Dual Energy CT and Its Use in Neuroangiography

Amogh Hegde,[1] *MD, FRCR*, Ling Ling Chan,[1] *FRCR*, Lydia Tan,[1] Muhammad Illyyas,[1] Winston EH Lim,[1] *FRCR*

Abstract

The dual energy CT (DECT) technology has been recently employed in the form of two X-ray sources of different energies to enhance the contrast between adjacent structures. Its use in the cardiac arena has been widely highlighted due to the higher temporal resolution. However, it may also be used in the craniocervical and peripheral vasculature for better differentiation between contrast-enhanced vascular lumina and calcified plaques, in the characterisation of ureteric stones, and in the evaluation of hepatic lesions. The objective of this paper is to revisit DECT physics, review the literature and discuss its use in CT neuroangiography with case illustrations from our institution, and impact on dose savings.

Ann Acad Med Singapore 2009;38:817-20

Key words: Craniocervical CT angiography, Intracranial aneurysms, Radiation dosage, Vascular stenosis

Introduction

Dual energy CT (DECT) technology, initially introduced in the 1970s, failed to make an impact due to its technical limitation.[1-3] It was recently reintroduced in the novel form of two separate X-ray sources and their respective detector sets, placed orthogonal to one another. The most highlighted application of this technological innovation is in coronary CT angiography (CTA). In this context, it would be more accurate to term it as dual source CT technology, since the two X-ray tubes operate at the same energy. Two X-ray tubes operating in sync at the same energy translates into higher temporal resolution, which is clearly advantageous in securing non-motion degraded images in the setting of an elevated heart rate.[4] In contrast, the application of DECT in neuro, pulmonary and peripheral angiography, characterisation of hepatic lesions, and ureteric stone detection is based on the simultaneous use of the two X-ray tubes at different energies.[5-9]

In this paper, we revisit DECT physics, review the literature on its use in neuroangiography, and share case illustrations from our institution.

Physics of DECT

The attenuation of most diagnostic X-ray beams by a material is due to the photoelectric effect and Compton scattering, the former being the dominant component. The photoelectric effect is in turn dependant on the energy of the beam and on the atomic number (z) of the material itself. A material with a higher z will generate more photoelectric effect, and thence greater attenuation of the beam. The K edge of the material is defined as the sudden increase in the attenuation coefficient of the beam photons, which occurs when the photon energy just exceeds the binding energy of the K shell electron of the atoms of the material interacting with the beam. Differences in the K edge between calcium and iodine is capitalised in DECT angiography (DECTA) for bone removal, since intravenous or arterial iodinated contrast agents are commonly used to opacify the vasculature. In comparison to calcium (z = 20), iodine has a higher atomic number (z = 53) and a higher K edge of 33.2 as well. A beam of 80 kV is closer to its K edge, and there is a higher degree of beam attenuation by iodine at 80kV than that at a higher beam of 140 kV. In contrast, no such difference in attenuation is seen for bone (calcium) or other soft tissues in the body because their K edges are just too small to be significant at these energy ranges. The CT attenuation value of iodine changes significantly between the 2 beam energies, compared to bone and soft tissues. Hence, when the 2 energy datasets obtained from a single spiral scan are subtracted, bones and soft tissues get subtracted out, whilst iodine in the vessels remains. This principle is useful in craniocervical and peripheral

[1] Department of Diagnostic Radiology, Singapore General Hospital, Singapore.
Address for Correspondence: Dr Chan Ling Ling, Department of Diagnostic Radiology, Singapore General Hospital, Outram Road, Singapore 169608.
Email: chan.ling.ling@sgh.com.sg

angiograms for the subtraction of bones and soft tissues, and the optional removal of calcified plaques.

