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PROGRESS IN CARDIOLOGY

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New Series

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PREFACE

It is obvious that a significant portion of the evaluation of the cardiac patient has shifted from the catheterization laboratory, for years the citadel of the final cardiac diagnosis in the living patient, to other areas and disciplines in the hospital. The contemporary cath lab has become as much a treatment center as a laboratory for cardiac assessment. Virtually all of these other diagnostic techniques employ cardiac imaging of one kind or another. Therefore, we thought it appropriate to focus volume *3/1* and a part of *3/2* on an update about cardiac imaging.

Once again, we have been privileged to have as contributors the major "players" in the field. We have divided the discussion in volume *3/1*, somewhat arbitrarily since unavoidable overlap exists, into sections on magnetic resonance imaging, echocardiography and Doppler, positron emission tomography, digital subtraction angiography, and a relatively new area of interest, cardiac sympathetic imaging. In volume *3/2*, we will conclude the subject of imaging with an article on the hibernating myocardium and one on myocardial metabolism.

To diversify volume *3/1* a bit, in response to requests by many readers, we have included two articles on cardiac infections and a thorough summary on coronary thrombolysis. The latter will be supplemented by articles in volume *3/2* on new thrombolytic agents and an overview of the many clinical trials and their results.

Also in *3/2* will be chapters on lipids and contemporary coronary care. The latter will encompass the latest techniques dealing with angioplasty, atherectomy, and stents, as well as other contemporary issues about implantable defibrillators, geriatric cardiology, balloon valvuloplasty, and heart transplantation.

We are putting together the pieces for volume 4, to be published in 1991. It will feature new concepts about congestive heart failure, plus a variety of interesting articles related to coronary artery disease. Keep tuned in!

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Maleah Grover-McKay
David J. Skorton

GENERAL CONSIDERATIONS

SCOPE OF CARDIAC IMAGING AND ITS ROLE IN CARDIAC DIAGNOSIS

Modern cardiovascular practice requires precise and comprehensive diagnosis. With the exception of electrocardiography and electrophysiologic testing, the predominant laboratory approaches to cardiac diagnosis fall into the category of cardiac imaging methods.[1] Accurate evaluation of cardiac anatomy and physiology allows proper treatment. Important cardiac anatomic characteristics include cardiac chamber and great vessel size, myocardial mass, the presence of intracardiac masses (thrombus, tumor, or vegetation), valve anatomy, pericardial disease, coronary artery and bypass graft anatomy, and myocardial tissue composition. Significant physiologic variables, both at rest and during exercise or during coronary vasodilation, include diastolic filling characteristics, valvular stenosis and insufficiency, intracardiac shunts, regional and global myocardial contractile function, myocardial blood flow and coronary flow reserve, and my-

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ocardial metabolism. Currently available imaging methods permit precise delineation of gross cardiac morphology, coronary and graft anatomy, and chamber and valvular function (Table 1). Conventional imaging methods yield much less information on myocardial perfusion, metabolism, and tissue characteristics than several newer, evolving imaging techniques (Table 2). Therefore, evolving imaging techniques should increase the information available for physiologic investigation and management of patients.

WELL-ESTABLISHED AND EVOLVING CARDIAC IMAGING METHODS

When attempting to assess the relative merits of these imaging methods for evaluating the heart, knowledge of the "gold standard" for assessment of a given anatomic or physiologic variable is essential. Frequently, the independent standard against which newer methods are judged may be the established imaging methods, a practice that may not be appropriate. Pathologic examination provides the best standard for cardiac anatomy, but it is not available in most clinical investigations. Measurement of regional myocardial contractile function is most precisely performed with ultrasonic crystals,[2] a technique that is not applicable in patients because it requires surgical implantation of the crystals on and in the myocardium. Similarly, accurate measurements of regional myocardial blood flow, obtained using radiolabeled microspheres,[3] and of regional myocardial metabolism,[4] are not clinical procedures because one must obtain pieces of myocardium on which to perform the measurements. Therefore, because of the inherent limitations of clinical imaging investigations, it is sometimes difficult to assess the absolute or comparative efficacy of the different techniques. Nonetheless, based on currently available information, in this

