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Optimal operation of a cardiac CT center

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LEARNING OBJECTIVES

Upon completion of this activity, participants should be able to:

1. Enumerate the advantages of a team approach to cardiac imaging
2. Describe a patient's passage through the process
3. Explain the importance of voxel size and shape in reconstruction of a CT scan
4. Compare contrast and noncontrast image acquisition

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Neither Dr. Boxt nor Dr. Green has any significant financial arrangement or affiliation with any manufacturer of any pharmaceutical or medical device nor are they affiliated in any manner with any provider of any commercial medical or healthcare professional service.

The revolution in medical diagnosis that occurred with the development of computed tomography did not spill over into clinical cardiac imaging for nearly 25 years. Early CT scanners were slow and acquired image data at low resolution. The first scanners required about four minutes to obtain two image slices at a time; despite low image resolution (80 x 80 pixels), computation time was nearly seven minutes per picture. Changes in x-ray-beam geometry and increases in gantry rotation speed shortened acquisition time and increased spatial resolution, allowing the tremendous growth in CT applications to include neurologic, musculoskeletal, and abdominal and noncardiac chest disease. By the 1990s, multislice CT scanners became available, allowing coverage of whole organs within a single breath-hold. Faster rotational speeds and improved detectors leading to 64-slice CTs provided the means for fast and accurate visualization of the coronaries.

The nature of the 64-detector scanner is significant. This device acquires image data in cubic picture elements, so-called isotropic voxels. The importance of the isotropic voxel lies first in its small size, which allows high spatial resolution during both image acquisition and postprocessing, but also in the fact that these elements are themselves cubes. That is, they are the same dimension on each side. Thus, reconstruction of image data in any arbitrary tomographic plane can be performed without introducing an artifact caused by differences in the length of an individual voxel. This is important for the diagnosis of coronary heart disease.

The epicardial coronary arteries and their major branches meander along the surface of the heart, their path is not necessarily within one particular plane. In other words, reconstruction in a series of arbitrary and frequently changing planes is needed in order to get a longitudinal or cross section view of a vessel. The ability to do this is very closely tied to small voxel size. No matter how small a voxel may be, however, when a series of them are included in a reconstruction, the shape of the voxel; i.e., whether it is a cube or a rectangular solid, has a significant effect on the appearance of the reconstruction.

ECG-gated CT acquisition provides

image data sets which can be reconstructed at intervals throughout the cardiac cycle. So rather than acquiring a stack of image slices at one particular interval of the cardiac cycle, we acquire stacks of image slices, each reconstructed at a different place in the cardiac cycle. Display in a loop mode gives the appearance of cardiac motion ("cine" display). Quantitative analysis of segmental changes in myocardial wall thickness and radial shortening, as well as ventricular chamber area, provide the tools for functional ventricular analysis.

A TEAM APPROACH

The clinical potential of cardiac CT does not depend exclusively on the engineering attributes of a particular scanner or the injection protocol for a particular patient. Rather, the environment in which a scanner is operated, and in particular the team performing and interpreting the data obtained by the scanner, play an important role in the integration of cardiac CT scanning into the clinical practice of cardiac medicine. In our institution, cardiac CT is performed and interpreted in a collaborative environment between cardiology and radiology.

This collaboration covers patient scheduling and preparation, and examination performance, supervision, and interpretation. Our scanner is dedicated to the evaluation of patients with cardiac disease. Our team includes nurses with cardiac ICU experience and technologists with catheterization laboratory and body CT backgrounds. A radiology or cardiology attending physician, cardiology and/or radiology fellow, and radiology resident participate in the management of patients through the scanning process and interpretation of the examination itself.

The clinical collaboration between cardiology and radiology makes sense on many levels. CT examination of the heart can be performed safely and reliably when careful attention is paid to patient selection and preparation and image acquisition protocol. Accurate and complete diagnosis is enhanced by understanding the physical principles of image formation as well as the clinical problem that initiates the request for examination and the effect of pathophysiologic processes on the images obtained at examination. Clearly, cardiology and radiology bring complementary expertise to the CT examination. Radiologists are traditionally trained in the physics and science of image formation, and the principles of CT image interpretation. Cardiologists are trained in the diagnosis and management of patients with cardiac disease, and so traditionally have expertise in conventional coronary arteriography and echocardiographic and nuclear tomographic cardiac imaging.

