Catheterization and Cardiovascular Interventions 85:181–191 (2015)

CORONARY ARTERY DISEASE

Clinical Decision Making

Optimal Use of Left Ventriculography at the Time of Cardiac Catheterization: A Consensus Statement from the Society for Cardiovascular Angiography and Interventions

Osvaldo S. Gigliotti,[1*] MD, FSCAI, **Joseph D. Babb,**[2] MD, FSCAI, **Robert S. Dieter,**[3] MD, FSCAI, **Dmitriy N. Feldman,**[4] MD, FSCAI, **Ashequl M. Islam,**[5] MD, FSCAI, **Konstantinos Marmagkiolis,**[6] MD, FSCAI, **Phillip Moore,**[7] MD, FSCAI, **Paul Sorajja,**[8] MD, FSCAI, **and James C. Blankenship,**[9] MD, FSCAI

The rationale to perform left ventriculography at the time of cardiac catheterization has been little studied. The technique and frequency of use of left ventriculography vary by geographic regions, institutions, and individuals. Despite the recent publication of guidelines and appropriate use criteria for coronary angiography, revascularization, and noninvasive imaging, to date there have been no specific guidelines on the performance of left ventriculography. When left ventriculography is performed, proper technique must be used to generate high quality data which can direct patient management. The decision to perform left ventriculography in place of, or in addition to, other forms of ventricular assessment should be made taking into account the clinical context and the type of information each study provides. This paper attempts to show the role of left ventriculography at the time of coronary angiography or left heart catheterization. The recommendations in this document are not formal guidelines but are based on the consensus of this writing group. These recommendations should be tested through clinical research studies. Until such studies are performed, the writing group believes that adoption of these recommendations will lead to a more standardized application of ventriculography and improve the quality of care provided to cardiac patients.

Key words: ventriculography; cardiac catheterization; left ventricular function

INTRODUCTION

Left ventriculography has gone from the status of prima ballerina to understudy in the ballet of left ventricular assessment. Critics argue that it adds to the cost and risk of cardiac catheterization and may be replaced by noninvasive imaging [1]. The use of left ventriculography varies widely across different geographic zones and different hospitals [1], reflecting differences in practice styles and uncertainty about its role in cardiac diagnosis.

[1]Seton Heart Institute, Austin, Texas
[2]East Carolina University Brody School of Medicine, Greenville, North Carolina
[3]Loyola University Medical Center, Maywood, Illinois
[4]Weill Cornell Medical College, New York, New York
[5]Tufts University School of Medicine, Springfield, Maryland
[6]Citizens Memorial Hospital Heart and Vascular Institute, Bolivar, Missouri
[7]University of California, San Francisco, California
[8]Minneapolis Heart Institute, Minneapolis, Minnesota
[9]Geisinger Medical Center, Danville, Pennsylvania.

*Correspondence to: Osvaldo S. Gigliotti, Seton Heart Institute, 1301 West 38th St., Suite 400, Austin, TX, 78705, E-mail: osgigliotti@seton.org

Received 15 August 2014; Revision accepted 17 August 2014

DOI: 10.1002/ccd.25642
Published online 17 August 2014 in Wiley Online Library (wileyonlinelibrary.com)

While guidelines and appropriate use criteria (AUC) have addressed the indications for *left heart catheterization* associated with coronary angiography [2] and to evaluate heart failure [3], they have not addressed the role of *left ventriculography*. This document attempts to fill that void. It deals only with left ventriculography (invasive imaging of the left ventricle with contrast injection) and does not address left heart catheterization (catheter placement in the left ventricle, usually to assess pressures).

Currently, there are no specific guidelines on the performance of left ventriculography at the time of coronary angiography or left heart catheterization. Recent AUC for diagnostic catheterization define clinical scenarios where coronary angiography and/or left heart catheterization is appropriate, uncertain, or inappropriate, but the decision to perform ventriculography is left to the discretion of the operator. Patel et al. have suggested clinical scenarios where cardiac catheterization (defined as including coronary angiography, left heart catheterization, and left ventriculography) is an appropriate imaging modality in the evaluation of a possible ischemic etiology of heart failure [3]. They did not define specifically the appropriateness of left ventriculography alone, particularly when other measurements of LV systolic function are available.

Regional variation in the performance of ventriculography in the United States has been noted by several authors. Joffe et al. demonstrated variability in use of left ventriculography versus echocardiography to determine ejection fraction in patients presenting with an acute myocardial infarction from 1997 to 2005 in the Worcester metropolitan area [4]. Wittles RM et al. examined insurance claims data from the Aetna health care database from all adults undergoing coronary angiography in 2007 and found significant regional variation in the use of left ventriculography, with utilization highest in the South Atlantic region and lowest in New England, the Pacific, and West North Central regions [1]. Heidenrich et al. has recently examined variability of ventriculography utilization in the Veterans Affairs Health System [5]. The authors also found significant variation in performance of ventriculography among examined hospitals, and a decreasing trend in ventriculogram performance from 2000 to 2009.

These same studies demonstrate duplication in the assessment of EF in 20%–88% of patients. This duplication has been suggested to increase costs and potentially be done for financial gain. However, EF measurements by echo and LVG in patients treated for acute myocardial infarction may differ significantly [4].

