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New Frontiers in the Evaluation of Cardiac Patients for Noncardiac Surgery

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PERIOPERATIVE myocardial complications after noncardiac surgery affect more than 1 million operations each year and are leading causes of morbidity and mortality, especially among patients undergoing vascular surgery. Myocardial complications such as perioperative myocardial infarction (MI) are common and are the most likely cause for perioperative death in all surgical populations.[1] In general surgery, the risk for perioperative MI is 0.8% in men older than 50 yr[2] and varies with the cardiovascular status, comorbidities, and the extent of the procedure, reaching more than 20% among patients undergoing vascular surgery.[3] As patients become older and sicker and procedures become more aggressive and extensive, physicians must find novel approaches to evaluate and prepare cardiac patients for noncardiac procedures and reduce perioperative myocardial events.

The American Heart Association–American College of Cardiology guidelines for cardiac risk evaluation use the patient's history, physical examination, and functional capacity, and taking into account the expected surgery, one may recommend further assessment with noninvasive testing or coronary angiography.[4] The purpose of this review is to provide an overview of available imaging tools that could potentially be used for perioperative evaluation of cardiac patients before noncardiac surgery, in accord with recent guidelines and with focus on the recent progress made with cardiac computed tomography (CT).

Preoperative Evaluation

Traditionally, preoperative evaluation has relied on the patient's history, physical examination, and functional capacity. After preoperative evaluation, the physician should determine the clinical predictors as major, intermediate, or minor[4] and evaluate the functional capacity of the patient. New York Heart Association class II heart failure, which equals 4 metabolic equivalents,[4] has also been found to be an important predictor of perioperative cardiac complications after major noncardiac surgery. The cutoff value of 4 or more metabolic equivalents determines an adequate cardiac functional capacity and reserve and predicts perioperative cardiac events in patients treated with high-risk noncardiac surgery.[5] Finally, the extent and risk associated with the procedure should be categorized as major, intermediate, or minor. The cardiac risk is the combined incidence of cardiac death and nonfatal MI and is greater than 5% for high-risk procedures, whereas intermediate-risk procedures have less than 5% cardiac risk (1–5%), and low-risk procedures have less than 1% cardiac risk.[4]

Indeed, based on these criteria, the flowchart of Eagle *et al.*[4] suggests when a noninvasive test or coronary angiography may be appropriate to evaluate cardiac function, reserve, or ability to withstand surgical stress. Pertinent to the utility of evaluating cardiac structure and function, new imaging techniques for evaluation of the heart have emerged in the past couple of decades. These techniques may provide more comprehensive information regarding the structure and function of the heart and coronary arteries, and evaluate adequately patients who have mechanical restrictions to perform exercise-induced stress. Such developments in cardiac imaging may eventually provide an opportunity to revise and refine the steps involving the evaluation of cardiac patients.[6,7]

This approach should be evaluated cautiously and should take into consideration recent recommendations and guidelines. For example, the current American Heart Association–American College of Cardiology guidelines recommend the use of perioperative β-blocker therapy

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as an alternative approach to decrease cardiovascular risk.[8] β-Blockers initiated at least 1 week before major vascular surgery and continued for 30 days postoperatively reduced significantly the perioperative incidence of nonfatal MI and death from cardiac causes in high-risk patients.[9] In addition to beta blockers, statins may reduce perioperative mortality in patients undergoing major vascular surgery and may have an additive effect to β-blockers.[10,11]

The strategy of preoperative coronary artery revascularization before elective major vascular surgery to reduce perioperative cardiac morbidity and mortality was investigated in the Coronary Artery Revascularization Prophylaxis trial, a multicenter study involving patients with vascular disease and significant coronary artery disease (CAD), but no unstable angina. Cardiac revascularization did not result in increased survival, either perioperatively or in long-term follow-up, in patients who needed elective vascular surgery.[12] However, although the Coronary Artery Revascularization Prophylaxis study is a cornerstone trial in the perioperative care of cardiac patients for noncardiac surgery, it had some limitations. In particular, only 9% of the patients scheduled to undergo vascular operations were eligible for the study. The main reasons for exclusion were insufficient cardiac risk, an urgent vascular surgery, previous revascularization without ischemia, severe coexisting illnesses, left main coronary artery stenosis of at least 50%, left ventricular ejection fraction less than 20%, and severe aortic stenosis. The outcome of these patients has not been adequately evaluated.

Indeed, taking into consideration the patient's perioperative cardiac risk according to clinical predictors, functional capacity, and the extent of the future surgery, the anesthesiologist must decide whether further cardiac assessment or perioperative medical management are indicated. Patients whose functional capacity is difficult to establish, who underwent previous coronary revascularization, who have unstable or changed cardiac status, or who have severe comorbidities may need further evaluation. Several imaging techniques are available for evaluation of cardiac patients, including cardiac CT, coronary angiography, stress echocardiography, cardiac magnetic resonance imaging (CMRI), and myocardial nuclear studies.

