Cardiac CT: Where are we today and where are we going?

Not only have advances in scanner technology made cardiac CT a clinical reality, but automated software has reduced image postprocessing time to mere minutes.

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The state of the art of computed tomography (CT) is constantly changing. Today, new technology is being introduced every 12 to 18 months, a pace that is expected to continue, if not accelerate.

Cardiac CT is driving innovation. Although CT is indispensable for the evaluation of the liver, pancreas, lung, and musculoskeletal system, manufacturers are intensely focused on meeting the clinical demands of cardiac imaging.

Cardiac CT demands high temporal resolution, high spatial resolution, and true volume data sets. Today, the typical rotation time is approximately 0.33 seconds, slice thickness is submillimeter, and data sets consist not of hundreds of slices, but thousands. Isotropic resolution enables cardiac CT data to be acquired in a single plane but viewed with the same high resolution in any plane.

Some of the future innovations in CT are predictable—faster scanning, for example—but others are not. New concepts constantly develop, from multiple X-ray tubes to new detector displays and arrays. We truly are in an exciting era of technologic achievement in cardiac CT.

Technologic advances

The evolution in CT technology over nearly 2 decades has been impressive. Single-slice spiral CT was introduced in 1989. It was another 10 years before 4-slice CT was introduced. After that, it took only 3 years until the release of 16-slice CT and another 2 years until the release of 64-slice CT. It took just 1 year to progress from 64-slice CT to dual-source CT.

In the era of 4-slice scanners, cardiac CT was in a proof-of-concept phase. Choi et al[1] noted that although interest in cardiac CT was high, artifacts and other pitfalls caused significant problems for the accurate diagnosis of coronary artery disease. Sixteen-slice scanners were the first to truly reveal the clinical potential of cardiac CT.[2] Still, most clinical studies were published by investigators from just a few select institutions.[3-5]

Sixty-four slice scanners made cardiac CT a viable clinical tool for use in medical practices across the country. A recent study by Nikolaou et al[6] reported that, with 64-slice CT, per-patient sensitivity, specificity, and negative predictive value were 97%, 79%, and 96%, respectively. Moreover, some 90% of coronary segments were assessable by CT. For the detection of stenoses >50% and >75%, per-segment sensitivity was 82% and 86%, respectively. Per-segment specificity and negative predictive value were as high as 95% and 97%, respectively.

Ehara et al[7] found the diagnostic accuracy of 64-slice CT to be similarly high. In comparison with invasive angiography, the sensitivity of CT angiography (CTA) was 90% for the detection of stenosis >50%. Specificity was 94%; positive predictive value, 89%; and negative predictive value, 95%.

Defining success

The design of 64-slice CT scanners differs from manufacturer to manufacturer. For example, the GE LightSpeed VCT uses a 64-detector array with 0.6-mm detectors and 40-mm coverage per rotation (GE Healthcare, Waukesha, WI). Isotropic resolution is 0.35 mm. The Siemens Sensation 64 uses a floating focal spot to create 2 overlapping beam projections on a 32 × 0.6-mm array feeding 32 channels. The isotropic resolution is ≤0.4 mm (Siemens Medical Solutions USA, Inc., Malvern, PA).

Each institution must determine which technology best suits its needs. It is important to remember, however, that the success of cardiac CT depends on far more than such technical factors as the number of detectors, slice thickness, rotations per second, and spatial resolution.

A successful cardiac CT scan begins when the study is ordered and ends when the correct interpretation is sent to the referring physician, and the patient is managed based on those results. The number of detectors does not necessarily

