Applications of dual energy CT in clinical practice: A pictorial essay

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Abstract

In dual-energy CT (DECT), two different x-ray spectra are used to acquire two image datasets of the same region, to allow the analysis of energy-dependent changes in the attenuation of different materials. Each type of material demonstrates a relatively specific change in attenuation between images obtained with a high-energy spectrum and those obtained with a low-energy spectrum. Based on the relatively specific change in attenuation with two different energies, material composition information can be obtained to allow tissue characterization. The DECT ability of material differentiation allows bone removal in various CT angiography studies and bone marrow edema depiction, while with material optimization, metal artefacts can be significantly reduced to almost nil. DECT allows material separation to differentiate uric acid crystals from calcium to determine the composition of urinary calculi and to diagnose gout. Using the DECT ability of material decomposition, iodine maps can be generated, which are useful in the evaluation of any enhancing lesion in the body without the need to obtain a plain scan and allow perfusion maps to be created in cases of pulmonary thromboembolism.

Key words: Dual energy CT; iodine map; material; metal artefact; uric acid

Introduction

In diagnostic imaging, the photoelectric effect is the most important mechanism by which the x-ray photons interact with matter. The chances of this effect increase as the energy of the x-ray beam approaches the K_{edge} of the particular atom.[1] Different atoms have different K_{edge} values and hence behave differently at different energies of the x-ray beam.

In dual-energy CT, two different x-ray spectra are used to acquire two image datasets of the same anatomic region, allowing analysis of energy dependent changes in the attenuation of different materials.[2] Every material shows a relatively specific change in attenuation between images obtained with a high and a low-energy spectrum and this attenuation difference allows better characterization of the tissues. Two different materials that show similar attenuation on images acquired with one of the two energy spectra, may show substantial differences in their attenuation on the images acquired with the other spectrum and hence may be easily differentiated.[3]

There are multiple techniques available for dual energy CT imaging which can be broadly classified as:
1) Dual source DECT
2) Single source DECT.

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Single source DECT can be further divided based on the exact mechanism to generate two different energy spectra as:
1) Fast kV switching
2) Dual layer detector
3) Slow kV switching
4) Dual spiral dual energy
5) Twin beam dual energy.

We use the Siemens Somatom Definition Edge CT scanner which is based upon a single source twin beam dual energy technique [Figure 1].

In twin beam DECT, two different filters Tin (Sn) and Gold (Au) are used to split the x-ray beam from a single source into two beams of different energies. The greatest advantage of this technique over the many of the other techniques mentioned above is eliminating temporal mis-registration.

Applications in Clinical Practice

Material differentiation

Bone removal in angiography
As DECT has the ability to differentiate different materials from one another, calcium in the bones is readily separated from iodine in the contrast media. Hence the bones in any angiography study can be easily removed. This is particularly useful in cerebral [Figure 2] and lower limb angiography [Figures 3 and 4], where manual methods can be difficult and time consuming, especially when the vessels lie close to bones. Similarily, calcified plaques can be removed for better visualisation of the lumen [Figure 5].

Bone marrow edema
Bone marrow edema is best visualised on MRI imaging. However with DECT, it is now possible to evaluate bone marrow edema on CT scan as well. As DECT can differentiate calcium from other elements, it can also selectively remove calcium from the region of interest. This is called virtual non-calcium (VNC) technique and it allows visualisation of bone marrow edema.[4] Multiple studies have validated this technique for bone marrow edema detection.[5,6]

It is especially useful in acute fractures where MRI may not be possible [Figures 6 and 7]. Kaup M et al.[9] demonstrated the utility of DECT for bone marrow edema evaluation in osteoporotic vertebral compression fractures and found that its diagnostic performance approached that of MRI.

Material optimisation

Metal artefact reduction
Metal in prosthesis can cause significant artefacts and hamper evaluation of periprosthetic soft tissue. These metal artefacts are caused by beam hardening artefacts.[10]

Radiographs are typically obtained post-operatively but they have low sensitivity and specificity.[11] MRI is a great tool to assess bone marrow edema and soft tissue lesions but the images are distorted by metal artefacts.[12]

With the conventional CT, multiple techniques are available to reduce the metal artefacts.[13] Increasing in tube current, increasing voltage and reducing slice thickness can help reduce metal artefacts. Various modifications in reconstructions techniques like changing the deconvolution

Figure 1: In twin beam DECT, two different filters Tin (Sn) and Gold (Au) are used to split the x-ray beam into two beams of different energies. The Gold (Au) filter, filters the high energy photons and produces a low energy beam while Tin (Sn) filter, filters the low energy photons and produces a high energy beam.
Using DECT, the artefacts from metal can be significantly reduced to almost nil. As the artefacts are more at lower energy x-ray beams, the monochromatic images at higher keV settings show significantly less artefacts.