Computed Tomography

Computed tomography is widely available in large medical centers and is routinely used in clinical practice. The basic principle of CT is that a fan-shaped, thin x-ray beam passes through the body at many angles to allow for cross-sectional images. After collimation of the beam (*i.e.*, achieving a definitive slice thickness using a collimator) to reduce scatter, the photons are recorded on a corresponding detector array, and the transmission data are digitized. A "filtered back projection" reconstruction algorithm, which takes into account the attenuation of the x-ray beam along its path, allows for reconstruction of the grayscale values of each picture element (pixel) with reference to the value for water and air, to depict cross-sectional images. Reconstruction algorithms and multirow detectors applied in current scanners enable three-dimensional volumetric imaging and multiple high-quality reconstructions of various volumes of interest.[13]

Current clinical scanners used for cardiovascular imaging employ either a rotating x-ray source with a circular, stationary detector array (*e.g.*, helical CT) or electromagnetic deflection of an electron beam to replace mechanical motion (electron beam computed tomography [EBCT]).[14] Multidetector computed tomography (MDCT) is a helical CT with a large array of detectors, which allow it to acquire a large number of slices simultaneously (4–256) and greatly increase its resolution. However, to obtain quantitative measurements of tissue opacity within a specific cardiac phase (*e.g.*, for measurement of perfusion), the scanning time should generally be less than 100 ms.[15] Sufficiently high temporal resolution (the time required to acquire the data for one image) is currently offered only by the EBCT (50 ms/image) and the novel Dual-Source CT (SOMATOM® Definition; Siemens Medical Systems, Forchheim, Germany) (83 ms/image), a recently released model of MDCT that has two x-ray tubes (rather than one) positioned at 90° to each other, thereby doubling temporal resolution.[16] However, this technique remains to be validated for such measurements.

Electron Beam Computed Tomography

Electron beam computed tomography was developed in the 1980s and hailed as an ultimate cardiac scanner. It allows almost simultaneous data acquisition from up to eight parallel slices (7–8 mm thick) by rapid sweeping of an electron beam along target rings in as little as 50 ms per scan. Because it does not involve moving parts (and therefore decreases the need for cooling), the speed of acquisition (temporal resolution) with EBCT is faster than with MDCT (table 1) and usually does not require slowing the heart rate pharmacologically. The high speed of EBCT is offset by moderate image quality and relatively restricted power for acquisition of a large number of images, which decreased its popularity for comprehensive cardiac studies. Consequently, its availability is limited, resulting in declining use of this technology.

Multidetector Computed Tomography

Multidetector computed tomography is a relatively ubiquitous and newer scanner that has temporal resolution of 330–400 ms/image, which enables many studies of cardiac anatomy and global function (*e.g.*,

Table 1. Comparison between Cardiac EBCT and MDCT

Technical Principles	EBCT	MDCT
Basic principle	Electron gun runs at a constant tube current of 625 mA 130 kV; electron beam focused onto one of four target tungsten rings	Multiple (4-256) detector rings simultaneously targeted by the rotating x-ray tube. Voltage and mA can vary.
Data acquisition protocols	(1) "Single slice mode" with either a non-ECG-synchronized continuous volumetric data acquisition or a prospective ECG-triggered stepwise volumetric data acquisition. (2) "Multislice mode" protocol utilizes 50 ms sweeps along 1-4 target rings in rapid succession.	Prospective ECG triggering and retrospective ECG gating allow reconstruction of images at any given time in the RR interval
Resolution	Lower spatial resolution, higher image noise	Higher spatial resolution, lower image noise
Radiation (mSv)		
Coronary calcium scoring	0.7–1.3	2.0–6.2
Coronary angiography	1.1–4.4	6.7–14.5*
Cardiac function	7.6	6.7–14.5 *
Shortest acquisition time (ms)	50–100	165**
Contrast media injection		
Flow rate (ml/s)	3	3–5
Volume (ml)	90–180	60–120
Scan duration (s)	60	12 (MCDT-64)
Preparation for scanning	Preoxygenation may be useful to prolong the breath-hold period	β-blockers often needed to reduce motion-artifacts with heart rate >70
Clinical Applications	**EBCT**	**MDCT**
Calcium scoring	Gold standard	Equivalent
Coronary angiography	High sensitivity and specificity for detection of stenosis in proximal coronary arteries; 25% nonassessable coronary segments	Over 90% of coronary artery segments are assessable
Cardiac function	Gold standard	Retrospectively gated MDCT accurately estimate LV volumes, and regional LV wall thickening
Coronary arteries evaluation and cardiac function from single scan	No, requires additional scans with contrast media and radiation	Yes, the same scan data can be used