The clinical collaboration between cardiology and radiology makes sense on many levels

The value of this collaboration is reflected in the manner in which patients are managed in our center. Our diagnostic imaging is interpreted in terms of anatomic and physiologic abnormality, and reported in the context of the patient's clinical situation.

STARTING OFF RIGHT

Cases are booked on a dedicated phone line. At the initial phone call, the patient's name, date of birth, referring physician, indication for examination, history of previous catheterization and/or cardiovascular intervention, and any previous CT examination (with or without contrast-enhancement) are obtained. In our institution, renal function tests are not required for patients younger than 65 years. In those over 65, we request a recent report of serum BUN, creatinine, and corticotropin-releasing factor (CRF). Generally, we book two days ahead in order to complete precertification paperwork and order pertinent medical records, when indicated. Emergency and elective inpatients (predominantly from our consult service) can be accommodated on short notice. Our ratio of outpatient-to-inpatient cases is about 10:1. We do not book cases without physician referral. When cases are booked, patients are instructed to take all medications the morning of their examination, and to refrain from eating for three hours prior to examination.

Patients present to our department one half-hour prior to their scheduled time. They are registered into the hospital information system, and an examination request form with unique identifiers, including medical record number and case accession number, is generated. After registration, they are escorted to our CT facility where they are introduced to our nurse. After the patient changes into a hospital gown, vital signs are obtained, and a high-flow 20 gauge intravenous cannula is placed in the right antecubital fossa.

The first clinical interaction with a physician is with either a radiologist or cardiologist member of our team. At this time, we engage in a more detailed discussion of patient signs and symptoms and the nature of the examination is outlined. Our physician discusses the technique of cardiac CT with the patient, including risks and potential benefits of the procedure. The physician emphasizes the steps of the exam, making sure the patient understands the gantry rotation noise and the sensation of contrast administration during the test dose and actual diagnostic examination. The use of intravenous β-blockade (when indicated) and sublingual nitroglycerine are described.

To better assess the risk of contrast administration and to aid in choosing an appropriate contrast agent, we elicit a history of previous contrast administration or adverse reaction to medication. Informed consent is obtained, and the patient is transferred to the scanner room, where he or she is introduced to our technologist. The patient is placed on the scanner table and made comfortable with pillows placed beneath the head and (slightly flexed) knees. ECG leads are attached to the anterior chest wall, the injector is attached to the intravenous line, and the patient's arms are raised over his or her head. The patient is instructed to take a deep breath and hold it at peak inspiration. Heart rate and blood pressure are constantly monitored. If the resting heart rate is greater than 60 beats per minute, 5-mg doses of metoprolol are administered by IV until the rate lowers to 60 bpm. In the rare instance when rate control cannot be obtained, the patient is discharged from the CT lab with a prescription for a two to three-day course of oral β-blockade, and the exam is rescheduled. Otherwise, the examination is now ready to begin.

BEYOND THE HEART'S WALLS

The complete examination commences with a noncontrast-enhanced scan of the chest. We feel that a complete examination is not limited to the heart and use this opportunity to evaluate for calcification in the lungs, chest wall, and pleura and pericardium. These images are automatically formatted into slices 2.5 mm thick, and the field-of-view is open to view the entire chest. In addition, the same image data are reconstructed over the heart itself, with a smaller field-of-view, for coronary calcium scoring. If heart rate control is maintained, 0.4 mg of nitroglycerine is administered sublingually. Following this, we perform a test injection of 20 cc of contrast injected at 5 cc/sec to time contrast arrival at the aortic root.

The patient is instructed to take a deep breath and hold it, and the contrast is administered. One image per second is generated, and a region of interest placed over the aortic root is analyzed for attenuation. The time to peak aortic opacification is measured, and the delay for the contrast administration calculated. In order to obtain the maximum vasodilatory effect of the nitroglycerine administration, the full contrast-enhanced acquisition is obtained immediately after calculation of the timing delay. Intravenous contrast is a potent vasodilator which has a direct depressive pharmacologic effect on left ventricular myocardium function. Deep inspiration affects venous return to the heart, which also has a depressive effect on cardiac output. Nitroglycerine affects heart rate and blood pressure. Careful attention must be paid to the order and timing of these aspects of the examination in order to minimize the negative effects these interventions have on the production of high-contrast cardiac CT images.