EVOLUTION OF TECHNIQUE AND USE OF LEFT VENTRICULOGRAPHY

Forssmann initiated heart catheterization in 1929, but catheter access to the left ventricle began in the 1940s with apical, subxyphoid, and left mainstem bronchus puncture. The term "angiocardiography" was first used by Ponsdomenech and Nuñez in 1951 to describe 45 patients undergoing direct transthoracic LV punctures. In the early 1960's, imaging was performed with a Schonander biplane cut-film x-ray unit which exposed antero-posterior and lateral images at the rate of 4–6 films per second for 5–7 sec. In the 1970's preechocardiogram era, left ventriculography became the gold standard for assessment of left ventricular function. Biplane ventriculography provided more accurate assessment of left ventricular wall motion in patients with coronary artery disease compared with single-plane imaging [6,7]. It was also used to evaluate contractility of left ventricular segments, left ventricular volume and mass, pressure-volume diagrams, wall forces, and compliance [8]. Over time, the equipment costs, radiation exposure, and complexity of biplane ventriculography caused its decline in favor of single plane ventriculography.

When a left ventriculogram is performed, it should generate high quality data which can direct patient management. Proper technique of left ventriculography has been described elsewhere and will not be detailed here [9], however, several points deserve emphasis. Hand injections are inadequate for quality left ventriculography studies and power injection is required. Power injection or even hand injection may be dangerous through a single end-hole catheter; multisidehole catheters are safest and most effective. Contrast volumes must be sufficient to completely opacify the ventricle [10]. Appropriate angulated views should be employed to best visualize the cardiac anatomy [11]. The ventricle should be positioned in the isocenter of the fluoroscopy system to enable automated, accurate quantitation of left ventricular volumes and aortic dimensions, now easily measured in our modern digital labs. The imaging of objects for calibration is no longer required, and their additional use may increase radiation exposure. A breath hold is useful for minimizing motion artifacts.

INFORMATION OBTAINED FROM LEFT VENTRICULOGRAPHY

Ejection Fraction

Ejection fraction of the left ventricle can be derived in both a qualitative and a semiquantitative manner using rapid, automated digital methods. Techniques and formulas for the calculation of ejection fraction can be found elsewhere and are beyond the scope of this consensus document [9]. Biplane ventriculography can be used for the evaluation of left ventricular volumes and ejection fraction; however, it does not consistently provide incremental information regarding those two parameters when compared to single plane ventriculography [12]. Ejection fraction determined visually by left ventriculography correlates variably to ejection fraction from echocardiography, particularly in patients with coronary artery disease [13–15]. Biplane left ventriculography correlates better than monoplane left ventriculography when compared to cardiac magnetic resonance imaging (MRI) for ejection fraction, ventricular volumes, and wall motion [16].

Wall Motion and Ventricular Thrombus

Left ventriculography is commonly performed in the right anterior oblique projection. This view allows the visualization of the anterior, apical, inferior, and high lateral walls. The left anterior oblique projection with steep cranial angulation allows visualization of the apical, lateral, and septal walls [17] and ventricular septal defects. Left ventriculography can estimate myocardial viability by comparing a baseline cardiac cycle to one that follows a premature ventricular contraction, inotrope infusion, or even nitroglycerin administration [18–20]. The presence of an apical filling defect suggestive of thrombus should not be overlooked as it may be visualized on ventriculography yet missed on noncontrast transthoracic echo.

Ventricular Volume

Current digital labs provide rapid, accurate measurements of left ventricular volume that have been validated directly with human heart casts [21] and cardiac MRI [22]. End-systolic and end-diastolic volumes predict outcomes in regurgitant valvular lesions and should be routinely obtained when left ventriculography is performed, as ejection fraction alone is inadequate for medical decision making in such cases, per current ACC/AHA guidelines [23].

Regurgitant Lesions

Left ventriculography has been applied for many years to assess mitral regurgitation severity. The initial criteria proposed by Sellers, Levy, Amplatz, and Lillehei in 1964 are still used today [24], but their inaccuracy was demonstrated several decades ago, particularly in patients with large chamber sizes or poor left ventricular function [25]. Large, long-term outcome studies of aortic and mitral regurgitation in the 1990's determined that quantitative measures of regurgitation are the best outcome predictors. The American and European Societies of Echocardiography issued guidelines in 2002 identifying "specific" quantitative measures of regurgitation severity, such as regurgitant volume, and demoted the subjective "1+ 2+ 3+" color flow grading system to "supportive signs" of lesion severity [26]. Left ventriculographic volume data also correlate with outcome [27]. When left ventricular volumes are measured as described, and combined with invasive thermodilution or measured Fick cardiac outputs, regurgitant volumes and fractions can be obtained for both aortic and mitral valves. If left ventriculography is performed to assess valvular regurgitation it should generate reliable, quantitative measures that augment medical decision making using the currently recognized outcome predictors. A recent review of mitral regurgitation stated that "a high-quality angiogram, along with quantitation of regurgitant volume and regurgitant fraction, may be very useful in resolving discrepancies or uncertainties regarding quantitation of MR severity in selected patients" [26]. When an LAO projection is used, care must be taken to apply sufficient cranial angulation to avoid superimposing the ventricle and atrium and obscuring regurgitation, as well as foreshortening the ventricle and impairing volumetric accuracy. Occasionally, the etiology of the regurgitation can be identified (e.g., mitral valve prolapse or a flail leaflet), but echocardiography is required for surgical planning.

Aneurysms, Pseudo-Aneurysms, and Ventricular Septal Defects

Aneurysms or pseudoaneurysms of the left ventricle can be identified by ventriculography as an out pouching with dyskinetic or akinetic movement compared to the surrounding ventricular segments. In contrast, a diverticular outpouching usually contains all layers of the heart and therefore contracts normally [28]. Diverticula are uncommon in adults. Although histopathologically different than aneurysms or pseudoaneurysms, their distinction can be difficult by left ventriculography. True aneurysms of the left ventricle are typically broad based whereas pseudoaneurysms or contained ruptures usually have a narrow neck. Free wall ruptures represent a continuum with pseudoaneurysms. The ideal view depends upon its location.

