Findings showed that 3D myocardial scar and coronary imaging with fused volumetric display is clinically feasible and may be valuable for the planning of vascular-based interventions when regional myocardial scar is pertinent to therapeutic success.

Future imaging technologies are likely to improve risk stratification and selection of patients for implantable cardioverter defibrillators, resynchronization devices, and other interventions by overcoming remaining problems in stress echocardiography and nuclear stress testing (Table 1). Motivated by the promise to transform preclinical research and clinical care, cardiovascular molecular imaging alone promises great progress via hybrid protocols and the pairing of technology-driven opportunities with those from genomics, proteomics, immunology, and vascular and systems biology [Leuschner F, Nahrendorf M. *Circ Res* 2011].

Table 1. Remaining Problems of Imaging in Evaluation of Coronary Artery Disease.

	Stress Echo	Stress Nuclear
LBBB	Paradox septum	False +
Women	—	Breast attenuation
Inferior wall	Site of false +	Diaphragmatic attenuation
LVH	False – (DSE)	False +
Severe ischemia	—	'Fixed Defect'
3V Disease	Flat EF response	Balanced perfusion
Hypertensive response	Flat EF, False +	—

3V=3 vessel; DSE=dobutamine stress echocardiography; EF=ejection fraction; LBBB=left bundle branch block; LVH=left ventricular hypertrophy.

Among other advances, Dr. Zoghbi foresees high-speed nuclear cardiology cameras with multidetector systems focused on the heart, cadmium zinc telluride semiconductor detectors that decrease the size of the camera head and improve energy resolution by almost 2-fold, improved imaging efficiency and count rate statistics, reduced image degradation by scattered radioactivity, higher spatial resolution, and reduced radiation dose.

The last decade has already seen profound progress, and the future will bring new opportunities to multimodality cardiovascular imaging. These include detection of early disease/cardiovascular phenotype; possible use of imaging for novel drug development and as a surrogate for patient outcome, and the demonstration that novel technologies ultimately have an impact on patient care and outcomes.

Vascular imaging is moving toward the identification of total cardiovascular risk. Dr. Zoghbi predicts more robust quantitation and automation (eg, comparative volumetric 3D flows) in the imaging of valvular regurgitation as well as dynamic mapping of mitral valve strain pre- and post-valve repair. He also expects to see echo-guided interventions for valve repair/replacement, determination of aortic regurgitation post transcatheter aortic valve replacement, noninvasive imaging of plaques, echocardiography and CMR-compatible imaging flow loops, and TAVR patient-specific modeling and 3D heart printing.

Challenges will include the maintenance of innovation in individual modalities, avoidance of layering of multiple testing in individual patients to improve safety and lower costs, and the identification of the best and most cost-effective approaches to disease detection and management.

Noninvasive Assessment of Function and Anatomy Advance Interventional Cardiology

Written by Toni Rizzo

The ischemic cascade is the sequence of pathophysiological events following cardiac ischemia. Several imaging techniques (eg, single-photon emission computed tomography, stress echocardiography, magnetic resonance imaging [MRI], and positron emission tomography [PET]) scans) have been used to detect myocardial ischemia, while cineangiography and computed tomography angiography (CTA) have been used to evaluate anatomy. However, accurate noninvasive assessment of combined anatomy and function of coronary artery disease (CAD) is challenging. Magdy Rashwan, MD, Alexandria University, Alexandria, Egypt, discussed obstacles and advances in imaging technologies used to guide the management of patients with CAD.

A comprehensive assessment of CAD should include both information on coronary artery anatomy and functional information about the hemodynamic relevance of coronary artery lesions in order to guide revascularization procedures. However, it is common practice for physicians to make decisions regarding revascularization in the cardiac catheterization laboratory based on the results of angiography alone, even though such information does not correlate well with the functional significance of a coronary lesion [Kim JE, Koo BK. *Korean Circ J* 2012].

In patients with stable CAD, these decisions are primarily driven by the severity and extent of luminal stenoses determined by invasive coronary angiography

[Hussain ST et al. *J Cardiovasc Magn Reson* 2012]. But revascularization of stenotic lesions that do not lead to myocardial ischemia can be harmful [Kim JE, Koo BK. *Korean Circ J* 2012].

