Noninvasive Coronary Angiography Using Computed Tomography

Ready to Kick It Up Another Notch?

John A. Rumberger, PhD, MD

Electron beam (computed) tomography (EBT) has for some time been the only well-validated computed tomography (CT)-based imaging method that could reliably characterize cardiac mechanics and perfusion and provide insight into coronary atherosclerosis. The latter was accomplished initially by defining coronary artery calcification (CAC) and its relationship to atherosclerotic plaque. However, since the initial publications by Achenbach et al and Schmermund et al, EBT has been investigated increasingly as a means to perform noninvasive three-dimensional (3D) arteriography of the large epicardial coronary arteries, to examine coronary artery bypass grafts, and to characterize coronary artery anomalies. The published sensitivity and specificity of EBT for obstructive coronary disease as compared with invasive coronary arteriography has ranged from 85% to 90%. Recent changes in protocols to perform 1.5-mm slice imaging as opposed to the traditional 3.0-mm slice imaging, as well as development of improved post-processing methods, have further enhanced the robustness of the method and provided more reliable and more complete epicardial artery interrogation (personal experience and personal communication, Dr Matthew Budoff, Harbor UCLA Medical Center, Los Angeles, Calif, 2002).

Improvements in traditional CT imaging have likewise been far from slow, especially in the past several years, and have challenged the dominance of EBT in the cardiac imaging arena. Spiral or helical CT was plagued for years with x-ray source rotational speeds 10 times slower than EBT, and thus was not able to avoid image blurring due to cardiac motion. Additionally, single or even dual slice imaging with the older versions of spiral CT scanners required two or more breathholds just to complete thin sectioning of the heart.

Considerable improvements in rotational speed and the advent of multi-slice spiral CT systems (MSCT) have been so rapid that the major equipment companies introduce “new and improved” devices as often as twice per year. The latest generation of MSCT scanners now has rotational speeds of about 400 to 500 ms per revolution and has increased the number of tomographic slices imaged per rotation to 16 or more. Rumors in the industry suggest that scanners with 32, 64, or even higher numbers of multiple detectors capable of imaging similar numbers of slices may be practical in the next several years.

The ability to scan multiple tomographic slices per sweep or rotation of the x-ray source considerably reduces the time necessary to complete scans of the organ under question and thus allows implementation of thinner and thinner tomographic imaging. However, no matter how “thin” these slices are, imaging of the heart, which is in constant motion, is still dictated by the need to image very quickly to avoid inherent motion artifacts in the tomographic images which can then confound 3D registration of the tomographic data.

In this issue of Circulation, Nieman and colleagues from Rotterdam report on their initial experience in 59 patients using a new 12-slice helical CT scanner. This MSCT scanner has a rotational speed of 440 ms and can achieve cardiac tomographic slice thicknesses of <1.0 mm. These researchers realized that despite improvements in rotational acquisition speed above most current helical scanners, resting heart rate would still be a major factor in image quality. To avoid this additional and potentially confounding factor, individuals with a resting heart rate >65 beats per minute were given 100 mg of oral metoprolol 1 hour before the procedure (average heart rate during study of 56 beats/min). Fifty-eight of 59 patients examined had successful and analyzable data sets. Subsequent analysis showed a sensitivity and specificity for defining luminal obstructive disease of 95% and 86%, respectively, as compared with traditional coronary arteriography.

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TABLE 1. Current “Characteristics” of EBT Versus MSCT

<table>
<thead>
<tr>
<th>Modality</th>
<th>True Temporal Resolution</th>
<th>Spatial Resolution</th>
<th>“Practical” Heart Rate Limitations for a Diagnostic Study</th>
<th>Cardiac Function and Myocardial Perfusion</th>
<th>Radiation Exposure, mSv</th>
<th>Clinical Availability</th>
<th>Coronary Calcium Quantitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBT</td>
<td>50–100 ms</td>
<td>1.5 mm vessels</td>
<td>50–100 beats/min</td>
<td>Yes</td>
<td>1–2</td>
<td>Increasing slowly</td>
<td>Yes, extensively validated</td>
</tr>
<tr>
<td>MSCT</td>
<td>230–1000 ms</td>
<td>1.0 mm vessels</td>
<td>&lt;60–65 beats/min</td>
<td>No</td>
<td>2–10 (depending on method)</td>
<td>Expanding rapidly</td>
<td>Yes, limited validation</td>
</tr>
</tbody>
</table>

The data provided in the article by Nieman et al., coupled with the prior and continuing data from EBT scanning, beg the question, “Is coronary CT arteriography (CTCA) ready to kick it up another notch?”

Before this question can be further addressed, we need to be sure of the current playing field, which is likely to continue to evolve in the coming years for both EBT and MSCT. Table 1 lists some important current issues related to these methods addressing “true” temporal resolution, spatial resolution, practical heart rate limitations for application, issues of functional/perfusion imaging in the same scanning session, and use of CAC for plaque quantitation in addition to luminal evaluation, radiation exposure, and availability.