Ventricular septal defects are usually best seen in the LAO projection. In the adult population, free wall ruptures, ventricular septal defects, and pseudoaneurysms are acute or subacute processes. Left ventriculography can often provide the first suggestion of myocardial disruption which would guide further imaging and urgent surgical or catheter based treatment [29,30].

ALTERNATIVES TO LEFT VENTRICULOGRAPHY

Cardiac MRI

Cardiac MRI is considered the gold standard for the measurement of left ventricular volumes and global function [22,31,32]. A key role of cardiac MRI in left ventricular assessment has been for the validation of the accuracy of the competing modalities for left ventricular assessment. In clinical practice cardiac MRI is often relegated to the roles of clarifying the left ventricular ejection fraction after other modalities provide indeterminate results, and in the assessment of myocardial viability where it has also emerged as the gold standard [33].

Echocardiography

Echocardiography is the most common imaging modality for assessing the left ventricle. Advantages of echocardiography include real-time imaging, portability and widespread availability, absence of radiation exposure, and the opportunity to assess for co-existent lesions (e.g., structural cardiac disease, diastolic, and right heart function). Left ventricular function can be assessed qualitatively and/or quantitatively using certain geometric assumptions, which usually describe chamber geometry as ellipsoid when two-dimensional methods are utilized. Comparative studies have shown strong correlation of echocardiographic data with other methods of left ventricular assessment, though the level of agreement can be modest [34,35]. Notably, even among highly trained interpreters, the inter- and intraobserver variability with echocardiography can be as high as 30%. Assessment of left ventricular function with echocardiography can be challenging in patients with poor acoustic windows due to body habitus (e.g., lung disease, pectus excavatum, and obesity). Use of three-dimensional techniques, harmonic imaging, and echocardiographic contrast injection can be used to enhance endocardial border definition and improve reliability of echocardiography for assessment of left ventricular function.

Radionuclide Ventriculography

Introduced nearly 50 years ago, radionuclide ventriculography entails labeling of the blood pool with a radioactive tracer (e.g., Tc-99m), whose movement through the circulatory system is captured with a gamma camera. The radioactive counts over the left ventricle are gated to the R-R interval, and summated over a period of time (typically 5–10 min) or in a single pass to derive measurements of left ventricular volume, filling rates, systolic ejection, and regional wall assessment. Because the measurements with radionuclide angiography are independent of geometrical assumptions, this method is highly accurate and very reproducible, with inter-observer variability of <5% [36,37]. Radionuclide ventriculography can be used to examine both atria and ventricles, and also is largely independent of body habitus. With first pass studies, regurgitant valvular lesions and intracardiac shunting can be examined. The principal disadvantage of radionuclide ventriculography is radiation exposure.

Cardiac Computed Tomographic Angiography (CCTA)

CCTA provides volumetric data of the heart within a few seconds with high temporal and spatial resolution (0.4–0.5 mm slice thickness). The advantages of left ventricular functional assessment by CCTA include its noninvasive nature and rapid acquisition during a single breath hold. However, it requires iodinated contrast and radiation exposure and can suffer from artifacts and poor image quality especially in the presence of fast heart rate and cardiac arrhythmia.

CCTA allows accurate assessment of left ventricular function especially in individuals with normal ejection fraction and wall motion [38–40]. CCTA is superior to left ventriculography, echo and 3D echo for assessing ejection fraction, end-diastolic volume and end-systolic volume, using CMR as the gold standard [41,42]. Newer generation 320-detector row CT scanners allow axial volumetric imaging without stair-step or breath-hold artifacts and uniform contrast enhancement compared to previous generation CT scanners [43].

Quantitative 4-dimensional volumetric analysis of the left ventricle by 64-detector row CCTA correlates well with left ventriculography with respect to end-diastolic volume, end-systolic volume, stroke volume, and ejection fraction [44].

The very high spatial resolution of CCTA and the ability to perform post processing makes this the best technique for the assessment of complex LV geometric anomalies such as aneurysms or pseudo aneurysm. In this regard CCTA is far superior to cardiac MRI and the other competing modalities.

COMPLICATIONS

Complications Related to Contrast Agents

A 35–40 cc contrast injection for left ventriculography may increase the total contrast use of a diagnostic study by up to 100%. The use of automated contrast injector reduces overall contrast use but not the contrast-associated complications [45]. Patients with chronic kidney disease, hypotension, anemia, and congestive heart failure are at higher risk to develop contrast-induced nephropathy. The "Mehran risk score" is the most studied and validated score to identify such patients [46]. For patients at high risk of contrast-induced nephropathy, alternative imaging modalities should be considered to evaluate the left ventricle. During cardiac catheterization it is prudent to monitor total contrast use and when it nears a predefined limit (e.g., 3.7 times creatinine clearance), avoid performance of left ventriculography [47].

Embolization

In the setting of severe aortic stenosis, retrograde catheterization of the aortic valve is associated with silent and clinically apparent apparent neurologic deficits in 22% and 3% of patients, respectively [48]. Catheter-induced embolization of aortic valve vegetations could result from crossing the aortic valve. Left heart catheterization and left ventriculography should be performed in these patients only if noninvasive imaging is inadequate. Embolization of air, thrombus or the catheter tip due to technical errors have been reported [49,50].