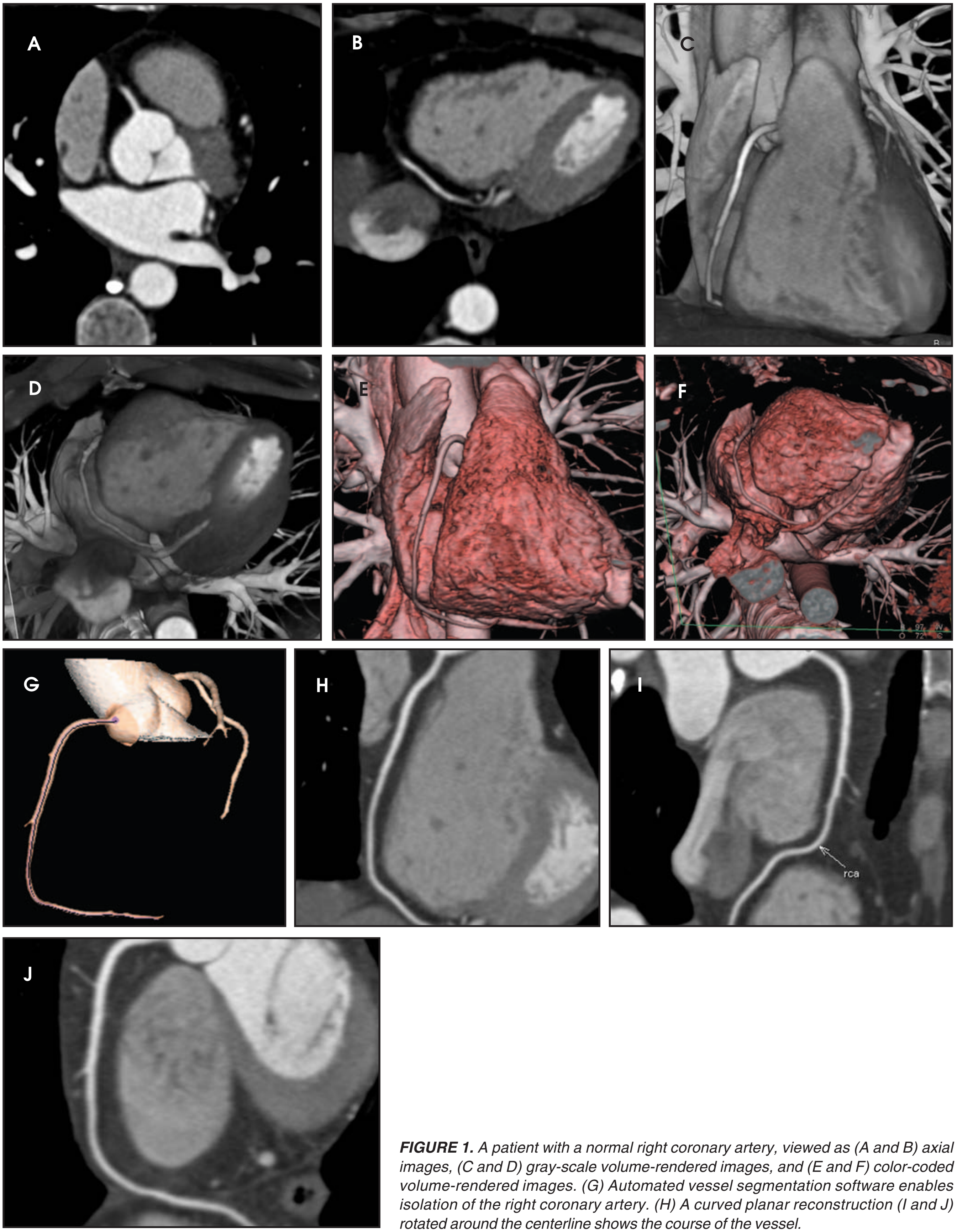

FIGURE 1. *A patient with a normal right coronary artery, viewed as (A and B) axial images, (C and D) gray-scale volume-rendered images, and (E and F) color-coded volume-rendered images. (G) Automated vessel segmentation software enables isolation of the right coronary artery. (H) A curved planar reconstruction (I and J) rotated around the centerline shows the course of the vessel.*