The most glaring differences between EBT and MSCT are still considerable differences in temporal resolution, which then influence practical limits on resting heart rate in subjects under examination. EBT has superior temporal resolution, but at the present time, MSCT has superior spatial resolution. Nieman and colleagues administered metoprolol orally to nearly 60% of the test subjects before performing the study to induce relative bradycardia with resting heart rates at <60 beats/min. Such a practice of administering high dose β-blockers before or in conjunction with the study solely to lower the resting heart rate so that the study can be performed adequately may limit use of even the latest MSCT to hospital-based imaging centers or specialized outpatient centers with adequate support for monitoring of the patient before and after the procedure. Additionally, only a minority of patients studied by Nieman et al could be examined using prospective ECG gating, and most required retrospective review of multiple-gated images to choose tomograms that displayed the least apparent coronary artery motion artifacts. Such a practice also significantly increases the radiation dose substantially above that for EBT. Using MSCT and retrospective ECG-gating, these values may approach that of invasive coronary arteriography (the average radiation dose was approximated at 7 mSv in the investigation by Nieman et al.). At present, unlike EBT, MSCT cannot perform ventricular functional imaging or perfusion imaging during the same scanning session. Finally, availability may be a major issue defining broad-based clinical utilization. Given its robust imaging of other parts of the body and lower initial cost, MSCT scanning is expanding rapidly, and its regional availability eclipses the current availability of EBT. The total contrast injected for the noninvasive arteriogram is around 150 mL for EBT and MSCT, which is similar to that used for an intravenous pyelogram. Although these doses are reasonable for many radiographic procedures, it will require that the patient’s creatinine be known before the study.

Despite the cogent issues related to CT scanning architecture and developing EBT/MSCT methodology, in my opinion, CTCA is ready to advance to the next step and “kick it up another notch.”

It is clear that the sensitivity and specificity of CTCA, under appropriate circumstances and in the right patients, is equivalent and perhaps superior to the use of stress testing using nuclear or echocardiographic imaging. As with many techniques that define their validity by comparisons to select patients undergoing clinically indicated coronary arteriography, the issue of referral bias must be borne in mind. As these alternative methods are introduced into clinical practice, the sensitivity may be lessened because of the referral bias inherent in their validation, but the specificity is often significantly improved. Such has been the case when attempting to predict coronary stenoses using CAC by EBT.

The fundamental issue here is that there must be an understanding of how and where CTCA may fit into clinical practice and this must be the “next step” before prime time! In my opinion, the next step needs to be cautious but conservative application of these methods into selected clinical practice situations. Although there has been discussion for some time about how these methods should be performed and how they should be analyzed, we need to keep track of why they are being investigated in the first place.

Although the use of stress testing, particularly perfusion and functional imaging, often has clinical value over and above merely defining the physiological significance of coronary artery stenosis, the vast clinical goal for such methods is as a noninvasive alternative to invasive arteriography to affirm or deny the presence of coronary obstructive disease. If there were a way to “visualize” the stenosis in a noninvasive, straightforward, practical, and safe manner, then it would in many instances be considered a very strong alternative to stress testing or an adjunct to conventional diagnostic coronary arteriography in low to intermediate likelihood individuals. Along this line, I offer some “potential” applications for CTCA in Table 2. Of course, as with any potential list such as this, proven validity will require additional investigations and comparison with more traditional methods.

The advantages of CT are that one is able to define CAC, a surrogate to defining mural atherosclerotic plaque burden, as well as the extent to which larger epicardial vessels may be narrowed. Functional and perfusion imaging may also be considered at the same time (currently limited to EBT...
imaging). Cardiovascular medicine specialists will, by default, need to learn the “new language” of 3D imaging such as MIP (maximum intensity projection), MPR (multi-planar reformation), SSD (shaded surface display), and VRT (volume rendering technique), and learn to cope with simultaneous opacification of coronary veins along with the arteries. Even the most advanced angiographers may have to go “back to school” to get this training, and I and others have voiced opinions to advocate implementation of a mentoring system to accomplish these goals.13

The disadvantage of CTCA is that it is unlikely at any time in the foreseeable future to achieve the resolution of cine film and is likely thus limited to examination of epicardial arteries 1 to 2 mm in diameter or larger. Subtle details of small collateral vessels, small coronary branch arteries, and regions such as distal anastomotic sites of bypass grafts may be lost. Furthermore, moderate to extensive focal coronary calcium may obscure adequate visualization of the lumen, and it is also unlikely that CTCA will be able to resolve in-stent stenoses.

However, despite these issues, we have seen considerable improvements in CT cardiac imaging even over the past few years, and the future remains secure as we “kick it up another notch.”

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References


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