Arrhythmias and Fascicular Block

Ventricular extra-systoles and ventricular tachycardias are common but usually transient during left ventriculography due to mechanical stimulation of the ventricular endocardium from the catheter or the injection jet. Atrial fibrillation, sustained ventricular tachycardia and ventricular fibrillation have been reported as rare peri-procedural complications [9,51]. Left anterior fascicular block may transiently occur during the left heart catheterization due to the proximity of the anterior fascicle of the left bundle to the left ventricular outflow tract. In rare cases of patients with right bundle branch block and left posterior fascicular block, complete heart block may occur.

Mechanical Complications

Myocardial and pericardial staining, myocardial rupture and pericardial tamponade have been described during left ventriculography [52,53]. Those rare complications occur due to improper catheter positioning or use of end-hole catheters.

Radiation Exposure

The performance of left ventriculography may increase total radiation exposure to the patient by up to 30% [54]. While this amount may not itself cause radiation injury, radiation dose should always be kept as low as reasonably achievable (ALARA). Elimination of the ventriculogram when radiation dose is a particular concern has been previously recommended [55].

TABLE I. Left Ventricular Uses in Pediatric Congenital Catheterization

Diagnostic
1. Sub, valvar, and supra valavar aortic stenosis
2. Multiple VSDs in setting of elevated RV pressures
3. Complex VSD with malposed AV or VA valves
Interventional
1. Muscular VSD device closure
2. Para-membranous VSD/VSA device closure

LEFT VENTRICULOGRAPHY IN PEDIATRIC HEART CATHETERIZATION

Left ventriculography is frequently indicated during pediatric congenital catheterization both for diagnostic evaluation and for guidance of interventional procedures (Table I). In the pediatric population, due to anatomic reasons and higher heart rates, echocardiography is the preferred method for the assessment of left ventricular function and anatomy. Left ventriculography can assess left ventricular systolic function but is rarely used for this purpose except as an adjunct to echo or cardiac MRI in select patients. However in patients with complex left-sided obstruction such as sub valvular or supra valvular aortic stenosis left ventriculography is routinely used in conjunction with pullback left ventricle to ascending aorta pressure measurements to determine both the site and significance of obstruction to plan surgical or interventional repair. Left ventriculography is frequently used in young infants with complex or multiple ventricular septal defects to determine number, size and location of defects. It has an advantage over color Doppler echocardiography in the setting of multiple defects when right ventricular pressure is systemic and ventricular shunt flow velocities are low. In addition, left ventriculography can be critical in children with complex ventricular septal defects and great vessel abnormalities, such as double outlet right ventricle with transposed great vessels or upstairs/downstairs ventricles with criss-cross atrio-ventricular valves in whom a surgical pathway from the left ventricle to the aorta is required for complete repair. Left ventriculography gives unique anatomical information regarding blood flow streaming patterns from the left ventricle to the aorta as well as highlighting potential problems such as a restrictive ventricular septal defect, or atrio-ventricular valve or conal outlet tissue residing in the baffle pathway.

Catheter based device closure of muscular ventricular septal defects and peri-membranous ventricular septal defects with associated ventricular septal aneurysm have become common in children. Left ventriculography is essential to define the location, size and surrounding structures of the defect before

TABLE II. Costs of Alternative Left Ventricle Imaging Modalities

	CPT code	Physician work RVUs	Physician practice expense RVUs	Facility expense RVUs	CMS payment to physicians	Total practice and facility costs	Total costs
Left ventriculography[a]	93543, 93555	1.10	0.20	1.60	$37	$54	$91
Blood Pool Imaging	78472	0.98	0.38	5.65	$27	$205	$232
Transthoracic echocardiography	93306	1.3	0.52	3.75	$44	$145	$189
Computed Tomography, Heart	75572	1.75	0.69	6.78	$60	$254	$314
Cardiac Magnetic Resonance for morphology and function	75557	2.60	1.05	10.74	$88	$401	$489

[a]Current Procedural Terminology codes specific to left ventriculography were deleted in 2011. Data shown here is for the left ventriculography codes before they were deleted. At present, CPT codes bundle left ventriculography, when performed, with left heart catheterization. Medicare currently provides no separate reimbursement for physician work, physician practice expense, or facility costs of left ventriculography.

closure, for peri-procedural assessment after device placement to assure appropriate device positioning, and for postprocedural assessment of satisfactory closure.

COSTS OF LEFT VENTRICULOGRAPHY AND ALTERNATIVE IMAGING MODALITIES

A major advantage of left ventriculography is its low cost and convenience. It adds only a few minutes to a cardiac catheterization procedure, and expenses for materials are limited to an injector syringe, tubing, diagnostic catheter, and 40–50 cc of contrast. While actual costs are notoriously hard to identify, the costs of left ventriculography and alternative left ventricular imaging modalities have been estimated by the Center for Medicare and Medicaid Services (Table II). Using data from 2010 for left ventriculography, other imaging modalities cost two to fivefold more. Therefore, obtaining a measure of the ejection fraction and assessing wall motion is more cost effective with ventriculography than performing an additional noninvasive study.

Since CMMS bundled payments for left ventriculography and left heart catheterization together in 2011, it has not reimbursed physicians or facilities separately for the work or cost of left ventriculography. This is an extremely important point as it has been suggested that left ventriculography was being performed unnecessarily for individual financial gain [1]. In fact, when looking at the performance of ventriculography in the VA system where the operators are salaried, financial gain could not be listed as a factor in variability of performance [5].