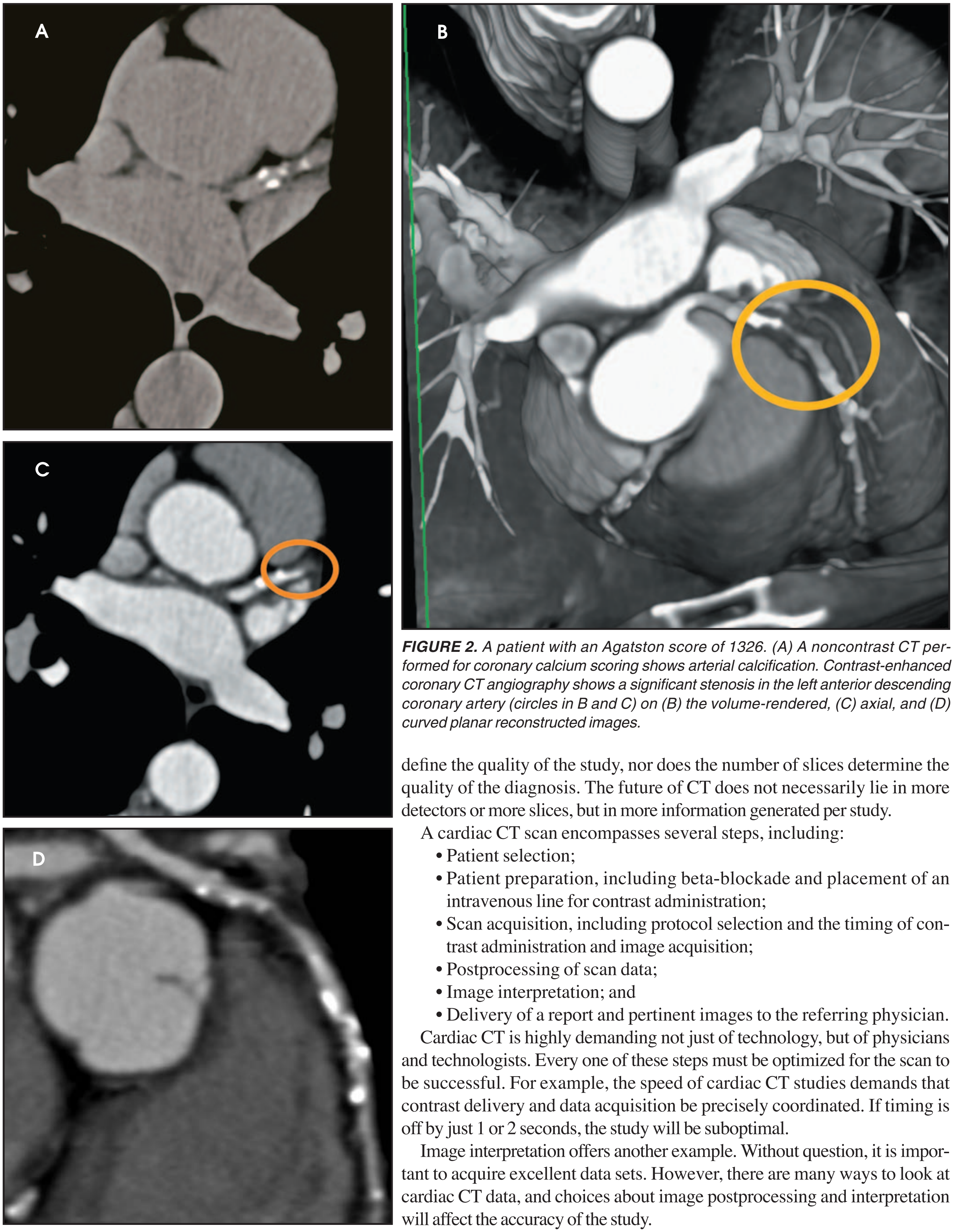

FIGURE 2. A patient with an Agatston score of 1326. (A) A noncontrast CT performed for coronary calcium scoring shows arterial calcification. Contrast-enhanced coronary CT angiography shows a significant stenosis in the left anterior descending coronary artery (circles in B and C) on (B) the volume-rendered, (C) axial, and (D) curved planar reconstructed images.

define the quality of the study, nor does the number of slices determine the quality of the diagnosis. The future of CT does not necessarily lie in more detectors or more slices, but in more information generated per study.