EBCT = electron beam computed tomography
ECG = electrocardiogram
EF = ejection fraction
LV = left ventricle
MDCT = multidetector computed tomography
RR = respiration rate
* ECG pulsing algorithms substantially reduce radiation exposure
** The Dual Source MDCT, which offers 83 ms/image, is still being evaluated

ejection fraction and cardiac output). Spatial resolution can be achieved with 64-slice scanners using isotropic voxels (consistent three-dimensional image quality in any reconstruction plane) of 0.4 × 0.4 × 0.4 mm. The technique involves continuous rotation of the x-ray tube and detectors and simultaneous translation of the patient through the gantry opening, and can acquire multiple simultaneous sections of variable widths using prospective electrocardiographic triggering.[17] Alternatively, retrospective electrocardiographic gating enables reconstruction of images at any desired time in the cardiac cycle. Data can be used from multiple slices to reconstruct other imaging planes. The images are of best quality when the resting heart rate (HR) is less than 70 beats/min. At faster heart rates, motion artifacts may become more prominent, and therefore HR may need to be pharmacologically decreased before scanning. The temporal resolution of MDCT determines the overall scan time. As gantry rotation speeds increase, the minimum slice thickness decreases, with submillimeter sections throughout the heart acquired during a single breath hold. The overall CT scan time is approximately 12 s, and the mean total time for the examination is less than 13 min with 64-slice technology.

Clinical Applications of Cardiac Computed Tomography

The Coronary Arteries

The improvement in MDCT technology enabled the assessment of significant luminal stenosis and identification of nonstenotic atherosclerotic plaques. Virtual noninvasive angiography, with three-dimensional reconstruction of coronary anatomy from cardiac CT images, can provide information about coronary luminal obstruction, calcium scoring, and composition of the plaque.[18] Furthermore, it has the added benefit of offering fine details of the examined vessels (fig. 1).

Excellent sensitivity and specificity were found for evaluation of proximal, middle and distal left anterior descending, first diagonal, proximal and distal circumflex, obtuse marginal and proximal mid and distal right coronary artery.[19] A meta-analysis of diagnostic performance of MDCT compared with invasive coronary angiography showed a sensitivity of 85% and a specificity of 95% for identification of CAD. On average, 87% of segments had diagnostic image quality, with a significant increase from 78% with 4-slice systems to 96% with the more recent 16-slice systems.[6]