RECOMMENDATIONS FOR USE OF LEFT VENTRICULOGRAPHY

1. Consider left ventriculography when left ventricular function or wall motion is unknown, or mechanical disruption is suspected and results of the study will help determine therapy. (Examples include acute coronary syndromes without prior noninvasive imaging, or when an acute change in clinical status suggests left ventricular function has recently changed.)
2. Perform left ventriculography selectively. Avoid it when an adequate alternative left ventricular imaging study has been performed.
3. Avoid left ventriculography in patients for whom it creates significant risk. Examples include patients with renal insufficiency (when left ventriculography could increase the risk of contrast induced nephropathy), elevated end diastolic pressure (when left ventriculography could increase the risk of acute respiratory decompensation), known or suspected left ventricular mural thrombus, aortic valvular vegetation, and in those that have already received high levels of radiation exposure.
4. Develop local criteria for performance of left ventriculography and work to decrease variation in its performance among operators within individual catheterization laboratories.
5. Perform left ventriculography with a multisidehole catheter using a power injector.
6. Include left ventriculography technique and indications in random case reviews as part of a comprehensive catheterization laboratory quality program.

SUMMARY

The role of left ventriculography has evolved radically over the last half-century, but has received little notice in the academic literature. The technique and frequency of use of left ventriculography vary across regions of the United States, institutions, and individuals. This reflects lack of consensus or guidelines regarding its optimal use. The recommendations in this document are based on the consensus of a writing group and would be level of evidence C if they were formal guidelines. They should be tested through clinical research studies. Until such studies are performed, the writing group believes that adoption of these recommendations will lead to a more standardized application of ventriculography and improve the quality of care provided to cardiac patients.

ACKNOWLEDGMENTS

We gratefully recognize the thoughtful review and suggestions for improvement from Christopher M. Kramer MD, Yasmin Hamirani MD, L Andrew Nassef MD, Robert Mangano MD, and Terry Bauch MD.

REFERENCES

1. Witteles RM, Knowles JW, Perez M, Morris WM, Spettell CM, Brennan TA, Heidenreich PA. Use and overuse of left ventriculography. Am Heart J 2012;163:617–623.
2. Patel MR, Bailey SR, Bonow RO, Chambers CE, Chan PS, Dehmer GJ, Kirtane AJ, Wann LS, Ward RP, Douglas PS, Patel MR, Bailey SR, Altus P, Barnard DD, Blankenship JC, Casey DE Jr, Dean LS, Fazel R, Gilchrist IC, Kavinsky CJ, Lakoski SG, Le DE, Lesser JR, Levine GN, Mehran R, Russo AM, Sorrentino MJ, Williams MR, Wong JB, Wolk MJ, Bailey SR, Douglas PS, Hendel RC, Kramer CM, Min JK, Patel MR, Shaw L, Stainback RF, Allen JM. ACCF/SCAI/AATS/AHA/ASE/ASNC/HFSA/HRS/SCCM/SCCT/SCMR/STS 2012 appropriate use criteria for diagnostic catheterization: American College of Cardiology Foundation Appropriate Use Criteria Task Force Society for Cardiovascular Angiography and Interventions American Association for Thoracic Surgery American Heart Association, American Society of Echocardiography American Society of Nuclear Cardiology Heart Failure Society of America Heart Rhythm Society, Society of Critical Care Medicine Society of Cardiovascular Computed Tomography Society for Cardiovascular Magnetic Resonance Society of Thoracic Surgeons. Catheter Cardiovasc Interv 2012;80(3):E50–81.
3. Patel MR, White RD, Abbara S, Bluemke DA, Herfkens RJ, Picard M, Shaw LJ, Silver M, Stillman AE, Udelson J. 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. J Am Coll Cardiol 2013;61:2207–2231.
4. Joffe SW, Chalian A, Tighe DA, Aurigemma GP, Yarzebski J, Gore JM, Lessard D, Goldberg RJ. Trends in the use of echocardiography and left ventriculography to assess left ventricular ejection fraction in patients hospitalized with acute myocardial infarction. Am Heart J 2009;158:185–192.
5. Heidenreich PA, Lin S, Knowles JW, Perez M, Maddox TM, Ho MP, Rumsfeld JS, Sahay A, Massie BM, Tsai TT, Witteles RM. Variation in use of left ventriculography in the veterans affairs health care system. Circ Cardiovasc Qual Outcomes 2013;6:687–693.
6. Walsh W, Falicov RE, Pai AL. Comparison of single and biplane ejection fractions in patients with Ischaemic heart disease. Br Heart J 1976;38:388–395.
7. Vogel JH, Cornish D, McFadden RB. Underestimation of ejection fraction with singleplane angiography in coronary artery disease: Role of biplane angiography. Chest 1973;64:217–221.
8. Rackley CE. Value of ventriculography in cardiac function and diagnosis. Cardiovasc Clin 1975;6:283–296.
9. Baim D. Cardiac Ventriculography. In: Grossman and Baim's Cardiac Catheterization, Angiography, and Intervention, 7th ed; Philadelphia: Lippincott Williams and Wilkins; 2006. pp 222–233.
10. Hodges MC, Rollefson WA, Sample SA, Rubal BJ, Stajduhar KC. Comparison of low-volume versus standard-volume left ventriculography. Catheter Cardiovasc Interv 2001;52:314–319.
11. Croft CH, Lipscomb K, Mathis K, Firth BG, Nicod P, Tilton G, Winniford MD, Hillis LD. Limitations of qualitative angiographic grading in aortic or mitral regurgitation. Am J Cardiol 1984;53:1593–1598.
12. Brogan WC, Glamann B, Lange RA, Hillis LD. Comparison of single and biplane ventriculography for determination of left ventricular volume and ejection fraction. Am J Cardiol 1992;69:1079–1082.
13. Muraka S, Attaran R, Movahed MR. Correlation between estimated ejection fraction measured by echocardiography with ejection fraction estimated by cardiac catheterization in patients awaiting cardiac transplantation. J Inv Cardiol 2010;22:571–573.
14. Joffe SW, Ferrara J, Chalian A, Tighe DA, Aurigemma GP, Goldberg RJ. Are ejection fraction measurements by echocardiography and left ventriculography equivalent? Am Heart J 2009;158:496–502.
15. Kudithipudi V, Kalra N, Bhatt RD, Sorrell VL. Comparison of LVEF obtained with single-plane RAO ventriculography and echocardiography in patients with and without obstructive coronary artery disease. Echocardiography 2009;26:630–637.
16. Grebe O, Kestler HA, Merkle N, Wöhrle J, Kochs M, Höher M, Hombach V. Assessment of left ventricular function with steady-state-free-precession magnetic resonance imaging. Reference values and a comparison to left ventriculography. Z Kardiol. 2004;93:686–695.
17. Starling MR, Walsh RA. Accuracy of biplane axial oblique and oblique cineangiographic left ventricular cast volume determinations using a modification of Simpson's rule algorithm. Am Heart J 1985;10:1219–1225.
18. Horn HR, Teichholz LE, Cohn PF, Herman MV, Gorlin R.Augmentation of left ventricular contraction pattern in coronary artery disease by an inotropic catecholamine: the epinephrine ventriculogram. Circulation 1974;49:1063–1071.
19. Helfant RH, Pine R, Meister SG, Feldman MS, Trout RG, Banka VS. Nitroglycerin to unmask reversible asynergy: correlation with post coronary bypass ventriculography. Circulation 1974;50:108–113.
20. Dyke SH, Cohn PF, Gorlin R, Sonnenblick EH. Detection of residual myocardial function in coronary artery disease using post-extra systolic potentiation. Circulation 1974;50:694–699.
21. Reiber JH, Viddeleer AR, Koning G, Schalij MJ, Lange PE. Left ventricular regression equations from single plane cine and digital x-ray ventriculograms revisited. Int J Card Imaging 1996;12:69–78.
22. Hundley WG, Meshack BM, Willett DL, Sayad DE, Lange RA, Willard JE, Landau C, Hillis LD, Peshock RM. Comparison of quantitation of left ventricular volume, ejection fraction, and cardiac output in patients with atrial fibrillation by cine magnetic resonance imaging versus invasive measurements. Am J Cardiol 1996;78:1119–1123.

