myocardial perfusion imaging in patients with new onset HF	(34)
			PET		NC
			Cath		NC
Malignancy • Current or Planned Cardiotoxic Therapy AND • No prior Imaging Evaluation	Chamber Anatomy Abnormalities		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Pericardial Abnormalities		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Global or Regional Ventricular Systolic Dysfunction		Echo	Reductions in LVEF due to chemotherapy or adjuvant treatments can be identified by Echo often before symptoms develop and these measures are used to guide therapy.	(35)
				Echo can follow the natural history of LVEF in patients with anthracycline cardiomyopathy and response to therapy	(36)
			CMR		NC
			CCT		NC
			SPECT		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
			PET		NC
			Cath		NC
	Global Ventricular Diastolic Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Valve Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Familial or Genetic Cardiomyopathy History	Chamber Anatomy Abnormalities		Echo	In hypertrophic cardiomyopathy patients, single center Echo studies have identified a relation between Doppler –derived LVOT gradient and outcome	(37)
				For optimal diagnosis of ARVC/D, multicenter trials have established Echo/CMR criteria for RV size and RV function and these are important components of the criteria for diagnosis	(38)
				Echo assessment of valves and myocardium can differentiate familial cardiac amyloidosis from hypertrophic cardiomyopathy	(39)
				Echo can assist in differentiation of infiltrative cardiomyopathies	(40)
			CMR	Detection by CMR of LV aneurysms in hypertrophic cardiomyopathy identifies a high risk group of patients.	(41)
				For optimal diagnosis of ARVC/D, multicenter trials have established Echo/CMR criteria for RV size and RV function and these are important components of the criteria for diagnosis	(38)
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Pericardial Abnormalities		Echo		NC
			CMR		NC
			CCT		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
			SPECT		NC
			PET		NC
			Cath		NC
	Global or Regional Ventricular Systolic Dysfunction		Echo		NC
			CMR	In patients with Thalasemia, myocardial T2* measured by CMR relates to LVEF and appears to be a promising approach for predicting the development of HF and iron overload cardiomyopathy.	(42)
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Global Ventricular Diastolic Dysfunction		Echo	In infiltrative cardiomyopathy, patterns of diastolic function assessed by Doppler Echo relate to outcome	(43)
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Valve Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Myocardial blood flow		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET	Impaired cardiac oxidative metabolism can be identified by PET in patients with Friedrich's ataxia despite no evidence of overt structural heart disease	(44)
			Cath		NC
Suspected Adult Congenital Heart Disease	Chamber Anatomy Abnormalities		Echo/CMR	Assessments of ventricular function and cardiac anatomy by Echo, Doppler and/or CMR are critical in the adult patient with history of unrepaired or repaired congenital heart disease and HF symptoms	(45)

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
			CMR	The value of CMR for assessment of cardiac structure and function in adults with congenital heart disease is diverse.	(46)
				CMR provides accurate assessment of anatomical connections, ventricular function, myocardial viability in adults with congenital heart disease	(47,48)
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Pericardial Abnormalities		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Global or Regional Ventricular Systolic Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Global Ventricular Diastolic Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Valve Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Acute Myocardial Infarction	Chamber Anatomy		Echo	In patients developing HF heart symptoms after acute myocardial infarction, Echo assessment of LV function is associated with more frequent use of	(49)

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
• Evaluation during Initial Hospitalization AND • Clinically Stable	Abnormalities			proper medications and subsequent lower mortality.	
			CMR	Use of CMR in identifying patients at risk for developing HF after acute myocardial infarction is advocated because of its ability to: provide accurate/reproducible longitudinal follow-up of LV volumes and mass, delineate infarct size and transmural extent, and detect microvascular obstruction	(50)
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Pericardial Abnormalities		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Global or Regional Ventricular Systolic Dysfunction		Echo	Following MI,assessment of cumulative regional dysfunction has slightly more prognostic value than LVEF in patients with LV dysfunction, HF, or both.	(51)
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Global Ventricular Diastolic Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Valve Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
			PET		NC
			Cath		NC
Peripartum cardiomyopathy			Echo	LV volume, mass and function can be measured and followed by Echo to differentiate the presence of peri-partum cardiomyopathy from normal	(52)
				In pregnant women with dilated cardiomyopathy, an index that combines Echo measures of LVEF and LA pressure identifies patients at highest risk for adverse outcome	(53)
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC

