Quantitation of Left Ventricular Anatomy and Function by Ultrafast CT

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Abstract. Ultrafast computed tomographic (CT) scanning provides cross-sectional millisecond tomography, similar in many ways to cineangiography. The technique, which combines digital imaging and high resolution without the need for cardiac catheterization, is rapidly being validated. Fifty millisecond scans at rates of 3/second allow quantitation of left ventricular function using typical calculations including global and regional ejection fraction but ultrafast CT also has the potential for providing unique data concerning regional wall thickening, mass, and even regional myocardial perfusion. Furthermore, interventional studies with exercise and pharmacological agents have commenced and are currently being evaluated.

Key words: Left ventricular function—Ultrafast CT—Coronary heart disease

Cardiovascular disease represents the most pressing health care problem in the western world, accounting for 55% of all deaths in the adult American population [1]. The 1987 statistics from the American Heart Association estimate that almost 6 million Americans are suffering from atherosclerotic occlusive disease and the majority only experience symptoms relatively late (Table 1). A large proportion of the annual 85-billion-dollar cost to the nation is spent on a wide variety of diagnostic procedures aimed at evaluating this disease. However, despite the multiplicity of these techniques, our ability to characterize the fundamentals of cardiac physiology and to quantitate cardiac function in such patients remains inadequate. There is a critical need for precise methods for measuring the spatial and temporal components of left ventricular muscle dynamics and to develop more sensitive techniques for measuring regional myocardial perfusion, upon which muscle dynamics so greatly depend. This article examines the indices currently used to assess left ventricular morphology and function, and discusses the present and potential role of ultrafast computed tomography (CT) for improving the diagnosis of heart disease.

Measurements Used for Assessing Cardiac Function

Ejection fraction is the index most commonly used to evaluate left ventricular function. This index has one of the strongest correlations with prognosis and surgical risk. There is a wide spectrum of cardiac disorders that may reduce global ejection fraction below the accepted normal value of 55%. These include coronary artery disease with or without myocardial infarction, volume overload states, valve disease, the presence of myocardial hypertrophy, congestive cardiomyopathy, and various forms of congenital heart disease. The ejection fraction is the ratio of stroke volume (the difference between end-diastolic and end-systolic volume) to end-diastolic volume, expressed as a percentage. Normally the ejection fraction increases during stress, which is induced by exercise or pharmacological interventions. Patients with coronary artery disease usually show an abnormal decrease in ejection fraction during stress due to an increase in end-diastolic volume. Ultrafast CT can provide this same information using an almost noninvasive procedure that can be readily performed as an outpatient examination.

Ultrafast CT Scanning Protocols

Iodinated contrast medium (0.3–0.5 ml/kg body weight) is injected into the patient’s arm vein at a flow rate of 4–7 ml/sec. Fast CT scanning (17 scans/sec) is performed during held inspiration and timed...
to coincide with maximal enhancement of the left ventricle. Eight levels (1-cm-thick slices) can usually be scanned during one injection and include the entire ventricle from apex to base (Fig. 1). All the images at each level are acquired during only one heart cycle, which eliminates the need for any EKG-gated acquisition. Fast CT also avoids blurring due to increased noise associated with respiratory motion, which adversely degrades image quality and introduces errors in identifying myocardial wall boundaries. The image plane is flexible and operator selected—the degree of table angulation and tilt is registered and displayed on the scanner gantry near the patient. The patient’s EKG is continuously monitored and may be used to initiate, as well as program, the CT scan exposures, each of which is 50 m/sec in duration.

**Table 1.**

<table>
<thead>
<tr>
<th>CVD Type</th>
<th>Prevalence</th>
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<tbody>
<tr>
<td>Stroke</td>
<td>1,960,000</td>
</tr>
<tr>
<td>Primary Heart Disease</td>
<td>2,120,000</td>
</tr>
<tr>
<td>Coronary Heart Disease</td>
<td>4,810,000</td>
</tr>
<tr>
<td>Hypertension Disease</td>
<td>57,770,000</td>
</tr>
<tr>
<td>Other CVD</td>
<td>63,400,000</td>
</tr>
</tbody>
</table>

Number of Persons (in millions) 0 10 20 30 40 50 60

Source: American Heart Association

An independent off-line console provides reconstruction, display, and archival functions away from the control console used to operate the scanner. The sequential images obtained are subsequently displayed either individually in a frame-by-frame format, as shown in Fig. 2, or continuously as a closed loop movie. The matrix is currently 256 [2]. All the advantages of digital imaging are available, including multilevel image selection, EKG referencing of every scan exposure, not only at each level, but also at the corresponding phase of the cardiac cycle; electronic magnification is online, together with an extensive array of operator-interactive computer software facilitated by a trackball-guided cursor. Quantitation is performed at each level for calculating the area ejection fraction by planimetering the end-diastolic and end-systolic left ventricular cavity. Image selection can be done in one of two ways: these images can be selected by a computer program that automatically displays images close to 0% (end-diastole) and 40% (end-systole) of the R-to-R interval (Fig. 3); or the operator can display all the images at each level and manually select those with the largest and smallest cavity areas. Using the trackball-guided cursor, the operator then traces the left ventricular endocardial borders for each image, a process simplified by an automated edge-assist program. Since the slice thickness is known and the chamber areas are proportional to the volume of blood in the slice, the program automatically calculates the ejection fraction for each level. The global ejection fraction is obtained using Simpson’s rule by summing up all the volumes at each level for each of the two phases of the cardiac cycle. The results are then displayed in numerical and graphic form almost instantaneously on the cathode ray oscilloscope screen. The use of ultra-fast CT to determine left and indeed right ventricular ejection fraction (from the same study) has been validated [2]. It is important to discuss the methods recommended for reliably identifying the endocardial boundaries. This aspect of quantitation should be critically scrutinized for every imaging modality. Reproducibility is critical; consistent errors are forgiving aspects of any program, as corrections can be made for them. This is the approach currently used for several established modalities.

**CT-Boundary Detection—Strengths and Pitfalls**

Quantitative studies performed using early conventional whole-body CT scanners explored this important issue [3, 4]. The objectives have not changed, although several methods have been successfully