23. Bonow RO, Carabello BA, Chatterjee K, de Leon AC Jr., Faxon DP, Freed MD, Gaasch WH, Lytle BW, Nishimura RA, O'Gara PT, O'Rourke RA, Otto CM, Shah PM, Shanewise JS. ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Develop Guidelines for the Management of Patients With Valvular Heart Disease). Circulation 2006;48: e1–e148.
24. Sellers RD, Levy MJ, Amplatz K, Lillehei CW. Left retrograde cardioangiography in acquired cardiac disease: technical, indications and interpretations in 700 cases. Am J Cardiol 1964;14: 437–447.
25. Croft CH, Lipscomb K, Mathis K, Firth BG, Nicod P, Tilton G, Winniford MD, Hillis LD. Limitations of qualitative angiographic grading in aortic or mitral regurgitation. Am J Cardiol 1984;53:1593–1598.
26. Grayburn PA, Weissman NJ, Zamorano JL. Quantitation of mitral regurgitation. Circulation 2012;126:2005–2017.
27. Crawford MH, Souchek J, Oprian CA, Miller DC, Rahimtoola S, Giacomini JC, Sethi G, Hammermeister KE. Determinants of survival and left ventricular performance after mitral valve replacement. Department of Veterans Affairs Cooperative Study on Valvular Heart Disease. Circulation 1990;81:1173–1181.
28. Makkuni P, Kotler MN, Figueredo VM. Diverticular and aneurysmal structures of the left ventricle in adults. Tex Heart Inst J 2012;37:699–705.
29. Krakau I, Lapp H, Wolfertz J, Gulker H. Direct visualization of left ventricular free wall rupture by levocardiography. Catheter Cardiovasc Interv 2002;56:238–242.
30. Topaz O, Taylor AL. Interventricular septal rupture complicating acute myocardial infarction: from pathophysiological features to the role of invasive and noninvasive diagnostic modalities in current management. Am J Med 1992;93:683–688.
31. Bellenger NG, Burgess MI, Ray SG, Lahiri A, Coats AJS, Cleland JGF, Pennell DJ. Comparison of left ventricular ejection fraction and volumes in heart failure by echocardiography, radionuclide ventriculography and cardiovascular magnetic resonance. Are they interchangeable? Eur Heart J 2000;21:1387–1396.
32. Qi X, Cogar B, Hsiung MC, Nanda NC, Miller AP, Yelamanchili P, Baysan O, Wu YS, Lan GY, Ko JS, Cheng CH, Lin CC, Huang CM, Yin WH, Young MS. Live/real time three-dimensional transthoracic echocardiographic assessment of left ventricular volumes, ejection fraction, and mass compared with magnetic resonance imaging. Echocardiography 2007;24: 166–173.
33. Kwon DH, Halley CM, Carrigan TP, Zysek V, Popovic ZB, Setser R, Schoenagen P, Starling RC, Flamm SD, Desai MY. Extent of left ventricular scar predicts outcomes in ischemic cardiomyopathy patients with significantly reduced systolic function: a delayed hyperenhancement cardiac magnetic resonance study. J Am Coll Cardiol Cardiovasc Imaging 2009;2:34–44.
34. Naik MM, Diamond GA , Pai T, Soffer A, Siegel RJ. Correspondence of left ventricular ejection fraction determinations from two-dimensional echocardiography, radionuclide angiography, and contrast cineangiography. J Am Coll Cardiol 1995;25:937–942.
35. Nosir YF, Fioretti PM, Vletter WB, Boersma E, Salustri A, Postma JT, Reijs AE, Ten Cate FJ, Foelandt JR. Accurate measurement of left ventricular ejection fraction by three-dimensional echocardiography. A comparison with radionuclide angiography. Circulation 1996;94:460–466.
36. Nichols K, Adatepe MH, Isaacs GH, Powell OM, Pittman DE, Gay TC, Begg FR. A new scintigraphic method for determining left ventricular volumes. Circulation 1984;70:672–680.
37. Rigo P, Chevigne M. Quantification of valvular regurgitation using radioisotopes. Eur Heart J 1987;8 Suppl C:63–69.
38. Greupner J, Zimmermann E, Grohmann A, Dübel HP, Althoff TF, Borges AC, Rutsch W, Schlattmann P, Hamm B, Dewey M. Head-to-head comparison of left ventricular function assessment with 64-row computed tomography, biplane left cineventriculography, and both 2- and 3-dimensional transthoracic echocardiography: comparison with magnetic resonance imaging as the reference standard. J Am Coll Cardiol 2012;59: 1897–1907.
39. Dewey M, Müller M, Eddicks S, Schnapauff D, Teige F, Rutsch W, Borges AC, Hamm B. Evaluation of global and regional left ventricular function with 16-slice computed tomography, biplane cineventriculography, and two-dimensional transthoracic echocardiography: comparison with magnetic resonance imaging. J Am Coll Cardiol 2006;48:2034–2044.
40. Sarwar A, Shapiro MD, Nasir K, Nieman K, Nomura CH, Brady TJ, Cury RC. Evaluating global and regional left ventricular function in patients with reperfused acute myocardial infarction by 64-slice multidetector CT: a comparison to magnetic resonance imaging. J Cardiovasc Comput Tomogr 2009;3:170–177.
41. Wu YW, Tadamura E, Yamamuro M, Kanao S, Okayama S, Ozasa N, Toma M, Kimura T, Komeda M, Togashi K. Estimation of global and regional cardiac function using 64-slice computed tomography: a comparison study with echocardiography, gated-SPECT and cardiovascular magnetic resonance. Int J Cardiol 2008;128:69–76.
42. Puesken M, Fischbach R, Wenker M, Seifarth H, Maintz D, Heindel W, Juergens KU. Global left-ventricular function assessment using dual-source multidetector CT: effect of improved temporal resolution on ventricular volume measurement. Eur Radiol 2008;18:2087–2094.
43. Rybicki FJ, Otero HJ, Steigner ML, Vorobiof G, Nallamshetty L, Mitsouras D, Ersoy H, Mather RT, Judy PF, Cai T, Coyner K, Schultz K, Whitmore AG, Di Carli MF. Initial evaluation of coronary images from 320-detector row computed tomography. Int J Cardiovasc Imaging 2008;24:535–546.
44. Nakamura K, Funabashi N, Uehara M, Suzuki K, Terao M, Okubo K, Mita Y, Maeda F, Komuro I. Quantitative 4-dimensional volumetric analysis of left ventricle in ischemic heart disease by 64-slice computed tomography: a comparative study with invasive left ventriculogram. Int J Cardiol 2008;129:42–52.
45. Gurm HS, Smith D, Share D, Wohns D, Collins J, Madala M, Koneru S, Menees D, Chetcuti S. Impact of automated contrast injector systems on contrast use and contrast-associated complications in patients undergoing percutaneous coronary interventions. JACC Cardiovasc Interv 2013;6:399–405.
46. Mehran R, Aymong ED, Nikolsky E, Lasic Z, Iakovou I, Fahy M, Mintz GS, Lansky AJ, Moses JW, Stone GW, Leon MB, Dangas G. A simple risk score for prediction of contrast-induced nephropathy after percutaneous coronary intervention: development and initial validation. J Am Coll Cardiol 2004;44: 1393–1399.
47. Laskey WK, Jenkins FS, Marroquin OC, Wilensky RL, Glaser R, Cohen HA, Holmes DR. Volume-to-creatinine ratio: a pharmakinetically based risk factor for prediction of early creatinine increase after percutaneous coronary intervention. J Am Coll Cardiol 2007;50:584–590.
48. Omran H, Schmidt H, Hackenbroch M, Illien S, Bernhardt P, von der Recke G, Fimmers R, Flacke S, Layer G, Pohl C, Lüderitz B, Schild H, Sommer T. Silent and apparent cerebral embolism after retrograde catheterisation of the aortic valve in valvular stenosis: a prospective, randomised study. Lancet 2003; 361:1241–1246.