NC = none cited

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Clinical Scenario 2 – Ischemic Etiology in Patients with HF

Relevant Imaging Parameters

Anatomy

B. Coronary Artery Abnormalities (Including atherosclerotic disease, anomalies)

Function

G. Global Ventricular Systolic Dysfunction (Including reduced Ejection Fraction)
I. Valve Dysfunction (Stenosis/Regurgitation/Other Abnormalities) (Recommend removal – MP)

Myocardial Status

K. Fibrosis/Scarring (Transmural Extent/Mural Distribution/Pattern)
M. Regional Ventricular Systolic Dysfunction (Including wall thickening)
O1. Inducible Ischemia-Decreased Perfusion
O2. Inducible Ischemia-Decreased Contraction

Indications of Clinical Scenario #2 (All patients in this table are assumed to be candidates for revascularization unless otherwise noted**)**

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
Normal renal function	Coronary Artery Anatomy		Echo		NC
			CMR		NC
			CCT	Single center studies in HF patients showing high negative predictive value for absence of CAD	(1,2), [3]
			SPECT		NC
			PET		NC
			Cath	Cath used as test for CAD identification in CASS revascularization study for CHF	(4)
				Cath used to determine incident CAD in CHF population	(5)
				Cath shows CAD in patients with acute diastolic HF without clinical or ECG changes of ischemia	(6)
				FFR shown to direct revascularization in multi-vessel patients – Few patients studies who have depressed LVEF	(7)
	Ventricular Function		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
			Cath		NC
	Fibrosis/Scarring (Transmural Extent / Mural Distribution / Pattern)		Echo		NC
			CMR	CMR can be used to differentiate HF with CAD compared to HF without CAD based on detection of fibrosis.	(8,9,10)
			CCT		NC
			SPECT	SPECT can detect CMR-confirmed myocardial fibrosis	(11,12)
			PET	PET can detect CMR-confirmed myocardial fibrosis	(11)
			Cath		NC
	Regional Ventricular Systolic Dysfunction (Including wall thickening)		Echo	New or worsening wall-motion analysis on stress Echo for CAD is associated with worse prognosis	(13,14)
			CMR	Worsening wall-motion analysis on dobutamine CMR for CAD is associated with worse prognosis	(15)
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Inducible Ischemia – Decreased Perfusion		Echo		NC
			CMR		NC
			CCT		NC
			SPECT	Ischemia / ischemia score on SPECT predict CAD and cardiac events	(16,17,18)
			PET		NC
			Cath		NC
	Inducible Ischemia – Decreased Contraction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Moderate Renal Dysfunction			Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
Severe Renal Dysfunction Not on dialysis		Imaging with Iodinated contrast has risk of renal failure Gadolinium CMR with risk for NSF	Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Severe Renal Dysfunction On dialysis		Imaging Modalities with iodinated has risk of volume increase Gadolinium CMR with risk for NSF	Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC

NC = none cited

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Clinical Scenario 3 – Therapy – Consideration of Revascularization (PCI or CABG) in Patients with Ischemic HF and Known Coronary Anatomy Amenable to Revascularization

Relevant Imaging Parameters

Anatomy

A. Chamber Anatomy Abnormalities (Geometry/Dimension/Wall Thickness)
B. Coronary Artery Abnormalities (Including atherosclerotic disease)

Function

G. Global Ventricular Systolic Dysfunction (Including reduced Ejection Fraction)
I. Valve Dysfunction (Stenosis/Regurgitation/Other Abnormalities)

Myocardial Status

K. Fibrosis/Scarring (Transmural Extent/Mural Distribution/Pattern)
M. Regional Ventricular Systolic Dysfunction (Including wall thickening)
O1. Inducible Ischemia-Decreased Perfusion
O2. Inducible Ischemia-Decreased Contraction
P1. Hibernating State- Positive Contractile Reserve
P2. Hibernating State-Anaerobic Metabolism/Glucose Utilization
P3. Hibernating State-Resting Dysfunction/Minimal Scarring
P4. Hibernating State-Preserved myocyte cell membrane integrity

