An Introduction to Dual Energy Computed Tomography

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Introduction

The idea of computed tomography (CT) was first introduced in the 1960's with the development of modern computer technology. The first scanners were commercially available in the 1970's, and grew in popularity through the 1980's. The innovation of helical-scanning CT produced true volume imaging with sub-millimeter resolution. CT can be used for both anatomical as well as pathological purposes, such as angiography with the addition of a contrast agent.

Dual Source CT (DSCT) is a relatively new technique used for diagnostic imaging purposes which uses two different x-ray tubes in a single CT unit. With the additional tube comes the advantage of exposing the patient with two different energy spectrums. The idea of Dual Energy CT was initially investigated in the 1970's; however without the technology to employ dual energies in a single scan, the object would be scanned twice, which produced different iodine distributions in the sequential images[1]. While enhancing the contrast effects of CT, additional applications with the development of DSCT include tissue differentiation and visualization of tendons and ligaments.

Theory

Like conventional radiography, computed tomography utilizes x-rays generated from a rotating anode to expose a digital detector after passing through an attenuating object. The signal detected reflects the intensity of the x-ray after attenuation through the patient. Attenuation is dependent not only on the energy spectrum of the x-ray beam, but the material and length of the attenuating object. A typical CT unit would consist of a rotating tube with a stationary ring of detectors. Helical CT uses slip ring technology which allows the tube to continuously rotate while the patient may be passed through the bore of the unit on a moving table. This produces a spiral scanning effect along the length of the patient.

As the tube rotates around the patient, projection images are acquired by the detectors for an angle of rotation which is dependent on the sampling frequency. The resulting projections can be processed before or after they are subjected to a particular reconstruction algorithm which assembles the final image. Processing methods are applied to the image in either the spatial or frequency domain, and can reduce noise as well as smooth the image through the use of filtering algorithms. In angiography, the image may be subtracted from another image acquired using similar parameters. The second image is acquired when a contrast agent has been injected in the patient. The contrast agent displays different attenuation effects revealing the locations of blood vessels and arteries.

Dual Source CT uses two rotating tubes to acquire both high and low voltage images. Since the images are dependent on the attenuation of the x-ray beam, which depends on the voltage applied across the tube, each image acquired is energy dependent. Attenuation is also dependent on the density of the material through which the beam passes, and knowing the energy of the beam allows assumptions to be made about the attenuating material based on the spectral properties of the detected radiation.

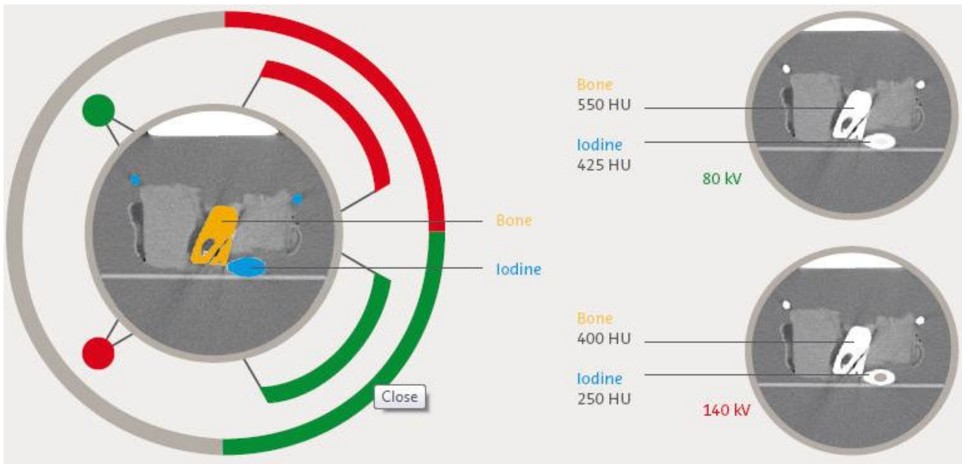

Figure 1: Schematic diagram of a Dual Source CT unit showing the two images acquired by using two tubes with different energy spectrums. The images show the attenuation differences reflected in the Hounsfield Unit (HU) which result from the different energy spectrums.[2]

The maximum and minimum voltage that can be applied across the tube is 140 kVp and 80 kVp. Thus the largest energy difference between the two tubes would be 60 kVp. However, since the x-ray beam consists of a continuum of energies which include the characteristic x-rays of the anode material, the average energies of the two spectrums are 76 keV and 56 keV, thus a smaller average energy difference[3]. Additionally, a tin filter may be placed in the path of the beam to remove the low energy x-rays from the spectrum, increasing the overall average energy to 92 keV[4]. This process of removing lower energy x-rays by including a tin filter in the path of the beam is known as beam hardening.