Materials and Methods

Data Acquisition – Protocol Parameters

The DECT neuro-angiographies are performed on the SOMATOM Definition (Siemens, Germany) in our institution. The dual-energy mode utilises 140 and 80 kV tube voltages at 50 and 210 effective mAs, respectively, 0.5-s rotation time, 64 x 0.6-mm collimation with z-flying focal spot, and a pitch of 0.7. The 140 and 80 kV raw image datasets are reconstructed separately in 0.6 mm sections at 0.4 mm increments using a D30 kernel for a field of view of 180 mm. For the average-sized patient of 60 kg, we inject 50 mL of iohexol (Omnipaque 370 mg I/mL) via the antecubital vein at the rate of 5 mL per second, followed by a 50 mL saline flush at the same rate. The delay time of the CT data acquisition after the injection is determined using the test bolus time-to-peak technique at the internal carotid artery at the C4 vertebral level. In our institution, this technique involves the dynamic acquisition of a series of low-dose monitoring scans (120 kV, 20 mAs) following an intravenous injection of 10 mL of contrast material to chart the time profile of the change in luminal density.

Post-Processing

The dual energy datasets are post-processed on the workstation (Multi Modality Workplace VE 31A; Siemens Medical Solutions, Germany) using the commercial dual energy taskcard (Syngo 2008G). The automated bone removal ("head bone removal" application) is not time consuming and takes less than a minute excluding data transfer and data saving time as noted by other authors.[8] Rotational maximum intensity projection (MIP) images are reconstructed from the bone removed dataset. In our experience, the commercially available automated bone removal programme is a robust and efficient technique which does not require a skilled operator or a good knowledge of vascular anatomy.

Radiation Dosage

On a single energy CTA study (regardless whether performed on a conventional single source multidetector CT scanner or a dual source scanner on a single source mode), the bone subtraction process necessitates a preliminary non-contrast bone-mask scan prior to the contrast enhanced scan, and this adds to the radiation dose. Using the dual energy mode, a "virtual" non-contrast enhanced phase and a post-contrast enhanced phase are generated from a single DECTA scan. Exploiting the material-specific change in attenuation on a dual energy scan obviates the need for a non-contrast bone-mask acquisition, and translates to dose reduction for the patient. In our clinical practice, the CTA scan utilising the dual energy mode translates to dose savings of 30% to 50% in comparison to the CTA scan performed on a single energy mode on the same scanner.

Data Interpretation

The bone removed MIP images, obtained using the dual energy software, are quite useful for an overview of the intracranial and/or extracranial vasculature. Similar to the tumbles of magnetic resonance angiographic images, these MIPs are an essential initial screen to exclude any obvious pathology, especially in the context of a busy clinical service with high patient throughput. However, the bone removed DECTA MIPs are subject to pitfalls as discussed below. Hence, the source images and their triplanar reconstructions must be reviewed in all cases to confirm pathology demonstrated or detect additional findings, which may have been overlooked on these bone removed DECTA MIP images.

Misregistration Artifacts

Misregistration artifacts are a major hindrance on the single energy bone-mask subtraction CTA technique. The patient position needs to be strictly maintained during and between the non-contrast mask and contrast-enhanced scans. This problem is entirely eliminated in the DECTA technique since it uses only a single scan to acquire the data for bone subtraction.[8]

Case Illustrations and Pitfalls

Intracranial Aneurysms

Some authors advocate CT angiogram as the primary method to evaluate cerebral aneurysms.[10,11] Watanabe et al found DECTA to be highly sensitive for the detection of

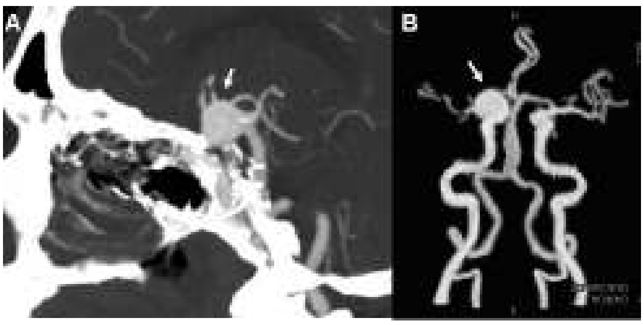

Fig. 1. DECTA of the circle of Willis of a patient showing a giant (A, B) aneurysm (arrows). Sagittal 2D thick MIP reformat view (A) shows the giant aneurysm close to the skull base. Bone removed 3D MIP image (B) reveals the origin of the aneurysm at the supraclinoid portion of the right internal carotid artery.