Additionally, iterative reconstruction protocols such as iMAR (interactive metal artefact reduction) can be used that further reduce the metal artefacts. When both the techniques are used together, the final result shows almost nil metal artefacts [Figures 8 and 9]. This allows the visualisation of periprosthetic soft tissue to identify complications such as periprosthetic osteolysis, fracture, infection, aseptic loosening, focal particle disease and tumor. Metal artefact reduction can also be used for evaluation of stents and to detect endoleak after aneurysm repair.\cite{14}

**Material separation**

DECT has the ability to separate different materials based on their specific dual energy ratio. Hence, uric acid crystal can be separated from calcium, both of which otherwise appears hyperdense on conventional single energy CT.
Urinary stones
As different types of renal calculi are treated differently, knowledge of the composition of stones may guide management decisions and predict the effectiveness of therapy. For example, uric acid calculi can be managed medically with urine alkalinization that facilitates dissolution, while non-uric acid calculi need other lines of treatment such as lithotripsy or surgery.\textsuperscript{[13]}

Using DECT, it is possible to differentiate uric acid from non-uric acid calculi. Keeping the dual energy ratio at 1.05, the uric acid stones lie below the line/slope and are coloured red, whereas the non-uric acid stones lie above the line/slope and are differently colour-coded (blue) [Figures 10 and 11].

Gout
Gout is characterized by an inflammatory response to the deposition of monosodium urate (MSU) crystals in the joints and soft tissue, which leads to acute or chronic arthropathy and gouty tophi formation. Diagnosis can be made on clinical and biochemical bases, and definite diagnosis requires microscopic demonstration of MSU crystals from
the aspiration of the joint fluid, a method that is invasive and may have false negative results.

Keeping the dual energy ratio specific to uric acid crystals, the uric acid crystals are coloured green, whereas calcium is coloured blue. The diagnosis of gout can be easily made, non-invasively [Figure 12].

With DECT, it is also possible to quantify the overall tophus burden or volume of urate deposition without any user variability. Thus, makes DECT an ideal tool for evaluating any change in tophus burden and can be used for follow-up to document response to treatment [Figure 13].

**Material decomposition**

**Iodine maps**

Lung

Pulmonary thromboembolism

The dual energy iodine maps allow us to evaluate lung perfusion and hence are useful to demonstrate perfusion defects in cases of pulmonary thromboembolism.

Figure 10 (A-D): The conventional CT images shows the calculi (arrows) in the kidney (A) and ureter (B) as hyperdense structures and their composition cannot be determined. With DECT uric acid calculus is shown in red (C) while non-uric acid calculus is shown as blue (D), allowing their differentiation. The graph also helps shows the two calculi differently, with the uric acid calculus lying below the line, and non-uric acid lying above.

Figure 11 (A-C): Another example of urinary calculi (arrows), two calculi are seen in the kidney in the CT scan image (A). DECT the calculus red (B) in colour and falling below the line (C), thus confirming uric acid calculi.

Figure 12 (A and B): A 35 years male presented with pain and swelling in right foot and wrist. Serum uric acid-13 mg/dl. Radiographs of both feet, knees and wrists (A) shows juxta-articular erosions (arrows) around right 1st metatarsophalangeal joint, right lateral femoral condyle, right distal ulna and 5th carpometacarpal joint with soft tissue. Diagnosis of gout was made. B. DECT (B) allows visualisation of the urate crystals seen as green coloured areas (arrows), confirming the diagnosis. Also, it shows involvement of the asymptomatic and radiographically occult areas and displays total tophus volume.
Additionally, the dual energy iodine maps also improve visualisation of filling defects/thrombi in a small segmental or subsegmental artery. Fink et al.[18] showed the sensitivity and specificity of dual-energy CT perfusion mapping for the assessment of pulmonary embolism to be 100% on a per patient basis and 60-66.7% and 99.5-99.8% on a per segment basis, as compared to CT angiography.

In patients with pulmonary thromboembolism, the dual energy perfusion maps show peripheral wedge-shaped areas of reduced perfusion representing perfusion defects [Figure 14]. They are also very useful for the follow up of such patients who are treated with anticoagulants to demonstrate both a decrease in perfusion defects as well as the thrombi [Figures 15 and 16].