A cardiac CT scan encompasses several steps, including:

- Patient selection;
- Patient preparation, including beta-blockade and placement of an intravenous line for contrast administration;
- Scan acquisition, including protocol selection and the timing of contrast administration and image acquisition;
- Postprocessing of scan data;
- Image interpretation; and
- Delivery of a report and pertinent images to the referring physician.

Cardiac CT is highly demanding not just of technology, but of physicians and technologists. Every one of these steps must be optimized for the scan to be successful. For example, the speed of cardiac CT studies demands that contrast delivery and data acquisition be precisely coordinated. If timing is off by just 1 or 2 seconds, the study will be suboptimal.

Image interpretation offers another example. Without question, it is important to acquire excellent data sets. However, there are many ways to look at cardiac CT data, and choices about image postprocessing and interpretation will affect the accuracy of the study.

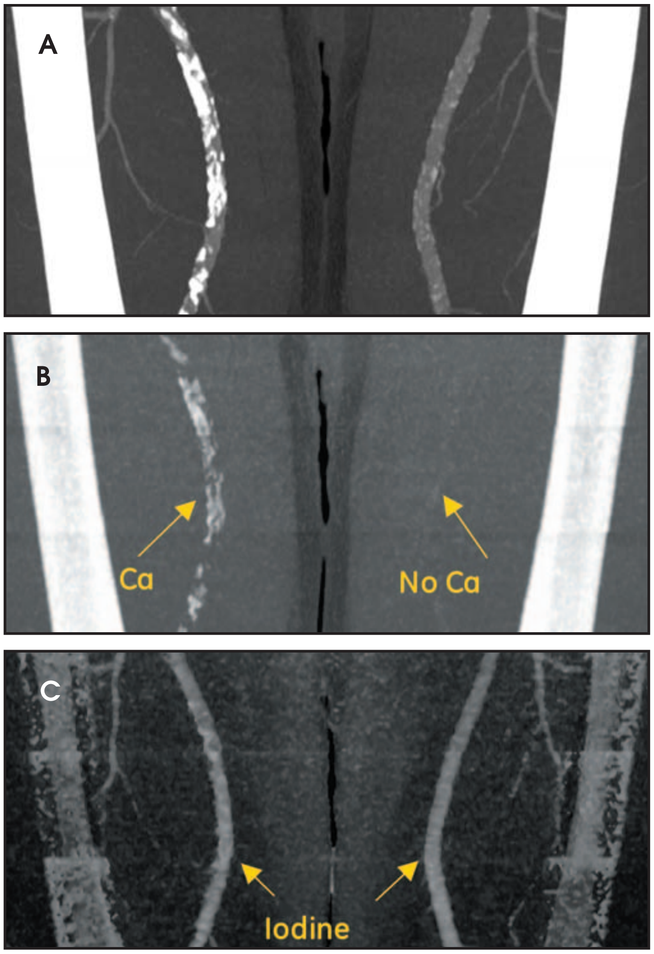

FIGURE 3. *The acquisition of volume dual-energy images at 80 kV and 140 kV on a 64-slice CT scanner using a generator-switching technique. This peripheral runoff study shows how calcium [Ca] is differentiated from iodinated contrast, enabling subtraction of arterial calcifications from the image and assessment of luminal patency. (A) The original CT angiogram shows calcification and contrast. (B) This image illustrates the segmentation of the calcium from the data set. (C) The final image depicts the segmentation of only the iodine from the data set. (Images courtesy of Dean Haas, GE Healthcare, Waukesha, WI.)*

Figure 1 shows a patient with a normal right coronary artery, viewed as an axial image, a gray-scale volume-rendered image, a color-coded volume-rendered image, an isolated vessel, and a curved planar reconstruction.

The ability to work interactively with the data and use various rendering techniques is critical. Today, that job is easier and faster than ever. A study that just a few years ago took 45 minutes to interpret can now be completed in 5 minutes, thanks to advanced software tools. At Johns Hopkins, we have always emphasized the important role of physicians in image postprocessing. Technologists do an excellent job of acquiring a high-quality data set, but it is critical that physicians work interactively with the data set to optimize visualization as they create and interpret various renderings and projections, including 4-dimensional displays.