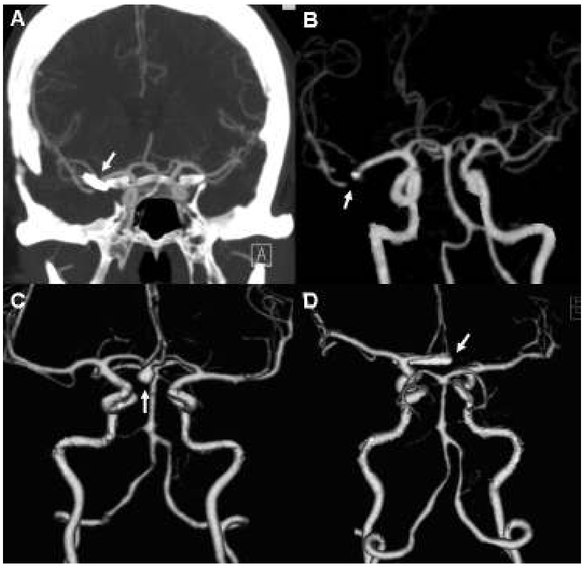

Fig. 2. DECTA of the circle of Willis of 2 patients status post clipping of aneurysm (arrows). In the first patient (A, B), the position of the surgical clip in relation to the right middle cerebral artery aneurysm is well depicted on the coronal 2D thick MIP reformat view (A). The bone removed 3D MIP image (B) shows focal enhancement defect along the right middle cerebral artery secondary to beam hardening artifacts arising from the clip. In addition, note that as with most surgical clips, the clip in this patient is subtracted following execution of the bone removal function. In the second patient (C, D), the relations of a small anterior communicating artery aneurysm (arrow) are clearly demonstrated on the bone removed 3D volume rendered (C) image. In contrast to the first patient, the surgical clip remains unsubtracted on the corresponding bone removed 3D volume rendered (D) post-clipping DECTA image despite the bone removal function. This is an unusual occurrence on the bone removed DECTA images, and is dependent on the make of the clip material.

intracranial aneurysms.[8] The DE automated bone removal software is effective and useful in the demonstration of aneurysms at the skull base (Fig. 1). In our experience, even small intracranial aneurysms are well demonstrated on MIP images of bone removed DECTA (Fig. 2). The extent of aneurysm wall calcifications is important for management strategies as heavily calcified aneurysms cannot be surgically clipped.[12] While this information is readily available on the conventional CT images, dense calcium may render the assessment of aneurysm neck, its shape and its relation to the parent vessel extremely difficult. With the commercial DECTA software, the user has the option of subtracting off or leaving the wall calcification on the MIP images. Similar to bone mask-subtraction CTAs, the MIPs of bone removed DECTAs are prone to false positive aneurysm detection caused by vascular infundibuli and venous sinus enhancement.[13,14] Hence, the source images must always be reviewed.

Surgical Clips

Most surgical clips, like other high density structures, are subtracted out on the DECTA (Figs. 2A, B) as is the case in single energy bone-mask digital subtraction CTA.[15] Rarely, the clip (e.g. titanium alloy Sugita in our experience) remains intact despite the bone removal function on DECTA scans (Figs. 2C, D). As in single energy bone-mask digital subtraction CTA, beam hardening artifacts also exist on the DECTA images, and its extent depends on the material of the surgical clip and the angle the long axis of the clip makes with the imaging plane (Fig. 2B).[15] When severe, beam hardening artifacts may preclude a clear depiction of nearby intracranial arteries and it remains mandatory to carefully inspect the source images for the occurrence of artifacts around the clip.[16]

Vascular Stenoses

We find that vascular stenoses tend to be overgraded on bone removed DECTA (Fig. 3), and Watanabe et al reported the same.[8] This overestimation of stenoses is inherent in CTA, and has also been demonstrated in non-neuroangiographic studies on dual and conventional single energy CT scanners.[17,18] Nonetheless, the bone removed DECTA MIPs allow significant ease of screening for critical stenoses of the vessels surrounded by the dense bones of the skull base, which are otherwise very difficult to assess on cross-sectional images. However, it remains paramount to confirm the degree of stenosis suggested