TABLE 1. USEFULNESS OF CONVENTIONAL IMAGING TECHNIQUES

	CXR	ANGIO	ECHO	Planar IVG	Planar Perfusion Imaging
Cardiac Anatomy					
Chamber size	+	+++	+++	++	0
Myocardial mass	0	+	+++	+	0
Intracardiac masses	0	++	+++	+	0
Valve anatomy	0	++	++++	0	0
Pericardial disease	+	+	++	0	0
Coronary anatomy	0	+++	+	0	0
Graft patency	0	++++	0	0	+
Cardiac Physiology					
Diastolic filling	0	++	+	+++	0
Valvular stenosis/insufficiency	+	++++	+++	+	0
Intracardiac shunt	+	++++	+++	++	0
Myocardial function	0	+++	++	+++	0
Myocardial blood flow	0	0	+	0	++
Tissue characterization	0	0	+	0	0
Myocardial metabolism	0	0	0	0	0

0, No information; ++++, maximum information; angio, angiography; CXR, chest roentgenogram; echo, echocardiography; IVG, isotope ventriculography.

TABLE 2. USEFULNESS OF EVOLVING IMAGING TECHNIQUES

	Digital Angio	Computer-Assisted/ Transesophageal Echo	SPECT IVG	SPECT Perfusion Imaging	MRI	MRS	UFCT	PET
Cardiac anatomy								
Chamber size	+++	+++	++	0	++++	0	++++	++
Myocardial mass	+	+++	++	+	++++	0	++++	++
Intracardiac masses	++	++++	+	0	+++	0	++++	0
Valve anatomy	++	++++	0	0	+++	0	+++	0
Pericardial disease	+	+++	0	0	++++	0	++++	0
Coronary anatomy	++++	++	0	0	++	0	++	0
Graft patency	++++	+	0	+	+	0	++	++
Cardiac Physiology								
Diastolic filling	++	+	+++	0	+	0	+++	0
Valvular stenosis/insuf.	++++	+++	+	0	++	0	++	0
Intracardiac shunt	++++	+++	++	0	++	0	+	0
Myocardial function	+++	+++	++++	0	++++	0	++++	+
Myocardial blood flow	+	+	0	++	+	0	++	++++
Tissue characterization	0	++	0	0	++	++++	+	+++
Myocardial metabolism	0	0	0	0	0	++++	0	+++

0, No information; ++++, maximum information; angio, angiography; echo, echocardiography; IVG, isotope ventriculography; MRI, magnetic resonance imaging; MRS, magnetic resonance spectroscopy; PET, positron emission tomography; SPECT, single photon emission computed tomography; UFCT, ultrafast computed tomography.

chapter we discuss and compare selected aspects of standard and evolving cardiac imaging methods.

The well-established cardiac imaging methods include chest roentgenography, conventional cardiac angiography, echocardiography (including Doppler studies), first-pass and gated isotope ventriculography, and ^{201}thallium myocardial perfusion imaging. With the exception of two-dimensional echocardiography, these are all planar techniques. Planar images are acquired by detection of energy on a two-dimensional surface, such as film cassette or gamma camera crystal. The heart is a three-dimensional organ whose structure changes over time. Therefore, two-dimensional imaging techniques provide limited information because cardiac structures are superimposed.

Newer imaging techniques have been developed to overcome some of the limitations of established techniques. Evolving cardiac imaging methods include digital angiography, transesophageal and computer-assisted echocardiography, single-photon-emission computed tomography (SPECT), ultrafast computed tomography (CT), nuclear magnetic resonance imaging (MRI) and spectroscopy (MRS), and positron emission tomography (PET). An important advance has been the development of CT methods, both radioisotope and x-ray based. Three-dimensional information is obtained by the tomographic techniques because images are acquired in multiple planes and the data may be reconstructed either mentally or by computer.[5] Another major advance has been the capability to characterize the physiologic state of tissue by its structure or biochemistry, which was not possible using conventional imaging techniques. Computer-assisted echocardiography, MRI, MRS, and PET provide information about tissue composition, and MRS and PET provide information about tissue biochemistry.