Indications of Clinical Scenario #3

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
Severely reduced ventricular function (EF< 30%) OR Myocardial region of interests with thin walls	Chamber Anatomy Abnormalities		Echo		
			CMR		
			CCT		
			SPECT		
			PET		
			Cath		
	Coronary Artery Abnormalities		Echo		
			CMR		
			CCT		
			SPECT		
			PET		
			Cath		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
	Global Ventricular Systolic Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
	Valve Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
	Regional Ventricular Systolic Dysfunction		Echo		NC
			CMR		NC
			CCT		NC
			SPECT	SPECT assessment of regional dysfunction defines target for assessment of viability	(1)
			PET		NC
			Cath		NC
	Fibrosis/ Scarring	Severe wall motion/ thickening abnormal-ity at rest with no contractile reserve	Echo	Stress Echo identifies low likelihood of functional recovery and predominant infarct; it may underestimate lack of viability if wall is thinned.	(2)
		Gadolini-um enhance-ment	CMR	CMR directly Identifies location, extent and transmurality of infarct	(3,4)
			CCT		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
		Severe resting defect on rest study or severe fixed defect on stress/rest study	SPECT	SPECT identifies low likelihood of functional recovery and predominant infarct; it may underestimate lack of viability if wall is thinned.	(5,6)
		PET "match" pattern	PET	Metabolic PET identifies low likelihood of functional recovery and predominant infarct	(7,8,9)
			Cath		NC
	Viable myocardial tissue (Inducible Ischemia or hibernating State)	Severe wall motion/ thickening abnormal-ity at rest with no contractile reserve	Echo		NC
		Gadolini-um enhance-ment	CMR	CMR identifies location, extent and transmurality of infarct; absence of enhancement suggests viability	(3,10)
		Mild resting defect/ normal uptake on rest study or non-severe fixed	SPECT	SPECT identifies higher likelihood of functional recovery and predominant viability/ischemia; it may underestimate viability if wall is thinned.	(5, 10)

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
		defect or reversible defect on stress/rest study			
		PET "mismatch" pattern	PET	PET identifies high likelihood of functional recovery and predominant viability/ischemia/hibernation	(11,12)
			Cath		NC
Moderate Reduction (EF 30-39%) OR Myocardial region of interests with thin walls	Fibrosis	Severe wall motion/ thickening abnormal-ity at rest with no contractile reserve	Echo	Stress Echo identifies low likelihood of functional recovery and predominant infarct.	(13)
		Gadolini-um enhance-ment	CMR	CMR identifies location, extent and transmuraility of infarct	(14)
			CCT		NC
		Severe resting defect on rest study or severe fixed defect on stress/rest study	SPECT		NC
		PET "match" pattern	PET		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
			Cath		NC
	Viable myocardial tissue	Severe wall motion/ thickening abnormal-ity at rest with contractile reserve	Echo		NC
		Gadolini-um enhance-ment	CMR	CMR identifies location, extent and transmuraility of infarct; absence of enhancement suggests viability	(15)
			CCT		NC
		Mild resting defect/ normal uptake on rest study or non-severe fixed defect or reversible defect on stress/rest study	SPECT		NC
			PET		NC
			Cath		NC
	Regional function	Wall motion and thickening	Echo		NC
			CMR		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
			CCT		NC
		Wall motion and thickening	SPECT		NC
			PET		NC
		Left ventriculo-gram	Cath		NC
Preserved Function (EF > 40%) Significant regional dysfunction in the territory of a stenotic vessel OR No regional wall motion abnormalities in the territory of a stenotic vessel	Assessment of inducible ischemia	Deterioration of wall motion/ thickening with stress. Abnormal EF response to stress	Echo		NC
		Reversible defect with vasodilator stress. Deterioration of wall motion/thickening with dobutamine stress.	CMR		NC
			CCT		NC
		Reversible defects	SPECT		NC

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
		Reversible defect with vasodilator stress.	PET		NC
			Cath		NC

NC = none cited

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Clinical Scenario 4 – ICD & CRT