We use a three-phase protocol for intravenous contrast administration: 50 cc of nonionic 350 mg/cc I contrast is administered at 5 cc/sec, followed by 20 cc injected at 3.5 cc/sec, flushed by 50 cc of normal saline injected at 3.5 cc/sec. We find this protocol reduces contrast within the superior vena cava and right heart, eliminating streak artifacts, but retains enough contrast in the right ventricle to allow identification of the interventricular septum and characterization of right ventricular structure. After the injection protocol is completed, the patient is instructed to take in a deep breath and hold it, and then imaging begins. When the injection has been completed, the axial acquisition data is inspected by the responsible physician, and if it is of adequate quality, the examination is complete. ECG leads are removed, the IV discontinued, and the patient is escorted out of the scanner area. Unless an untoward event occurs, by the time the patient has changed back into street clothes, he or she is ready to have vital signs checked a last time and be discharged from the lab.

IMAGE INTERPRETATION

By the time the patient has left the scanner area, the noncontrast-enhanced chest examination and coronary calcium scoring images have been passed to the reading area for interpretation. Immediately after completion of the contrast-enhanced scan, the image data obtained between R-waves is transferred for analysis and then the axial acquisition data are reconstructed in 10% increments from 5% to 95% of the time between R-waves, and passed to a workstation for analysis.

Analysis of each case is performed in much the same order. We begin by producing 3D surface-rendered reconstructions of the coronary arterial tree. In cases with coronary arterial bypass grafts, we produce trees of the epicardial coronary arteries and the bypass grafts. These reconstructions are displayed in oblique projections to demonstrate pertinent findings, such as patent or stenosed arterial segments, or patent or stenosed surgical anastomoses. Screen saves depicting these findings are produced and included in reports sent to referring physicians.

These surface-rendered reconstructions are of great value for diagnosis if there is no vascular calcification or intraluminal stent within a segment of concern. That is, while artifact caused by metal or calcium may not degrade the surface-rendered figure, it may severely impair our ability to judge luminal narrowing or focal occlusion.

We then obtain multiplanar reformatted images of each individual artery and major side branch, as well as bypasses. These reconstructions provide the foundation for our diagnostic reporting. Vessels are analyzed in longitudinal section and in reconstructed cross section. This allows evaluation of luminal patency as well as characterization of the arterial wall in these areas. The heart and pericardium are evaluated in axial tomographic section. This allows evaluation of cardiac structure, and estimation of chamber enlargement and wall thickening or thinning. Whenever necessary, oblique tomographic sections are reconstructed for detailed analysis of cardiac structure.

Cardiac function is evaluated by visual inspection and semiautomated morphometric analysis. Axial acquisition images are reconstructed into sections parallel and orthogonal to the intrinsic left ventricular axes and displayed in loop mode for a cine cardiac examination. Regional wall motion abnormalities and regional myocardial thickening are evaluated in this manner. Cardiac chamber volumetric analysis is performed by automated and operator-interactive endocardial and epicardial planimetry of acquired and reconstructed images.

The findings of the noncontrast-enhanced chest examination, coronary calcium score, and contrast-enhanced cardiac examination are recorded in a patient report, which is faxed to the referring physician immediately on completion of the review. Selected images depicting pertinent positive and negative findings are selected and printed on paper. These are collated with a hard-copy report of the results, and the package is mailed to the referring physician within two work days.

Multiplanar reformatted images provide the foundation for our diagnostic reporting

GREATER THAN THE SUM OF PARTS

As we have discussed, the collaboration between radiology and cardiology in our facility includes the technical expertise of radiologists and cardiologists as well as technologists and nurses. We have brought the varied as well as common backgrounds of our team members to bear on administrative issues such as case booking and reporting; on clinical issues such as examination and contrast injection protocols; and on examination interpretation. There is nothing magical about the performance of cardiac CT. However, collaboration increases the chances of a successful venture, and enhances the quality of the service provided. There is no area of medical practice that calls out for collaboration as loudly as cardiac CT. Those physicians who hear this call will find satisfaction and clinical success.

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