Calcification

Cardiac CTA is not a perfect technique. Studies may fail because of technical factors (such as scanner malfunction), operator factors (such as technologist error or inadequate scan protocols), or patient factors (such as obesity or a high heart rate). In addition, extensive coronary artery calcification often limits the ability to analyze image data, though not always. The patient in Figure 2 had an Agatston score of 1326 on coronary calcium scoring. Still, contrast-enhanced coronary CTA showed a significant stenosis in the left anterior descending coronary artery on several different visualizations.

New dual-energy CT offers a possible solution to the problem of heavily calcified coronary arteries. Because X-ray absorption is energy-dependent, changing the kilovoltage of the X-ray tube results in material-specific changes in attenuation. By using different tube energies (80 kV and 140 kV), dual-energy CT is able to separate calcification from iodinated contrast material.

One implementation of this concept is dual-source CT, introduced last year by Siemens Medical Systems. A dual-energy scanner uses 2 X-ray tubes to simultaneously acquire data at 2 different energy levels. Temporal resolution is very high—83 msec.

Dual-energy CT can be accomplished without the use of dual X-ray sources, however. GE Healthcare is investigating the acquisition of volume dual-energy images on existing 64-slice CT scanners, using a sophisticated generator-switching technique. An example of a peripheral runoff study using this technique is shown in Figure 3.

Radiation

The effective radiation dose associated with coronary CTA is relatively high—approximately 15 mSv. There are many different dose reduction strategies, including X-ray beam filtration, X-ray beam collimation, X-ray tube current modulation and adaptation for body habitus (automatic exposure control), peak kilovoltage optimization, improved detection system efficiency, and noise reduction algorithms.[8] These strategies will not be discussed here, other than to point out the importance of building automatic dose reduction tools into scanner technology, rather than relying on their implementation by individual operators.

Today, the most common strategy for reducing radiation exposure is dose modulation, a technique in which X-ray tube output is 100% during diastole, but only 20% during systole. The result is a reduction in radiation dose of 30% to 50%.

Siemens' dual-source technology reduces dose by approximately 50%. GE Healthcare has developed an axial step-and-shoot acquisition that also reduces radiation dose by approximately half, to 5 to 7 mSv. Using this technique, data are acquired only in the diastolic phase of the cardiac cycle. Continued technological developments will undoubtedly play a critical role in further reducing the radiation dose.

Postprocessing

Although postprocessing tools make it much easier to view cardiac CT data in multiple renderings and from multiple perspectives, they were initially designed for use in larger vessels, such as the aorta. Quantification tools used to determine percent stenosis were either very limited or inaccurate for vessels with a diameter ≤4 mm. New tools that will enable accurate quantification of the severity of coronary stenosis are necessary.

Better techniques are also needed for going beyond static images to 4-dimensional imaging—a step that will enable assessment of not only cardiac morphology but also function, including that of native and prosthetic heart valves.[9]

As postprocessing tools improve, cardiac CT has the potential to be a one-stop shop, not only offering quantitative measurement of stenosis, but also analysis of left ventricular function, characterization of coronary artery plaque, measurement of cardiac chamber volume and wall thickness, and assessment of myocardial perfusion, through color polar mapping.

None of these techniques will be used in clinical practice if the interpretation of a cardiac CT study is too time-consuming. New technology and advanced analytical software will be necessary in order to simplify such tasks as automatic vessel segmentation and vascular mapping. Artificial intelligence must be perfected for the quantification of coronary stenosis, and for the calculation of ventricular volumes and ejection fractions with a simple touch of the appropriate chambers on a workstation screen, rather than through the drawing of lines to define endocardial borders.

Conclusion

Whatever the technologic developments of the future, it is critical to understand that cardiac CT is not a spectator sport. Physicians who want to be successful in performing cardiac CT studies must be aggressively involved at every level, defining and overseeing the details of patient preparation and data acquisition, and actively participating in image postprocessing.

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