Relevant Imaging Parameters

Anatomy

C. Coronary Vein Variations

Function

G. Global Ventricular Systolic Dysfunction *(including reduced ejection fraction)*
H. Global Ventricular Diastolic Dysfunction *(including reduced early ventricular filling)*
I. Valve Dysfunction *(stenosis/regurgitation/other abnormalities)*

Myocardial Status

K. Fibrosis/Scarring *(transmural extent/mural distribution/pattern)*
M. Regional Ventricular Systolic Dysfunction *(including wall thickening)*
N. Myocardial Wall Mechanics *(including strain and synchrony analysis)*

Miscellaneous

Q1. Thrombus-Atrial
Q2. Thrombus-Ventricular

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
Initial evaluation to determine patient candidacy	Global Ventricular Systolic and Diastolic Dysfunction	LVEF ≤ 35% is prerequisite	Echo	Post-ICD placement survival does not differ according to modality of pre-placement LVEF assessment by Echo vs. contrast left ventriculography.	[8]
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath	Post-ICD placement survival does not differ according to modality of pre-placement LVEF assessment by contrast left ventriculography vs. Echo.	(1)
	Myocardial Fibrosis/Scarring	Source of ventricular tachyar-rhythmias in HF [9-11]	Echo		NC
			CMR	LV midwall fibrosis in non-ischemic HF and subendocardial scar in ischemic HF detected by CMR in is predictive of ventricular arrhythmia and/or sudden cardiac death.	[12,13]
				Based on fibrosis/scar extent, pre-ICD placement CMR predicts adverse cardiac outcomes (i.e. HF hospitalizations, appropriate ICD firings, cardiac death) in non-ischemic HF post-ICD placement for primary prevention.	[14]
				Of CMR (e.g. total infarct size, LVEF) or clinical variables, infarct tissue heterogeneity on pre-ICD placement CMR is the strongest predictor of ventricular arrhythmia in ischemic HF post-ICD placement for primary	[15,16]

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
				prevention.	
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Follow-up evaluation to determine patient candidacy • After a course of maximal medical therapy OR • Coronary revascularization			Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Follow-up 3 months after placement • No deterioration in clinical status AND • No change in arrhythmia status			Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Follow-up 3 months after placement • Deterioration in clinical status OR • Change in arrhythmia status (i.e. ICD discharge)	Global Ventricular Systolic and Diastolic Dysfunction	Monitoring of LV function	Echo	At 2-14 months post-ICD placement, only 12% of non-ischemic HF patients demonstrate improved LVEF >35% on Echo.	[17]
				Restrictive LV filling pattern on pre-ICD placement Echo is strongly related to adverse cardiac events (e.g. death from pump failure) in the first year post-ICD placement.	[18] [19]
			CMR		NC
			CCT	Asymptomatic perforations by leads are common on CCT, especially with RA (vs. RV) leads and ventricular ICD (vs. ventricular pacemaker) leads, but rarely result in electrophysiologic consequences	(9)
			SPECT		NC
			PET		NC
			Cath		NC
Initial evaluation to determine patient candidacy	Global Ventricular Systolic and	LVEF $\leq$ 35% is prerequisit	Echo	Compared to pre-CRT measures of LV dysfunction on Echo, post-CRT measures indicate improved overall LV systolic function (e.g. increased LVEF).	[20,21]