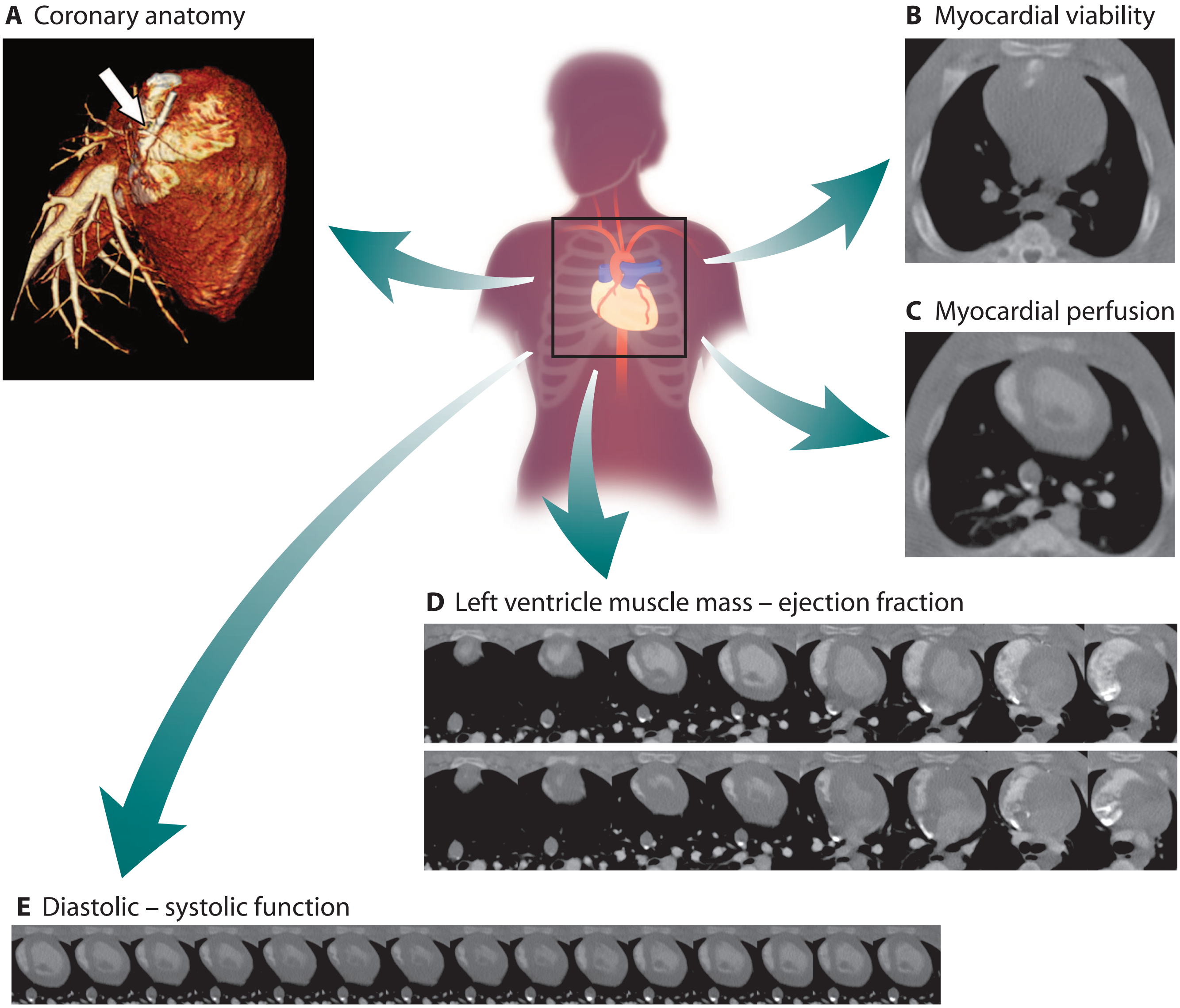
Multidetector computed tomography could provide a clinically useful tool in the workup of symptomatic patients before angiography.[20] A patient with chronic chest pain indicative of CAD could undergo CT angiography, and if low calcium score and no circumferential calcifications (or other test results indicative of ischemia) are found, invasive angiography may not be indicated, because MDCT has excellent negative predictive value to rule out CAD. By this approach, patients with primarily microvessel disease (which may cause angina and abnormal stress test results) may be identified and not required to go through unnecessary fluoroscopic angiography, and aggressive medical therapy would be indicated before surgery.[20] MDCT also has high diagnostic accuracy in detecting bypass graft stenosis and occlusions in symptomatic patients after coronary artery bypass grafting, which might potentially reduce dramatically the number of unnecessary invasive angiographies performed in these patients.[21] However, although the MDCT technique has been extensively evaluated for its accuracy for detection of CAD compared with standard coronary angiography,[6,19,20,22] it has not been applied for the routine evaluation of cardiac patients for noncardiac surgery and, to date, is not a recommended technique for perioperative risk stratification.

The main technical limitations of cardiac CT for evaluation of the coronary arteries include the difficulty in handling cardiac motion, arrhythmia, severe calcifications, vessel size less than 1.5 mm, breathing, the presence of stents, and poor enhancement.[22] Lesions with extensive calcified components and implanted coronary stents compromise the accuracy of MDCT coronary angiography by causing artifacts.[23] Stent type and diameter influence evaluability of in-stent restenosis by MDCT, but in evaluable stents, sensitivity is still 86% and specificity is 98%.[24] When HR is reduced below 70 beats/min, image quality is improved, especially in terms of the visualization of the right coronary and left circumflex arteries, which are both significantly prone to motion artifacts (particularly at higher HR) because of their close proximity to the atrium, which is reactivated during the early diastolic phase.[25]

For evaluation of coronary artery calcium volume with MDCT, thin-slice retrospective spiral electrocardiographic–gated scanning is desirable.[26] Most studies on coronary calcification have been performed using EBCT, which is still considered the "gold standard" (table 1). To image the coronary arteries with EBCT, 30–40 axial images are obtained with 3-mm slice thickness, using single-slice prospective electrocardiographic triggering in the craniocaudal direction along the full length of the heart. Rapid image acquisition at 100 ms allows accurate measurement of calcium deposits in the coronary arteries.[27] Quantification of coronary artery calcifications was found to be independently associated with cardiac events in a 3-yr follow-up of thousands of initially asymptomatic patients.[28] Noninvasive characterization and quantification of atherosclerotic plaque burden may also have important implications for the prevention of CAD progression and its complications.[18]

Cardiac Volumes and Function

For the past several years, CMRI has been considered the reference standard for assessment of left ventricular (LV) functions. However, cardiac CT is playing an increasingly important role in this evaluation. Both CT and CMRI surpass two-dimensional imaging techniques, such as standard two-dimensional echocardiography, for cardiac quantification because of their ability to generate