One should keep in mind the areas where artefacts are commonly seen and should not misinterpret them as areas of perfusion defects. These artefactual perfusion defects are commonly seen in the upper lobes due to beam hardening artefacts, in the medial segment of the right middle lobe and lingula due to cardiac pulsation and in the lung bases due to diaphragmatic motion. The other common pitfall is apparent perfusion defects in an area of lung parenchyma with systemic arterial supply. Also, parenchymal diseases such as collapse, consolidation, masses and emphysema show perfusion defects.[19]

Lung nodule
With DECT a single contrast enhanced scan is sufficient to differentiate an enhancing nodule from calcification with the use of virtual nonenhanced image reconstructions.[20] The enhancing and non-enhancing components of a heterogeneous lesion are better appreciated on iodine maps, which also help target the appropriate area for biopsy, to increase the yield [Figure 17].

Degree of contrast enhancement is an important factor to differentiate a benign from a malignant lesion.[21] Hence dual energy analysis with iodine maps is very useful in the evaluation of solitary or multiple pulmonary nodules. The enhancement in a nodule is not always easily appreciable on routine CT scan and DECT iodine maps help confirm or rule out enhancement conclusively [Figures 18 and 19].

Difference in the contrast wash out pattern of a metastatic nodule can be used to evaluate various types of primary malignant tumors. For example, metastases from colorectal carcinoma, malignant melanoma and thyroid carcinoma show a distinct wash out pattern whereas those from lung cancer, salivary gland cancer and sarcoma show increased enhancement in the delayed phase images.[22]

Liver lesions
A hypervascular lesion is more conspicuous on lower kV images on an arterial phase of the study, as iodine is more attenuating at lower energies.[23] DECT may be used to identify fat, iron, calcium, or hemorrhage within the tumor. Virtual non-enhanced images can be used to differentiate calcification in a lesion from enhancement.

DECT iodine maps are especially useful in differentiating a simple cyst from a complex cyst as they show the subtle enhancement in the lesion very well, which is often difficult to appreciate on a single energy CT scan [Figures 20 and 21].

Kidney lesions
DECT is useful in differentiating a hypodense cyst from an enhancing solid tumor. A hypodense cyst containing proteinaceous material or blood products may mimic a
solid enhancing tumor on a contrast enhanced scan. In such situations, iodine maps help as a hyperdense cyst will not show iodine uptake. Also, virtual non-enhanced images will show hyperdense contents in the cyst. Similarly, enhancement in a hyperdense lesion may be difficult to appreciate on routine CT images and DECT iodine maps show the enhancement well even in hyperdense parts of the lesion [Figure 22].

Adrenal lesions

The majority of the adrenal lesions seen on an abdomen CT scan are benign. On imaging the diagnosis of a benign adrenal lesion can be confidently made if it shows a Hounsfield value (HU) value of less than 10 on an unenhanced image (adenoma), shows macroscopic fat (myelolipoma) or has attenuation of water (cyst). The appearance of an adenoma on DECT is variable and may show decrease or increase in attenuation at lower kV images than higher, depending on the amount of lipid within the lesion. DECT iodine maps can help pick up enhancing focal lesions in an adrenal gland [Figure 23].

Bowel pathologies

DECT is helpful in the evaluation of inflammatory bowel pathologies and shows the inflammation/enhancement of
the wall better [Figure 24]. It is also useful in assessing the severity and evaluate extraintestinal manifestations. Iodine maps demonstrate bowel wall enhancement/hyperemia in cases of inflammatory bowel disease. Coexisting neoplastic lesion can also be better assessed with DECT in such cases.

Post ablation analysis
Radiofrequency ablation (RFA) is now frequently used to treat a focal lesion in the liver, lung or kidney. It is important to detect residual tumor post RFA to decide if re-ablation is necessary. Conventionally, contrast enhanced single energy CT has been used to evaluate the success of RFA, and it may be difficult to pick up residual tumor and differentiate it from post ablation changes. DECT allows better depiction of the enhancing component in residual lesions using iodine overlay images, while the necrotic post-ablation regions appear avascular and do not show iodine uptake [Figure 25]. Monochromatic images also allow selection of the optimal keV that shows the best contrast to noise ratio between the tissues, thus allowing better evaluation of the interface between the ablation zone and surrounding tissue.25

Atomic number maps (Rho/Z)
The new dual energy CT application allows calculation of the atomic number in the lesion, for separation of various materials. Mileto et al.26 showed that non-enhancing renal cysts, including hyperattenuating cysts, can be discriminated from enhancing masses on effective atomic number maps. They concluded 8.36 value was the optimal threshold with
the enhancing masses showing higher values. Our cases also showed similar results [Figures 26 and 27].

### Conclusion

DECT is useful in clinical practice and clearly has many advantages over conventional single energy CT scanners. Various applications described in this pictorial essay highlight the growing importance of DECT. Some new
applications which may be used in future are under evaluation. One such example is liver iron estimation in patients with thalassemia.[27,28]

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