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
• NYHA class III despite optimum medical therapy AND • Left bundle branch block on ECG	Diastolic Dysfunction	e [5-7]		Relative to pre-CRT measures of LV dilation on Echo, reversed LV remodeling (typically 10-15% decrease in end-systolic volume) is found post-CRT in 44-65% of HF patients.	[20-23]
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath	Compared to Cath-derived measures of baseline LV dilation and dysfunction, post-CRT measures demonstrate reversal of LV remodeling (e.g. decreasing end-systolic volumes) and/or improved overall LV systolic function (e.g. increased LVEF) within the first month.	14
	Regional Ventricular Systolic Dysfunction and Myocardial Wall Mechanics	LV mechanical dyssynchrony [5-7,25-27]	Echo	CRT candidates with more QRS prolongation have a higher likelihood of LV dyssynchrony on Echo, but approximately 30% with very wide QRS complexes (i.e. $\geq$ 0.15 seconds) lack inter- or intra-ventricular dyssynchrony.	[28,29]
				If HF patients with severe LV dysfunction have Echo evidence of dyssynchrony, approximately 50% may not have significant QRS prolongation.	[30]
				In patients with severe HF and narrow QRS complexes, LV dyssynchrony can be detected by Echo in 27-72%.	[29,31,32]
				The utility of LV dyssynchrony evaluation by Echo to guide CRT implantation when the QRS is not prolonged has not been consistently confirmed.	[33,34]
				Concordance between QRS duration and LV dyssynchrony in severe HF is not strong, and influenced by the type of dilated cardiomyopathy	(15, 19, 22, 23)
				There are predictive clinical benefits of Echo inter- or intra-ventricular dyssynchrony detection using various forms of tissue Doppler imaging in HF patients undergoing CRT evaluation.	[37,38], (24, 25)
				The technical challenges in Echo dyssynchrony analysis in mainstream clinical practice are highlighted in a large multicenter trial which stresses ongoing reliance on current guidelines.	[39]
				Despite considerable variability in techniques, Echo can reliably identify the latest mechanically contracting region of the LV in CRT candidates for optimal device implantation, almost always with improved response.	[23,36,40, 41] (13, 23, 27,28)
				Low-dose dobutamine stress Echo may accentuate LBBB-induced dyssynchrony which indicates a higher likelihood of response to CRT.	[42]

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
(continued) Initial evaluation to determine patient candidacy • NYHA class III despite optimum medical therapy AND • Left bundle branch block on ECG	(continued) Regional Ventricular Systolic Dysfunction and Myocardial Wall Mechanics	LV mechanical dyssynchrony [5-7,25-27]	CMR	CMR can be used to assess LV mechanical dyssynchrony in CRT candidates with results comparable to those derived by Echo.	[43,44]
				CMR assessment of LV dyssynchrony may help predict outcome from CRT.	[45,46] (32, 33)
			CCT	CCT may be used to assess LV dyssynchrony in CRT evaluation.	(34)
			SPECT	Various SPECT measures of LV dyssynchrony in HF patients undergoing CRT evaluation correlate well with those derived using Echo.	[48,49] (35, 36)
				SPECT measures of LV dyssynchrony in patients undergoing CRT can be used to predict response to therapy.	[50,51] (37,38)
			PET		NC
			Cath		NC
	Valve Dysfunction	Functional mitral regurgitation from mitral apparatus abnormalities due to LV dilatation and dysfunction. []	Echo	CRT immediately decreases mitral regurgitation possibly from improved strain on the papillary muscles or adjacent LV wall.	[52] (39)
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Procedure Planning: Considerations	Myocardial Fibrosis/Scarring	Amount/distribution of myocardial fibrosis and scarring may limit: • Contractile response	Echo	In ischemic HF, Echo assessment of global LV scar area (based on segmental end-diastolic wall thinning) correlates directly with lack of long-term LV reverse remodeling with CRT.	[54] (40)
				Indirect Echo measurement of myocardial fibrosis/scarring (based on absent myocardial contractile reserve) predicts lack of LV reverse remodeling with CRT.	[55] (41)
			CMR	Percentage scarring of total LV myocardial volume on CMR predicts a lack of response to CRT, presumably due to inadequate contractile reserve.	[56,57] (42, 43)
				The presence of potentially unstimulated posterolateral wall transmural (> 50%) scarring on CMR, near the CRT LV lead placement, indicates poor response rate and/or increased risk.	[58,59] (44,45)