A Coronary anatomy

B Myocardial viability

C Myocardial perfusion

D Left ventricle muscle mass – ejection fraction

E Diastolic – systolic function

Fig. 1. Application of cardiac computed tomography (CT) for anatomical and functional evaluation of the heart. (*A*) Coronary anatomy: Representative three-dimensional CT images of the heart and thoracic vessels, obtained during intravenous infusion of contrast media, showing a coronary artery (*white arrow*). (*B*) Myocardial viability: Cross-axial CT image of the heart showing late enhancement of an infarcted myocardial segment. (*C*) Myocardial perfusion: One of a series of cross-axial CT images (at the mid left ventricle of the heart) used for evaluation of the changes of myocardial density over time, and subsequently perfusion. (*D*) Left ventricle muscle mass and ejection fraction: Cross-axial images of the same heart obtained at different levels during the diastolic (*top*) and systolic (*bottom*) phases of the cardiac cycle. Such images are used for the reconstruction of left ventricular volumes and calculation of ejection fraction. (*E*) Diastolic–systolic function: Dynamic changes in left ventricular cavity size (shown at a representative cardiac level) observed throughout the cardiac cycle, which can be used for the assessment of systolic and diastolic function.

contiguous short axis cine images, allowing for three-dimensional measurements without the use of geometric assumptions.[29] Postprocessing tools allow fast and semiautomatic determination of LV function parameters from MDCT data in analogy to known CMRI evaluation approaches.[30] Studies have demonstrated excellent correlation between cardiac CT and CMRI for LV ejection fraction, end-diastolic volume, end-systolic volume, stroke volume, and myocardial mass.[30] Furthermore, global and regional LV functions agree well with echocardiography, with correlation coefficients ranging from 0.91 to 0.97 for MDCT and from 0.93 to 0.98 for CMRI.[7,30,31] Although MDCT is not considered to be the first-line modality for assessment of LV function, it can provide a combined assessment of cardiac morphology and function without the need for additional radiation exposure in patients undergoing MDCT coronary angiography. The acquisition of images is performed according to the R–R interval. For MDCT, the image data are gated with the electrocardiogram to allow reconstruction at various times throughout the cardiac cycle. CT allows quantitative analysis of regional and global systolic function in normal and pathologic conditions by using short axis slices from the base to the apex of the heart. End-diastole and end-systole are defined as maximal and minimal LV volume, and LV ejection fraction is the difference between them.[30] Diastolic function can also be assessed from the rate of change of the LV volume during diastole.[13] Also, because temporal resolution for electrocardiographic-gated cardiac CT scans (down to 165 ms) is poorer in comparison to cine CMRI (30–40 ms), CT imaging may miss peak ejection rate or peak filling rate. However, advances in MDCT imaging that will improve temporal resolution may correct this problem.[16]

Myocardial Viability and Wall Motion Abnormalities

Regional wall motion abnormalities, myocardial thinning, ventricular aneurysm, and mural thrombi in the infarcted area can all be detected by cardiac CT. Dual-phase contrast CT can detect acute MI characterized by an initial filling defect and late enhancement at the site of the damaged myocardium. Late enhancement may have the potential to distinguish viable from nonviable myocardium, and has significant prognostic value for the recovery of the myocardial wall motion and thickness after ischemia and in response to therapeutic revascularization.[32] In patients with previous MI, MDCT permits accurate, noninvasive assessment of coronary artery stenosis, LV function, and perfusion, assessed from a single data set.[33] If the myocardium supplied by the stenotic or occluded vessel is still viable, medical treatment or revascularization can be considered to reduce the risk of perioperative ischemia in the affected myocardium.

Myocardial Perfusion

Experimental studies in animals and humans demonstrated that cardiac CT could be used to assess microvascular function, although this technique is not used clinically, partially because of high radiation exposure. Evaluation of myocardial perfusion at rest and after infusion of vasodilators imposing cardiac challenge can reveal the presence of otherwise undetectable limited myocardial flow reserve, which might have a significant value for detection of borderline or very early alterations in cardiac microvascular function, as well as detecting increases in microvascular permeability that may reflect endothelial dysfunction or ischemic changes.[34]