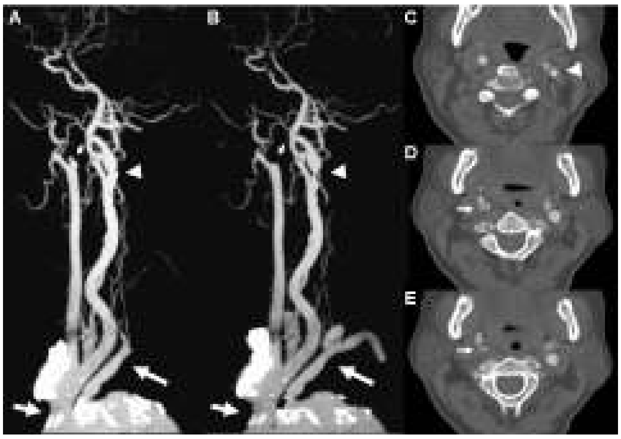

Fig. 3. Craniocervical DECTA. Bone removed 3D MIP image (A) demonstrates a heavily calcified plaque (arrowhead) at the left carotid bifurcation. Executing the option to subtract calcium better demonstrates the "severe" stenosis at the origin of the left internal carotid artery (B). Axial source images (C-E) moving in the caudal-cranial direction shows that the left internal carotid stenosis is in fact only moderately severe (arrowhead in C), i.e. there are over-estimation of the stenosis on the bone removed MIP images A and B. The occluded right internal carotid artery and its calcified plaque (small arrows) are confirmed on the axial source images D-E. In addition, note the clear vascular contours at the aortic arch in images A and B (large arrows), devoid of mis-registration artefacts secondary to respiratory motion and cardiac pulsation that are common on single energy bone-mask subtraction CTAs.

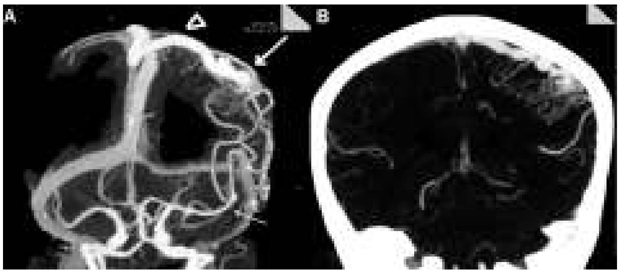

Fig. 4. DECTA image of the intracranial circulation demonstrates an arteriovenous malformation in the left high parietal region (single thick arrow). Effective bone removal on the MIP (A) image allows clear depiction of the supplying left middle cerebral artery (thin arrow) and venous drainage (arrowhead) into the superior sagittal sinus despite their adjacent lie to the calvarium. The coronal (B) multiplanar reformat demonstrates the close relations of the abnormality with the bony vault.

on the MIP images through review of the source images. Further, the DE bone removal software also allows optional subtraction of the calcified plaques for better assessment of the vascular lumen. While removal of calcified plaques is effective in vessels with a larger diameter, it suffers from over subtraction in smaller vessels and where the plaques are extremely dense.[17]

AV Malformations and Other Space Occupying Lesions

AV malformations and other neoplasms are well demonstrated on bone removed DECTA MIP images (Fig. 4). Bone removal is especially advantageous when the lesion is partly embedded in bony structures or in close proximity with the calvarium or skull base.[17] Otherwise, there is no major drawback or added advantage in evaluating these lesions on the dual energy mode.

Conclusion

DECTA is a robust and efficient technique for procuring bone removed CT neuroangiographic images of diagnostic quality in our clinical practice. Its ease of use and dosimetric savings for the patient has translated to exclusive use of the dual energy protocol for all neuroangiographic examinations on the dual source scanner in our institution. In addition, there are added editing options for removal of calcified plaques and surgical clips.

Acknowledgements

We wish to thank Siemens Medical Solutions, and especially Dr Christoph Panknin, for their technical expertise.

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