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
(continued) Procedure Planning: Considerations		to CRT [53] • Capture in region of latest activation by LV lead [7]	CCT	CCT has untested potential to delineate myocardial scar location, in combination with coronary vein mapping and LV dyssynchrony assessment, as part of CRT planning in ischemic HF.	[60] (46)
			SPECT	Based on SPECT delineation of extent and location of LV myocardial scarring, both overall scar burden and scar density near the LV lead portend an unfavorable response to CRT.	[61,62] (47, 48)
				Compared to CMR, SPECT overestimates scar tissue in non-ischemic HF (due to attenuation artifact) and identifies CRT non-responders less reliably.	[63] (49)
			PET	Indirect assessments of myocardial fibrosis/scarring by PET, can be used to predict lack of improvement in LVEF after CRT.	[64] (50)
			Cath		NC
	Coronary Vein Variations	Segmental description of coronary venous anatomy for optimal LV lead placement [65-68]	Echo		NC
			CMR		NC
			CCT	CCT has been used to direct ventricular lead placement for optimal CRT as effectively as retrograde angiographic venography.	[69,70] (51, 52)
				In ischemic HF, the left marginal vein is often absent on CCT, potentially interfering with optimal lead positioning for CRT.	[71] (53)
			SPECT		NC
			PET		NC
			Cath	Advances in catheter-based lead delivery systems, possibly including venoplasty and stenting, have improved the success rates of CRT LV lead implantation by retrograde angiographic venography.	[72,73] (54, 55)
				When the LV lead of a CRT system is placed under Cath guidance into a postero-lateral, rather than anterior, coronary sinus tributary, there are significant 6-month benefits (e.g. increase in LVEF).	[74] (56)
	Intra-Cavitary Thrombus	Potential embolism with CRT [75]	Echo		NC
			CMR		NC
			CCT		NC
			SPECT		NC
			PET		NC
			Cath		NC
Follow-up early (< 6 months) after implantation	Global Ventricular Systolic and	Lack of early response	Echo	Poorer early post-CRT response on Echo may reflect an ischemic etiology for HF.	[81,82] (57, 58)
				The severity of mitral regurgitation on Echo is an independent predictor of	[83,84]

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
• No improvement in symptoms OR • No improvement functional capacity	Diastolic Dysfunction	may reflect: • Poor candidate selection [76,77] • Inadequate lead placement [78,79] • Suboptimal device settings [80]		poor response to CRT by 6 months.	(59, 60)
				An Echo-dependent approach to optimization of CRT settings has immediate beneficial effects on early clinical response	[85,86] (61, 62)
			CMR		NC
			CCT		NC
			SPECT	Despite clinical improvement, patients with severe resting perfusion defects on pre-CRT SPECT do not show significant improvement in LVEF or LV volume reduction on SPECT at 3-month post-CRT.	[87] (63)
			PET		NC
			Cath		NC
Follow-up later (> 6 months) after implantation • Improved symptoms (i.e. from class III, IV to class I, II) OR • Improved functional capacity	Global Ventricular Systolic and Diastolic Dysfunction		Echo	In general, Echo demonstrates at 6 months post-CRT:	
				- Improved LV function (e.g. increased LVEF or stroke volume with sensitivities: 76-96% and specificities: 71-100%)	[88,89] (64, 65)
				- Increase cardiac output and systolic strain	[90,91] (66, 67)
				- Increased diastolic performance	[92](68)
				- Reverse remodeling (e.g. decreasing end-diastolic and end-systolic volumes with sensitivities: 87-97% and specificities: 55-92%)	[93,94] (69, 70)
				- Decreased LV dyssynchrony	[95,96] (71, 72)
				- Decreased mitral regurgitation.	(71,72)
				At 6 months, the benefits of CRT on Echo assessments of LV function (i.e. increased LVEF) and reverse remodeling (i.e. decreased LV EDV) are significantly better with non-ischemic HF.	[81,88] (57,64)
				CRT induces sustained LV reverse remodeling on Echo with progressive improvement during the first 3-9 months, with extent of remodeling primarily related to HF etiology and less to baseline interventricular mechanical delay.	[97] (73)
				At 6 months there may be slight benefit (e.g. increased LVEF) from early	[98](74)

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
				optimization of CRT device programming under Echo monitoring.	
				Despite LV reverse remodeling, interruption of CRT at 6 months results in worsening LV function and dyssynchrony on Echo, indicating the need for long-term CRT	[99] (75)
			CMR		NC
			CCT		NC
			SPECT		NC
			PET	By 6 months, PET demonstrates that CRT makes resting myocardial blood flow more homogenous and results in improved myocardial efficiency.	[100,101] (76,77)
			Cath		NC

NC = none cited

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Clinical Scenario 5 – Repeat Imaging Evaluation of HF

Relevant Imaging Parameters

The following imaging-based parameters were identified as potentially useful for the repeat imaging in heart failure. The performance of these parameters per imaging modality is presented in the previously presented tables. Specific literature references for repeat imaging in heart failure are presented in the brief table.