Limitations of Computed Tomography

The use of CT scanning is limited by the need for contrast media and radiation exposure (table 2). The risks associated with contrast media administration include extravasation at the contrast injection site, allergic contrast reaction, and a decline in renal function, as well as cardiac, neurologic, and vascular manifestations. In patients with manifested hyperthyroidism, administration of contrast media is contraindicated.[35] Contrast media dose has been progressively reduced and is lower than that used during angiography procedures,[36] and potential adaptation of alternative contrast agents, such as gadolinium, might further decrease the risk. Currently, various radiation dose-decreasing strategies are under investigation with MDCT, and improved scanning protocols may allow a decrease in radiation dosing.[37] In addition, measures of cardiac function and volumes may differ from beat to beat, potentially affecting any method based on gated acquisitions that average data over several cardiac cycles. Other limitations include the need to optimize image quality in obese patients and the need for well-trained and experienced physicians for acquisition and interpretation of cardiac CT data sets.[38,39]

One of the limitations of MDCT is the need to decrease heart rate at time of acquisition, often requiring β-blockade, which may be contraindicated in some patients. It further underscores the need for advancing CT technology to shorten acquisition time over a greater volume of coverage. Newly developed scanners such as the Dual-Source MDCT may address this goal.[16] With respect to temporal resolution, the number of artifact-free phases that can be generated from axial CT images is limited only by gantry rotation speed and patient heart rate.[29]

Echocardiography

A decreased ejection fraction (<40%) in echocardiography is associated with decreased overall survival postoperatively and with increased incidence of congestive heart failure, but no association has been found with postoperative MI.[40] The main echocardiography factor associated with postoperative cardiac events is the presence of wall motion abnormalities,[41] which has a low positive predictive value.[42] Preoperative echocardiography is deemed appropriate in patients who meet American Heart Association–American College of Cardiology clinical guidelines and who would require echocardiography even if no surgery were planned, as well as in those with suspected aortic stenosis.[43]

The sensitivity of echocardiography can be enhanced by stressing the heart either physically or pharmacologically. An echocardiography stress test with administration of dobutamine (DSE) can provide information about cardiac function, ventricular and valvular function, and pulmonary pressures.[44] Dobutamine, a β-1 stimulator, is given in incremental doses to achieve 85% of age-predicted maximal HR or until symptoms, hemodynamic instability, or arrhythmia appears. Ischemia manifests as stress-induced wall motion abnormalities, whereas a reduction in ejection fraction in response to dobutamine administration is a marker of more severe CAD. DSE has excellent negative predictive values (90–100%) and good sensitivity (85%), but moderate specificity (70%), and is significantly operator dependent.[45] Perioperative

Table 2. Comparison among Different Modalities for Cardiac Evaluation

Technical Principles	CAG	DSE	Nuclear Studies	CMRI	Cardiac CT
Study type	Coronary artery anatomy plus cardiac structure and function	Cardiac structure and function	Cardiac perfusion	Coronary artery anatomy plus cardiac structure and function	Coronary artery anatomy plus cardiac structure and function
Technique	X-rays	Echo-Doppler	Gamma camera	Magnetic field	X-rays
Contrast injection	+	Echo contrast in selected cases	Radionucleotide	+/– gadolinium	+
Perfusion	–	+	+++	++	++
Viability	–	++	+++	+++	+++
Specificity	Gold standard	70%	86% (49**)	87%*	95%*
Sensitivity	Gold standard	85%	89% (83**)	72%*	85%*
Cost	+++	++	++(SPECT) /+++ (PET)	++	++

Clinical Applications	CAG	DSE	Nuclear Studies	CMRI	Cardiac CT
Coronary artery visualization	+++	–	–	+	++
Calcium scoring	–	–	–	++	+++
Heart function, volumes	++	+++	+++	+++	+++
Coronary graft patency	+++	–	–	+	++
In-stent stenosis	+++	–	–	+/–	++
Aortic arch evaluation	++	+	–	+++	+++
Valvular status	++	+++	–	++	+++
Wall motion abnormalities	+++ with LV angiography	+++	+++	+++	+++
Best at	"Gold standard" coronary angiogram; opportunity for immediate intervention	Global cardiac and valvular function	Detect viable myocardium post infarct	Reference technique for ventricular size and function	One stop shop
Characteristics					
Invasive	+	–	–	–	–
Radiation	+	–	+	–	+
Nephrotoxic contrast	+	–	–	+/–	+
Direct coronary artery visualization	+	–	–	+/–	+
For unstable patients	+	–	+	+	+
Metal Interference	–	–	–	+	±
Acute cardiovascular complications	++ Vascular access, myocardial infarction, arrhythmia, heart failure	+ Arrhythmias, hypotension	+ TD: Arrhythmia, hypotension, chest pain	–	± (rare) Vascular access

