Innovations in Cardiac Computed Tomography: Cone Beam CT/Volume CT and Dual Source CT

Jaron Chong, Medicine 2010 and Jason Essue, Medicine 2011
Reviewed by Dr. Ali Islam

Two recent innovations in cardiac Computed Tomography (CT) of Cone Beam CT or Volume CT (VCT) and more recently, Dual-Source CT (DSCT) offer physicians clinically viable alternatives to invasive coronary angiography for the imaging of coronary artery stenoses. Performing the procedure termed CT angiography or Multi-Detector CT angiography, both technologies provide the necessary spatial and temporal resolution, in addition to a variety of other advantages to image the cardiac patient. Both report improvements over conventional CT with reduced acquisition time, greater image quality, and with DSCT an ability to perform cardiac imaging on tachycardic patients as well as reduce radiation dose, all without compromising image quality. While only being two examples of new technologies in cardiac imaging, VCT and DSCT represent the current and next steps, in what promises to be many exciting developments to come.

Introduction

The field of Computed Tomography (CT) has realized many significant developments over the past four decades that have dramatically improved the clinical applicability of this technology. CT became widely available in the 1970s with the introduction of single-detector CT scanners that captured one slice per rotation. In 1992, the first Multi-Detector CT (MDCT) scanner was produced (CT-Twin, Elscint) capturing two slices per rotation. Since then, the field has advanced to the point where modern MDCT scanners are routinely able to capture up to 64 slices per rotation.

The past decade has seen multiple generations of CT scanners emerge, and when 64-slice scanners first arrived, the sensitivity and specificity of detecting coronary artery stenosis via CT angiography began to approach that of invasive angiography. In years past, what some in the press have dubbed the ‘slice wars’ between the four major vendors of GE, Siemens, Toshiba, and Phillips in the push for greater spatial and temporal resolution has evolved into a more complex marketplace with different vendors pursuing different strategies. Toshiba has decided to pursue greater slice count to an industry record of 320 slices and coverage area up to 12cm. Phillips has taken efforts to increase the gantry rotation speed (i.e. the speed at which the X-ray sensors rotate around the patient) which in conjunction with reconstruction algorithms provides a temporal resolution of 270ms. However, for the purposes of this article, we will be reviewing in greater detail GE’s Volume CT (VCT) and Siemens’ Dual-Source CT (DSCT) systems.

Cardiac CT Imaging

With respect to cardiac imaging, many efforts utilizing CT have focused on the imaging of coronary artery stenoses, a technique termed CT angiography or MDCT angiography (Figure 1). In comparison with the gold standard of invasive conventional coronary angiography, non-invasive CT has the advantage of avoiding risks of arterial vascular complications such as arterial punctures, vessel damage, and dislodged aortic plaques causing myocardial infarct or stroke.
Estimates place the total risk of an adverse event between 1.7-2.0% for all causes\textsuperscript{9–11} In contrast, the major risks of CT angiography are a reaction to intravenous contrast and the radiation dose potentially causing cancer, both of which are equally present in traditional invasive angiography. The risk of a severe or fatal anaphylactic reaction to contrast is estimated at 0.04% and the lifetime risk of dying from cancer due a CT angiography scan is estimated to be less than 0.1%\textsuperscript{9} With regards to the radiation dose, significant advances have been made to decrease the radiation absorbed while maintaining image quality and is the focus of much active research.

Cardiac imaging poses the very unique challenge of imaging a moving target, requiring any clinically effective scanner to complete an image acquisition during an akinetic end-systolic or diastolic period.\textsuperscript{12,13} As a natural consequence of this, the faster a scanner can complete a rotation to avoid parts of the cardiac cycle with motion, the clearer the image will be, generally speaking. This quick scanning speed also proves advantageous during tachycardia without the need to use drugs like beta-blockers for heart rate control.

**Cone Beam CT/Volume CT**

Conventional MDCT scanners collect projections from a fan beam of x-rays.\textsuperscript{14} In comparison, Cone Beam CT or Volume CT (VCT), expand the x-ray beam from a fan to a pyramid or cone (Figure 2).\textsuperscript{3,14} A computer algorithm then processes the 2D cone-beam projections into a 3D image of a patients’ anatomy. With the advent of scanners able to capture up to 64-slices per rotation, this has created the platform necessary for Volume CT to emerge.\textsuperscript{3}

One such scanner is the *LightSpeed VCT* model introduced by General Electric (GE) in 2004. GE’s *LightSpeed VCT* scanner features a 64-slice detector and rotation speed of 370 milliseconds with slice widths of 0.625-millimeters, enabling the system to generate 64 sub-millimeter images totaling 40 millimeters of anatomic coverage with a single rotation.\textsuperscript{14,15} GE attributes some of the image acquisition improvement to the development of a new detector technology named V-Res, which is able to acquire 64 channels of data while spinning at less than 0.4 seconds per rotation.\textsuperscript{3}

The combination of high volume and high resolution demonstrated by the *LightSpeed VCT* scanner translates into three major tangible clinical benefits:

* **Dramatically reduced acquisition time:** Scanning time is half that needed for conventional MDCT scanners. Static organs can be imaged in one second, the lung in two seconds, the heart and coronary arteries in fewer than five seconds, and a whole body scan in less than 10 seconds.\textsuperscript{3,15}

The quicker imaging process is more comfortable for patients because it requires shorter breath-holds, can be especially useful for trauma patients when time is of the essence, and may help to alleviate lengthy queues for diagnostic imaging given that a higher volume of patients can be imaged on a given day.\textsuperscript{3}

* **Improved image quality:** The characteristic thin slicing capacity of the Volume CT allows for the generation of high resolution images, which translates to better diagnostic accuracy.\textsuperscript{16,17} In addition, multi-planar reformattting of images in any plane, including curved planes, is also possible. This improves the depiction of pathologic features particularly in cardiac imaging because such structures do not lie in the standard planes (x, y, z), which also improves diagnostic accuracy.\textsuperscript{18,19}

* **New diagnostic possibilities:** Volume CT offers the possibility to acquire a complete angiogram within five heartbeats (at 60 beats/min, approximately 5 seconds) making the procedure less susceptible to irregular heartbeats, helping
physicians rule out, or in, the three main causes of life-threatening ER chest pain (i.e. aortic dissection, pulmonary embolism, and coronary artery disease) in one scan, and ensure a more thorough stroke work-up because the entire Circle of Willis can be dynamically acquired with high resolution. More recently in 2007, GE introduced the LightSpeed VCT XT scanner (an improved version of their LightSpeed VCT scanner) that operates on a new scanning platform called ‘SnapShot Pulse’, which claims to reduce radiation dosage by as much as 70-83% when compared to conventional helical techniques without compromising image quality by pulsing the x-ray beam during akinetic portions of the cardiac cycle as opposed to continuously engaging the beam.  

Dual-Source CT (DSCT)

Dual-Source CT, a more recent development, innovates upon modern CT systems by utilizing multiple X-ray sources and detectors to reduce the length of time required to perform one scanner pass. As of this writing, the only commercially DSCT system available, known as the SOMATOM Definition, is manufactured by Siemens Medical Solutions. Utilizing two X-ray tube sources and two corresponding detectors offset by 90°, the SOMATOM system yields significant gains in temporal resolution making it ideal for cardiac applications (Figure 3). 

In a typical single-source CT scanner, the length of time required to perform a scan is limited by what is known as the ‘gantry rotation time’ which can range from 0.33s to 1.0s. This is the amount of time it physically takes to rotate the fan-shaped X-ray source and detector 180° through the field of view gathering the necessary images to re-construct a slice or array of slices. By utilizing the second-source X-ray tube and detector array, the time taken is halved to 165ms while maintaining equivalent spatial resolution. Steady Imaging Up To 100 BPM: The ability to image at this enhanced speed has numerous implications for the cardiac imaging challenges mentioned earlier. DSCT allows for steady imaging of the heart irrespective of heart rate up to 100 beats/min whereas a single-source CT can only guarantee temporal resolution at 66 beats/min or lower (Figure 4). Thus, with single-source CT, stringent protocols are required during Coronary CT Angiography (CCTA) to lower a patient’s heart rate to less than 65 beats/min using beta-blockers. Such compensations are optional with DSCT. Increased Pitch/Reduced Radiation Dose at High Heart Rates: Another advantage of DSCT is the ability to increase pitch (i.e. the speed at which the patient is advanced through the scanner) for any given heart rate thereby reducing the duration of time the patient is exposed to radiation, and hence, overall radiation dose. A study conducted by McCollough et al. examined the dose performance of the SOMATOM in comparison to traditional multi-detector CT. The study noticed a decrease in radiation exposure when radiation dose
optimization methods were used for patients with high heart rates close to a factor of 2 (At >90 beats/min: 26.6mGy DSCT vs. 43.7mGy MDCT). However, this advantage is lost and almost completely reversed when imaging at very low heart rates (At <55 beats/min: 61.2mGy DSCT vs. 28.7mGy MDCT).

Consistent Image Quality: All of these advantages would not be particularly useful if diagnostic quality were compromised but DSCT maintains high standards in spite of high heart rates. Matt et al. managed to demonstrate no significant correlation between mean heart rate and image quality in a population of 80 patients that underwent DSCT, with heart rates ranging from 35 to 99 beats/min. In contrast, other studies with 64-slice MDCT have shown a decrease in image quality with increasing heart rate.

Conclusion
Both Cone-Beam CT / Volume CT and Dual-Source CT represent two examples of recent developments in cardiac imaging. While vendors have an interest to push the edge of technology to even greater heights, researchers, clinicians, and policy makers have an equally important responsibility to evaluate these new technologies with an eye toward efficacy, clinical benefit, and proper indications for usage. Numerous developments in CT scanners are currently undergoing clinical evaluation, and research is being conducted into further strategies for both reducing radiation dosage while improving image quality. Several vendors are already looking at dual-energy CT that has the potential to improve characterization of varying tissue densities and minimize metal image artifacts. It may be many years before we see wide-spread adoption of these technologies here in Canada, but there can be no doubt as to the important implications of work like this. Two sources or one, 320-or 64-slices, cardiac imaging is only just getting started.

References