49. Goldenberg I, Shupak A, Shoshani O, Boulos M. Left ventriculography complicated by cerebral air embolism. Cathet Cardiovasc Diagn 1995;35:331–334.
50. Akpinar I, Dogan SM, Karabag T, Sayin MR, Kucuk E, Buyukates M, Turan SA, Aydin M. Pigtail catheter fracture and embolization into the abdominal aorta: an extremely rare angiographic complication. J Cardiovasc Med 2012;13:648–650.
51. Carosio G, Taverna G, Ballestrero G, Reale M, Massa R, Ravazzi PA. Use of 5 French catheters in percutaneous femoral coronaro-ventriculography (500 consecutive procedures with 5 French catheters). G Ital Cardiol 1991;21:725–730.
52. Basit A, Nazir R, Hahn H. Myocardial and pericardial staining by transradial Optitorque Jacky shape catheter during left ventriculogram. J Invasive Cardiol 2012;24:128.
53. Planas A, Pomar F, Vilar JV, Perez E. Cardiac rupture and tamponade during ventriculography. Int J Cardiol 2007;118:128–129.
54. Clark AL, Brennan AG, Robertson LJ, et al. Factors affecting patient radiation exposure during routine coronary angiography in a tertiary referral centre. Br J Radiol 2000;73:184–189.
55. Einstein AJ, Moser KW, Thompson RC, Cerqueira MD, Henzlova MJ. Radiation dose to patients from cardiac diagnostic imaging. Circulation 2007;116:1290–1305.