CAG = coronary angiography
CMRI = cardiac magnetic resonance imaging
CT = computed tomography
DSE = dobutamine stress echocardiography
LV = left ventricle
Nuclear studies = single photon emission computed tomography and positron emission tomography
* Available for coronary artery disease
** SPECT performed with thallium dypiridamole (TD)

and long-term cardiac risk stratification using initial cardiac risk assessment and then selective noninvasive testing with DSE may facilitate the perioperative and long-term treatment of patients undergoing major vascular surgery.[46] In comparison with other noninvasive modalities, DSE shows a positive trend toward better diagnostic performance.[45,46] Furthermore, new semiquantitative indices of DSE (semi-DSE) may improve cardiac event risk stratification compared with standard DSE in patients undergoing noncardiac surgery whose functional capacity cannot be evaluated by exercise stress testing.[46]

Dobutamine stress echocardiography has a relatively low cost and can assess cardiac structure and function, wall thickness, chamber sizes, valves, aortic root, and the presence of pericardial effusion. However, DSE has lower sensitivity for detection of single vessel disease and is unable to distinguish between cardiomyopathy, microvascular disease, and CAD (table 2), because wall motion abnormalities can be found in all.

Cardiac Magnetic Resonance Imaging

Rapid progress has been made during the past decade in CMRI, which is used to evaluate a variety of heart diseases and anomalies, including CAD. CMRI is based on the characteristics of hydrogen nuclei, which behave like magnets and align to an external magnetic field. During CMRI imaging, a radiofrequency pulse causes transient deflection of the hydrogen nuclei away from the direction of the main magnetic field axis. The signal is formed during the relaxation of the protons back toward their original alignment in the magnetic field.[47] Many excitation relaxation sequences are performed, and data lines are used for image reconstruction; therefore, many image acquisitions are gathered for assessment of global ventricular (left and right) function, ejection fraction, stroke volume, viability and mass, detection of CAD, and acute and chronic MI.[48] Three-dimensional LV strain can be semiautomatically and objectively quantified using computer analysis of patient-specific, tissue-tagged CMRI-derived displacement data,[49] and may find growing use in the clinical arena.

Cardiac magnetic resonance imaging has higher temporal resolution but lower spatial resolution (the ability to distinguish between two closely spaced points on the image) than cardiac CT,[6,50] with typical in-plane spatial resolution of 1.5 × 1.5 mm.[51] MDCT may have an advantage over CMRI for detection of CAD, because its overall accuracy in the detection of coronary artery stenosis is higher (table 2). The high-resolution axial image of MDCT allows viewing more complex vascular morphologic features (such as tortuosity) compared with CMRI that may create artifacts due to turbulent blood flow.

The weighted average sensitivity and specificity of CMRI for detection of high-grade coronary artery stenosis are 72% and 87%, respectively, whereas 83% of coronary segments are assessable.[6,50,52] CMRI is noninvasive and provides high-quality images of the heart (table 2). However, CMRI examination cannot be applied in patients who have a pacemaker, implantable defibrillator, intracranial metal, or claustrophobia, and the presence of clips and stents can severely distort CMRI images and lead to false diagnoses. Another limitation is the prolonged duration of the test (more than an hour), during which the patient must be immobilized. Nevertheless, CMRI is an important noninvasive tool and does not necessitate the use of potential nephrotoxic contrast media. Studies are needed to evaluate its use as a perioperative tool and its correlation with perioperative cardiac outcome.

Myocardial Nuclear Studies

The use of myocardial single-photon emission computed tomography (SPECT) and positron emission tomography (PET) has progressively grown in the past two decades because of their success in providing useful information about myocardial perfusion and function based on administration of an unstable radionucleotide. SPECT with thallium dipyridamole has been used for many years for preoperative cardiac evaluation. Dipyridamole mimics the coronary vasodilator response associated with exercise testing (but not the HR response) and has been used in patients scheduled to undergo peripheral vascular surgery. However, thallium dipyridamole has low sensitivity, specificity, and negative predictive value, and thallium redistribution was not significantly associated with the incidence of perioperative MI, prolonged ischemia, or other adverse outcomes.[53,54] On the other hand, the cost effectiveness of this test was improved when used in patients undergoing aortic surgery whose risk status could not have been reasonably estimated on the basis of clinical factors alone.[55]

The value of SPECT technetium-99m sestamibi imaging (MIBI) for preoperative cardiac assessment in high-risk populations has been demonstrated in patients before renal transplantation and vascular surgery.[3,56] Assessment of myocardial viability with MIBI is particularly important in patients with impaired LV function consequent to CAD, and the potential of revascularization preoperatively can be estimated. These studies showed excellent correlation of MIBI with postoperative cardiac events, both perioperatively within 30 days and at long-term follow-up.[3,56] SPECT has high sensitivity (90–94%) in multivessel coronary disease but limited sensitivity (60–76%) for detecting significant single-vessel disease and nonobstructive CAD (table 2). It also provides little functional data other than myocardial perfusion defects and has relatively low spatial resolution that limits the quality of anatomical information. Current SPECT/PET scanners have a maximal allowable weight of approximately 400 lb,[57] and caffeine abstinence is required for 12–24 h before the performance of dipyridamole myocardial perfusion scintigraphy, because the coronary vasodilator effect of adenosine or dipyridamole is inhibited by caffeine.[58]