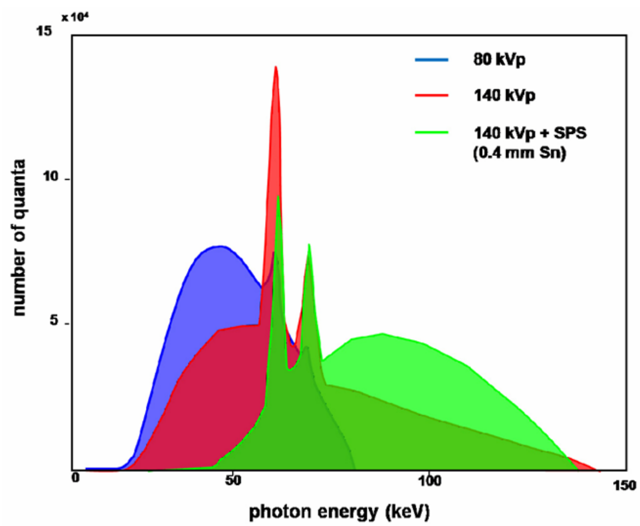

Figure 2: Corresponding energy spectrum for 80 and 140 kVp voltages, as well as resulting energy spectrum after beam hardening using tin filter.[5]

Attenuation at moderate energy levels is primarily due to Compton scatter, but at lower energy the photoelectric effect is dominant. Certain elements within the body, such as calcium or magnesium, have different attenuation properties and can be visualized when images are acquired at lower tube voltages. This is particularly useful in angiography in which iodine is used as a contrast agent for vascular enhancement.

The current applied across the tube is modified to maintain the exposure following standard protocol. The resulting images for the 80 kVp and 140 kVp scans will contain more noise than a normal CT obtained at 120 kVp and same dose. The images are weighted during reconstruction, and normalized so the noise and spectral properties resemble that of the 120 kVp CT scan. In Figure 1 it can be seen that the two tubes are positioned at 90^{o} from each other. No projection will be obtained at both exposures from the different tubes. This makes processing the projection data very time-consuming and image processing is performed on the reconstructed image.

Applications of Dual Energy CT

Dual Energy CT has already shown its immediate usefulness through its variety of applications in the clinic. Angiography is one field of CT which has improved through the use of a Dual Source CT unit. Bone can be identified through the use of Dual Energy CT based on its spectral properties and can be removed from an angiogram. The iodine in the blood vessels remain the only dense material and can imaged with quality near that of a magnetic resonance angiogram (MRA). Additionally, plaque distribution in the vessels which have calcified can be viewed to diagnose atherosclerosis. A typical protocol for a dual energy neck angiogram to detect plaque in atherosclerotic arteries would call for 140 and 80 kVp applied across the tubes, and last about four seconds.

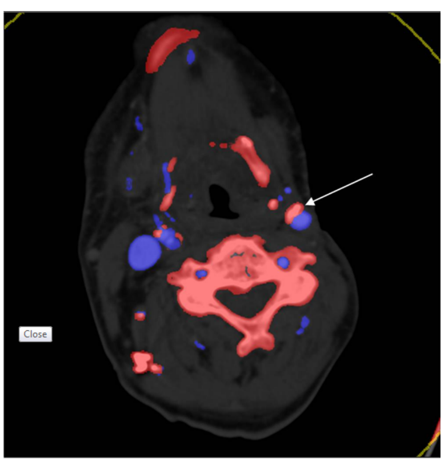

Figure 3a: The plaque distribution in the carotid artery can be visualized due to the differentiation of calcium (red) and iodine (blue).[6]