Anatomy

A. Chamber Anatomy Abnormalities *(Geometry/Dimension/Wall Thickness)*
B. Coronary Artery Abnormalities *(Including atherosclerotic disease,anomalies)*
C. Pericardial Abnormalities *(Including calcification / fluid / constriction)*

Function

G. Global Ventricular Systolic Dysfunction *(Including reduced ejection fraction)*
H. Global Ventricular Diastolic Dysfunction *(Including reduced ventricular relaxation/filling)*
I. Valve Dysfunction *(Stenosis/Regurgitation/Other Abnormalities)*

Myocardial Status

J. Fibrosis/Scarring *(Transmural Extent/Mural Distribution/Pattern)*
M. Regional Ventricular Systolic Dysfunction *(Including wall thickening)*
O1. Inducible Ischemia-Decreased Perfusion
O2. Inducible Ischemia-Decreased Contraction
P1. Hibernating State- Positive Contractile Reserve
P2. Hibernating State-Anaerobic Metabolism/Glucose Utilization
P3. Hibernating State-Resting Dysfunction/Minimal Scarring

Indications of Clinical Scenario #5

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
New or increasing orthopnea or exertional dyspnea)	Anatomy A. Chamber Anatomy Abnormalities (Geometry/Dimension/Wall Thickness)		Please refer to literature review from Section Table 1		

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
	Anatomy B. Coronary Artery Abnormalities (Including atherosclerotic disease anomalies)		Please refer to literature review from Section Table 1		
	Anatomy C. Pericardial Abnormalities (Including calcification / fluid / constriction)		Please refer to literature review from Section Table 1		
	Function G. Global Ventricular Systolic Dysfunction (Including reduced ejection fraction)		Please refer to literature review from Section Table 1		
	Function H. Global Ventricular Diastolic Dysfunction (Including reduced ventricular relaxation / filling)		Please refer to literature review from Section Table 1		

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
	Function I. Valve Dysfunction (Stenosis/Regurgitation/Other Abnormalities) Myocardial Status		Please refer to literature review from Section Table 1		
	Function J. Fibrosis / Scarring (Transmural Extent / Mural Distribution / Pattern)		Please refer to literature review from Section Table 1		
	Function M. Regional Ventricular Systolic Dysfunction (Including wall thickening)		Please refer to literature review from Section Table 1		
	Function O1. Inducible Ischemia-Decreased Perfusion		Please refer to literature review from Section Table 1		
	Function O2. Inducible Ischemia-Decreased Contraction		Please refer to literature review from Section Table 1		

Clinical Indications	Imaging Parameter	Specific Insights	Modality	Major Points	Reference
	Function P1. Hibernating State- Positive Contractile Reserve		Please refer to literature review from Section Table 1		
	Function P2.Hibernating State-Anaerobic Metabolism / Glucose Utilization		Please refer to literature review from Section Table 1		
	Function P3. Hibernating State-Resting Dysfunction/Minimal Scarring		Please refer to literature review from Section Table 1		
No new symptoms AND No other change in clinical status Routine monitoring	G. Global Ventricular Systolic Dysfunction (Including reduced ejection fraction)		Radionuclide	Serial 123I-MIBG studies in patients with depressed LVEF – delayed washout was prognostic for cardiac death and sudden death. Note patients were recruited after Acute CHF admission	(1)
			Radionuclide	Serial BMIPP studies in patients post MI shows infarct size and perfusion defect size predicts future clinical events	(2)
			CMR	Serial CMR Studies – nuclear cine CMR and routine cine CMR in patients with heart failure undergoing medical therapy – ACE-I or Spirnolactone can identify improved function	(3-5)
			Echo	Serial Echo studies show patients with Heart failure getting medical therapy can have improved LVEF	(4,6)

NC = none cited

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