Cardiac PET with F-18 fluorodeoxyglucose can be used to predict functional recovery of viable myocardium after coronary artery revascularization.[59] During PET, a high-energy positron is emitted from a nucleus, travels a few millimeters in tissue, and collides with an electron.[60] This collision results in complete annihilation of both the positron and the electron, with conversion to energy in the form of electromagnetic radiation composed of two high-energy gamma rays, which travel in opposite directions (180° from each other) and are detected by a pair of radiation detectors at opposite ends. The difference in time until the photons strike each radiation detector is used to detect the source of the event. Hundreds of paired radiation detectors are arranged in the PET gantry with million of counts per seconds forming the image. PET imaging is useful in noninvasive quantification of myocardial blood flow and coronary flow reserve, and is also capable of detecting early disease in high-risk asymptomatic individuals and monitoring the progression or possible regression of diffuse disease. PET is superior to SPECT, especially in obese patients and in those undergoing pharmacologic stress,[61] although obesity remains a significant challenge.[62] However, its high cost and limited availability currently restrict its use as a screening tool.[60]

Coronary Angiography

The technology of coronary angiography is well established and involves intraarterial injection of contrast media into the coronary artery lumen, followed by imaging in multiple planes. Arterial narrowing is quantified by comparison of lumen diameter at a stenotic site with that of a normal reference segment.[63] Cardiac catheterization can evaluate coronary stenosis, LV function, and valvular status (table 2).[22]

However, coronary angiography is an invasive technique and has a major complication rate of 1.7%, including mortality in 0.11% of cases.[64] Furthermore, it may involve discomfort for the patient and is associated with other complications, such as vascular access–related complications (0.8–1.8% for diagnostic and 1.5–9% for interventional catheterization),[65] MI (0.05%), neurologic complications (0.07%), and hemodynamic complications (0.26%).[64]

When comparing the risk of selective coronary angiography with that of MDCT, some risks are common to both procedures, such as an allergic contrast reaction, contrast-induced nephropathy, and exposure to ionizing radiation, whereas others are unique to each. Nonionic contrast media injection causes severe allergic reactions in 0.2–0.7% of patients. Radiation exposures yield lifetimes risks of inducing a fatal cancer of 0.07% for MDCT angiography and 0.02% for coronary angiography. However, combining the radiogenic and nonradiogenic risks (0.02% and 0.11%, respectively) yields a 0.13% overall risk of mortality from coronary angiography—nearly double that for MDCT angiography (0.07%).[64] The use of a power injector in a peripheral vascular line with cardiac CT poses an additional risk of extravasations, which occurs in 0.3–0.6% of patients.[65]

Given the relatively significant number of negative invasive angiographies performed each year, eliminating the risks inherent to this procedure by using noninvasive methods can greatly contribute to diminishing the morbidity and mortality of conventional coronary angiography. Furthermore, reducing the number of negative angiographies might lead to significant saving, because the cost of cardiac catheterization may be as much as 6 times that of cardiac CT.[66]

In summary, evaluation of patients with suspected or known cardiac disease for noncardiac surgery has long been in the center of interest of cardiologists, anesthesiologists, and surgeons. The preoperative evaluation relies on assessment of clinical predictors, functional capacity, and the extent of the surgical procedure. The first-line strategies to reduce perioperative morbidity and mortality include medical therapy with β-blockers with tight HR control, and probably statins. However, the strategy may also include application of noninvasive imaging techniques that provide comprehensive and detailed assessment of cardiac structure and function. In particular, in patients with restricted physical activity in whom assessment of the functional capacity is difficult, meaningful findings obtained using imaging with complete evaluation of the heart may potentially help to direct treatment strategies. Cardiac CT is particularly versatile, can provide virtual coronary angiography for plaque assessment and scoring, and can assess LV size, function, and myocardial viability in a fast and relatively safe manner. CT can assist in ruling out significant CAD and determination of the need for invasive angiography. Hence, cardiac CT might potentially be the modern tool for overall evaluation of cardiac patients for noncardiac surgery. Nevertheless, at this time, there is no evidence that preoperative cardiac CT scanning is able to reduce perioperative risk. Clinical studies are needed to assess the role of cardiac CT in the evaluation of patients at risk for cardiovascular disease before noncardiac surgery.

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