Author Relationships with Industry and Other Entities (Relevant) — Optimal Use of Left Ventriculography at the Time of Cardiac Catheterization: A Consensus Statement from the Society for Cardiovascular Angiography and Interventions

Committee Member	Employment	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational or Other Financial Benefit	Expert Witness
Osvoldo S. Gigliotti, MD	Seton Heart Institute	None	None	None	None	None	None
Joseph D. Babb, MD	East Carolina University Brody School of Medicine	None	None	None	None	None	None
Robert S. Dieter, MD	Loyola University Medical Center	None	None	None	None	None	None
Dmitriy N. Feldman, MD	Weill Cornell Medical College	None	None	None	None	None	None
Ashequl M. Islam, MD	Tufts University School of Medicine	None	None	None	None	None	None
Konstantinos Marmagkiolis, MD	Citizens Memorial Hospital Heart and Vascular Institute	None	None	None	None	None	None
Phillip Moore, MD	University of California, San Francisco	None	None	None	None	None	None
Paul Sorajja, MD	Minneapolis Heart Institute	None	None	None	None	None	None
James C. Blankenship, MD	Geisinger Medical Center	None	None	None	None	None	None

This table represents relevant healthcare relationships of committee members with industry and other entities that were reported by authors, including those not deemed to be relevant to this document, at the time this document was under development. The table does not necessarily reflect relationships with industry at the time of publication. A person is deemed to have a significant interest in a business if the interest represents ownership of $\geq$5% of the voting stock or share of the business entity, or ownership of $\geq$\$10 000 of the fair market value of the business entity; or if funds received by the person from the business entity exceed 5% of the person's gross income for the previous year. Relationships that exist with no financial benefit are also included for the purpose of transparency. Relationships in this table are modest unless otherwise noted. Please refer to http://www.cardiosource.org/Science-And-Quality/Practice-Guidelines-and-Quality-Standards/Relationships-With-Industry-Policy.aspx for definitions of disclosure categories or additional information about the ACCF Disclosure Policy for Writing Committees.

*No financial benefit.

†Significant relationship.

‡Institutional relationship; person enrolls patients in trial per institutional requirement but has no direct relationship with the trial or trial sponsor. Therefore, this relationship was not deemed relevant to this document.

Author Relationships with Industry and Other Entities (Comprehensive) — Optimal Use of Left Ventriculography at the Time of Cardiac Catheterization: A Consensus Statement from the Society for Cardiovascular Angiography and Interventions

Committee Member	Employment	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational or Other Financial Benefit	Expert Witness
Osvoldo S. Gigliotti, MD	Seton Heart Institute	None	Astra Zeneca Janssen Pharmaceuticals	None	Astra Zeneca Janssen Pharmaceuticals Medtronic Abbott Vascular National Institutes of Health	None	None
Joseph D. Babb, MD	East Carolina University Brody School of Medicine	None	None	None	None	None	None
Robert S. Dieter, MD	Loyola University Medical Center	None	None	None	None	None	None
Dmitriy N. Feldman, MD	Weill Cornell Medical College	None	None	None	None	None	None
Ashequl M. Islam, MD	Tufts University School of Medicine	None	Edwards Lifesciences	None	None	None	None
Konstantinos Marmagkiolis, MD	Citizens Memorial Hospital Heart and Vascular Institute	None	None	None	None	None	None
Phillip Moore, MD	University of California, San Francisco	None	St. Jude Medical	None	St. Jude Medical Gore	None	None
Paul Sorajja, MD	Minneapolis Heart Institute	None	None	None	None	None	None
James C. Blankenship, MD	Geisinger Medical Center	None	None	None	Abbott Vascular Hamilton Health Sciences Tryton Medical Boston Scientific Stentys, Inc. Regado Biosciences Volcano Corp Astra Zeneca	None	None

This table represents all healthcare relationships of committee members with industry and other entities that were reported by authors, including those not deemed to be relevant to this document, at the time this document was under development. The table does not necessarily reflect relationships with industry at the time of publication. A person is deemed to have a significant interest in a business if the interest represents ownership of $\geq$5% of the voting stock or share of the business entity, or ownership of $\geq$\$10 000 of the fair market value of the business entity; or if funds received by the person from the business entity exceed 5% of the person's gross income for the previous year. Relationships that exist with no financial benefit are also included for the purpose of transparency. Relationships in this table are modest unless otherwise noted. Please refer to http://www.cardiosource.org/Science-And-Quality/Practice-Guidelines-and-Quality-Standards/Relationships-With-Industry-Policy.aspx for definitions of disclosure categories or additional information about the ACCF Disclosure Policy for Writing Committees.

*No financial benefit.

†Significant relationship.

‡Institutional relationship; person enrolls patients in trial per institutional requirement but has no direct relationship with the trial or trial sponsor. Therefore, this relationship was not deemed relevant to this document.