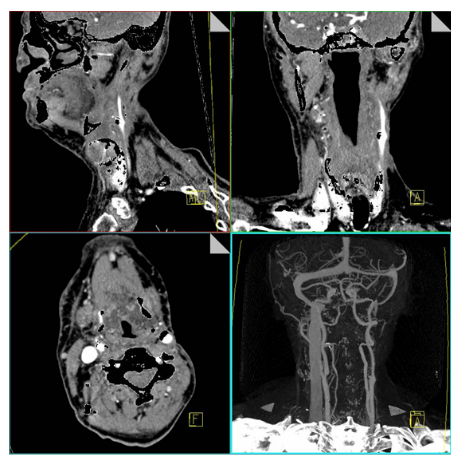

Figure 3b: Bone/plaque removal in a Dual Energy CT scan. All voxels containing calcium have been removed leaving the contrast agent iodine.[6]

Dual Energy CT has also introduced kidney stone differentiation by determining the specific properties of the stone, which will determine the best method of treatment. Stones containing calcium typically need to be removed manually or through shockwave treatment, whereas uric acid stones can be treated in vivo. Uric acid demonstrates weak spectral properties compared to calcium or struvite stones, thus stone differentiation is possible to determine whether invasive or non-invasive treatment is required.[7]

Differentiation of thick ligaments and tendons is possible through the use of Dual Energy CT. However, because the spectral properties of the connective tissue are weak, thin ligaments can not be visualized, limiting the actual use for this purpose. The ability to distinguish malignant and benign lesions has been investigated by determining the attenuation characteristics during a dual energy scan.[8] The attenuation properties will give information about the materials comprising the lesion, and a diagnosis can be made provided this information.

Ventilation and perfusion images can be acquired using Dual Energy CT along with information about the structure of the lung to diagnose a number of pulmonary diseases.[9] Contrast agents such as iodine or xenon gas can be injected in the patient to acquire either a ventilation or perfusion image of the lung.

Figure 4: Perfusion and ventilation images from pulmonary angiogram using Dual Energy CT with contrast enhancement.[8]

Dual Energy CT vs. Standard CT, SPECT

With any innovation in technology in the medical field, it is important that a new technique in imaging give of equal or superior results of an old imaging technique. One way of quantifying the advantages of Dual Energy CT over Standard CT was to compare bone removal, as well as vessel delineation, and vessel preservation. The advantage of Dual Energy CT allows the spectral properties of bone to be determined more accurately, so any voxels containing calcium can be eliminated from the image. Readers assessed images comparing Conventional bone removal to Dual Energy bone removal. Bony structures were found in the conventional image along with partial vessel truncation.[10,11]

Not only does Dual Energy CT provide better diagnostic images based on acquired data, it is also valuable in that it does not require additional dose compared to Single Energy CT. Images acquired using both techniques were compared and Dual Energy CT images provided better image quality with a decrease in noise without an increase in radiation dose than images acquired using Single Energy CT.[12]

Another way to quantize the ability of Dual Energy CT to perform to the standards set by other imaging techniques was to compare myocardial angiograms to SPECT and ICA images. The contrast agent iodine was used to determine if any myocardial perfusion was present in the Dual Energy CT images, and compared this to the sensitivity, specificity, and accuracy of the SPECT images. Results have shown that Dual Energy CT has the ability to perform integrative analysis of the coronary artery morphology and myocardial blood supply and is in good agreement with SPECT and ICA.[13]

Conclusions

Conventional radiography's progression has arrived at Dual Energy CT along with the technological development of a Dual Source CT unit. While performing at or above the standards set by standard CT units regarding imaging quality, tissue differentiation and therefore bone removal in angiography becomes a possibility. The ability to differentiate between two tissues is dependent upon the Dual Energy spectrum attenuation in the object. The spectral properties of the tissue are important because the atomic material which makes up a selected volume can be determined. This allows for image processing which can remove bone for angiograms and visualize plaque distributions in determining atherosclerosis. Dual Energy CT also has the ability to quantify ventilation and perfusion images with the use of a contrast agent such as iodine or xenon gas. The ability to distinguish between tissue types and enhance contrast will certainly lead to new discoveries in the diagnostic imaging.

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