Many advances in integrated noninvasive imaging techniques have enhanced our pathophysiologic understanding of CAD over the past decades. Coronary multislice computed tomography (MSCT) angiography has rapidly evolved, allowing visualization of coronary artery morphology and lesions with a resolution comparable to conventional coronary angiography. At the same time, the combination of CTA and myocardial perfusion imaging is noninvasive, and thus, allows noninvasive integrative assessment of CAD.

Naya et al. [*J Am Coll Cardiol* 2011] evaluated the effects of coronary atherosclerosis morphology and extent of myocardial flow reserve (MFR). They assessed the relationship between atherosclerotic plaque burden, morphology, and composition and regional MFR in 73 consecutive patients undergoing Ribidium-82 PET and coronary CTA (CCTA) for the evaluation of known or suspected CAD.

Atherosclerosis was seen in 51 of 73 patients and in 107 of 209 assessable coronary arteries. On a per-vessel basis, the percentage diameter stenosis (p=0.02) or summed stenosis score (p=0.002), integrating stenosis in series, was the best predictor of regional MFR. On a per-patient basis, the modified Duke CAD index (p=0.04) and the number of segments with mixed plaque (p=0.01) were the best predictors of low global MFR.

The authors concluded that CTA descriptors of atherosclerosis had only a modest effect on downstream MFR. On a per-patient basis, the extent and severity of atherosclerosis as assessed by the modified Duke CAD index and the number of coronary segments with mixed plaque were associated with decreased MFR.

Van Werkhoven et al. [*Heart* 2010] compared magnetic resonance myocardial perfusion imaging with anatomical assessment by MSCT coronary angiography and conventional coronary angiography. The main outcome measures included the presence of significant stenosis (≥50% luminal narrowing) as determined on MSCT and conventional coronary angiography. Ischemia on MRI was defined as a stress perfusion abnormality in the absence of delayed contrast enhancement.

A significant stenosis seen on MSCT in 15 (28%) of patients while ischemia on MRI was seen in 19 (36%). In the 38 patients without significant stenosis on MSCT, ischemia was seen in 10 (67%) of patients with a significant stenosis on MSCT, ischemia was seen in 10 (67%). In all patients without significant stenosis on MSCT and normal perfusion on MRI (n=29), significant stenosis was absent on conventional coronary angiography. All patients with significant stenosis on MSCT and abnormal MRI (n=10) had significant stenoses on conventional coronary angiography.

The authors concluded that anatomical and functional data obtained with MSCT and MRI are complementary for the assessment of CAD findings that support the sequential or combined assessment of anatomy and function.

Although CT is able to assess the coronary artery lumen, there may be a discrepancy between anatomy and myocardial blood supply. The vasomotor tone and coronary collateral flow cannot be estimated because the degree of stenosis is only a weak descriptor of coronary resistance. Therefore, only about 50% of the anatomically significant lesions detected with CTA are flow-limiting, said Prof. Rashwan.

The measurement of fractional flow reserve (FFR) during invasive coronary angiography has been used as a gatekeeper for angioplasty. Although FFR has become the gold standard assessment to detect ischemia-related lesions, it requires an invasive procedure, expensive devices, and pharmacologic intervention to induce maximal hyperemia [Tonino PAL et al. *N Engl J Med* 2009]. Prof. Rashwan said that although the use of FFR is likely to increase, its invasiveness and cost warrant noninvasive alternatives.

CT-derived computed FFR is a recent advance in CT technology used to assess the functional significance of coronary stenosis in addition to anatomical information. This approach enables the application of computational fluid dynamics to CCTA images. With this technology, FFR can be computed using images from conventional CCTA without any invasive procedure and without hyperemia.

The Fractional Flow Reserve (FFR) Guided Percutaneous Coronary Intervention (PCI) Plus Optimal Medical Treatment (OMT) Versus OMT [FAME II; NCT01132495] compared the clinical outcomes, safety, and cost-effectiveness of FFR-guided PCI plus OMT versus OMT alone in patients with stable CAD. The primary outcome was major adverse cardiac event rate within 24 months.

In patients with stable coronary artery disease and functionally significant stenoses, findings showed that FFR-guided PCI plus the best available medical therapy, as compared with the best available medical therapy alone, decreased the need for urgent revascularization. In patients without ischemia, the outcome appeared to be favorable with best available medical therapy alone [De Bruyne B et al. *N Engl J Med* 2012].