Before discussing the use of particular imaging methods in specific clinical problems, some general strengths and weaknesses of the several modes of cardiac imaging can be considered. Echocardiography does not use radiation to produce images, but adequate images are not obtained in all patients studied. Conditions that make imaging difficult include obesity, lung disease, abnormal chest-wall configuration, calcification of cartilage, and advanced age. Transesophageal echocardiography yields high-quality images in these patients; however, the test is more invasive. Doppler ultrasound methods offer unique information about cardiovascular blood flow velocity, direction, and pattern. With isotope ventriculography, it is possible to obtain images in most patients. Studies may be limited by the inadequate labeling of the red cells that can occur in patients receiving heparin and in those who have received chemotherapy. Excess tissue such as fat or breast can attenuate counts, thereby decreasing image quality. The coarse spatial resolution of radioisotope methods precludes an assessment of fine structural detail, such as wall thickness or valve motion. Radiation is delivered, but the dose to the patient is low (Table 3). MRI can produce tomographic images in a multitude of imaging planes without using radiation or contrast material; however, image acquisition is slow, and images must be gated to the cardiac cycle to overcome the low signal-to-noise ratio. Therefore, the acquisition of acceptable images may be limited by the inability to acquire an adequate electrocardiographic (ECG) signal to obtain ECG-gated images and by the inability of the patient to lie still for sufficient data collection. Newer, rapid scanning methods may obviate some of these problems.[6] It may not be

TABLE 3 RADIATION EXPOSURE TO PATIENT FROM CARDIAC IMAGING STUDIES

X-Ray Techniques

Method	Total Dose (rads)
CXR	0.05-0.1
Ultrafast CT	2-10 rads/slice
Cardiac cath	1-130 (24)

Radioisotope Techniques

Method	Isotope	Dose mCi	Dose MBq	Target organ	Target organ dose (rads)	Total body dose (rads)
IVG	^{99m}Tc	20	740	marrow	1.0	0.3
Thallium	^{201}Tl	3	111	kidney	3.6	0.72
PET						
	^{82}Rb	120	4440	kidney	2.16	0.15
	^{15}O	30	1110	lung	0.28	0.05
	^{13}N	20	740	lung	1.67	0.02
	^{11}C	20	740	liver	1.10	0.24
	^{18}F	10	370	heart	1.98	0.06

CT, computed tomography; IVG, isotope ventriculography; MBq, megabequerel; PET, position emission tomography; Rb, rubidium; Tc, technetium; Tl, thallium

advisable to use MRI in patients with implanted metal devices, such as pacemakers. Ultrafast CT uses ionizing radiation and intravenous contrast material during rapid acquisition of tomographic images. Exquisitely detailed cardiac anatomy is visible with ultrafast CT. Obesity, motion of the patient, and arrhythmias degrade image quality. PET provides unique, noninvasive information about myocardial metabolism. Information about myocardial blood flow and gated studies to evaluate regional wall thickening can be obtained and compared with myocardial metabolism at the same anatomic location. The radiation dose to the patient is low; however, anatomic resolution is not as clear as with other techniques. Angiography offers high spatial and temporal resolution, but it involves radiation, contrast material injection, and catheterization. In addition, information obtained from angiography is predominantly anatomic.

COST-BENEFIT CONSIDERATIONS

The cost of a given cardiac imaging procedure has at least two components: the cost to the institution and the cost to the patient. Several components of cost to the institution exist, including the purchase price of the equipment, maintenance, personnel, and overhead (including space). The cost to the patient is not only monetary, but also includes the biologic risks. The monetary cost of an imaging procedure to the patient varies among institutions and depends on institutional costs that take into account the number of studies performed. The rel-