Dual-energy CT applications in neurovascular emergencies

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Learning objectives

- To briefly review underlying concepts relevant to dual-energy CT acquisition and postprocessing.
- To demonstrate clinical application of dual-energy CT imaging in diagnostic evaluation of neurovascular emergencies, including stroke and intracranial hemorrhage.
Background

Dual-energy CT has been increasingly used to improve diagnostic sensitivity and specificity for a variety of clinical indications. It exploits differences in the quantitative relationship between x-ray energy and attenuation among different materials to allow increased specificity of tissue characterization on CT [1, 2]. Simultaneous CT acquisition at both a low energy and a high energy allows one to differentiate among materials that have similar or overlapping attenuation values on conventional single-energy CT. In neuroimaging, dual-energy approaches may permit more definitive identification of hyperattenuating intracranial findings as calcium, iodinated contrast, or acute blood.

Acquisition and postprocessing approaches

- At our institution, dual-energy CT imaging is typically performed using dual-source dual-energy scanners at 80 kVp and 150 kVp (with a tin filter).
- Routine viewing of the images is performed through use of blended images, which simulate single-energy acquisition at a typical kVp of 120 by combining data from high and low kVp acquisitions in a defined ratio.
- Postprocessing is performed in the imaging domain using vendor-provided software to obtain calcium and/or iodine maps or generate virtual non-contrast or non-calcium images using three-material decomposition [1-3]. In this technique, CT attenuation values for each voxel at high and low energies are used to decompose the voxel into contributions from three assumed materials: cerebrospinal fluid, brain parenchyma, and a high-atomic number material that may be iodine or calcium, depending on the context of the study. Higher concentrations of iodine or calcium produce greater increases in attenuation at the low x-ray energy than at the high energy as quantified by the material's dual-energy ratio, allowing a decomposition algorithm to determine the contribution of this high-atomic number material to a voxel's attenuation based on CT attenuation data at the two energies.
- If desired, results of material decomposition and expected attenuation properties of each material can be used to generate virtual monoenergetic images to simulate CT attenuation at a specified monoenergetic energy level, as opposed to typical imaging using a polychromatic spectrum.
Findings and procedure details

A variety of clinical cases are presented to illustrate practical clinical application of dual-energy approaches in common emergency neurovascular scenarios.

Calcification vs. hemorrhage

A common clinical scenario encountered when interpreting emergent head CT studies is the identification of focal intracranial hyperattenuation that could represent calcification or hemorrhage. Dual-energy CT acquisition combined with postprocessing using three-material decomposition for calcium can allow more definitive characterization of such findings.

As illustrated in the head CT study shown in Fig. 1 on page 6 performed on a 58-year-old female presenting to the emergency department with altered mental status, dual-energy techniques can be applied to definitively characterize an otherwise indeterminate intracranial hyperdensity. A calcium map was obtained using three-material decomposition to identify voxels containing calcium, and a virtual non-calcium image was also generated. Hyperattenuation on calcium maps that is completely nulled on the virtual non-calcium image allows one to confidently identify a finding as calcification. In an emergent setting, for which comparison studies may not be available, definitive characterization of an incidental intracranial hyperattenuating focus as calcium can circumvent the need for follow-up imaging for exclusion of hemorrhage, as dual-energy techniques have been found to be 99% accurate for hemorrhage detection [4].

The dilemma of calcification vs. hemorrhage is commonly observed in acute stroke evaluations (Fig. 2 on page 6), as calcifications are often seen incidentally at old infarcts, while exclusion of hemorrhage is crucial to emergent management of ischemic stroke. In the case of this 56-year-old female presenting with acute right upper and lower extremity weakness, dual-energy postprocessing can provide definitive identification of hyperattenuating findings as calcium, thereby obviating unnecessary delays in thrombolytic therapy.

Iodinated contrast vs. hemorrhage

Differentiating iodinated contrast from hemorrhage is another task for which dual-energy techniques can be applied in emergent settings. The approach is similar to differentiating
calcium from hemorrhage in that three-material decomposition techniques can be used; the main difference is that the dual-energy ratio for iodine is used, which is higher than for calcium.

In the setting of acute intracranial hemorrhage, risk of hematoma expansion can be predicted by detection of a CTA spot sign, which signifies active bleeding. However, if images are degraded by suboptimal timing or dilution of the contrast bolus, small CTA spot signs may be difficult to detect solely based on differences in single-energy attenuation between intravascular contrast and hyperdense hemorrhage. Dual-energy techniques can increase conspicuity of the CTA spot sign as shown in Fig. 3 on page 7 and thereby identify patients with high risk of hematoma expansion. Note that by suppressing visibility of the large hematoma via iodine mapping, very small sites of active contrast extravasation or small tumors and vascular malformations within the hematoma can be more readily identified [3].

In some neurovascular settings, there is expected mixture of iodinated contrast and blood, and determining the relative composition of contrast and blood within an area of hyperattenuation can be challenging based on attenuation values on conventional single-energy CT. For example, in Fig. 4 on page 8, images are shown following intraoperative rupture of a basilar tip aneurysm during coiling. After dual-energy postprocessing, it can be determined that most of the hyperdensity in the basal cisterns represents subarachnoid blood, whereas the hyperattenuating finding in the midbrain is predominantly contrast based on reduced attenuation on virtual non-contrast imaging. In the setting of acute ischemic stroke, a frequently encountered problem-solving scenario is the need to exclude hemorrhagic transformation in patients who underwent endovascular interventions (Fig. 5 on page 9) or received intravascular contrast for other reasons (Fig. 6 on page 10). Loss of integrity of the blood-brain barrier frequently leads to contrast material staining the brain parenchyma, which could be mistaken for hemorrhage and potentially delay antiplatelet or anticoagulant therapy. In these situations, iodine maps and virtual non-contrast images can assist in differentiating contrast staining from hemorrhage [5].

Other applications

Other neuroimaging uses of dual-energy techniques have also been described [2, 3]. For instance, bone subtraction based on nulling voxels that contain predominantly calcium may afford better visualization of the intracranial vasculature or of masses or hematomas located adjacent to bone. Virtual monochromatic imaging has potential to reduce artifact from aneurysm coils or clips or other metallic objects [6].
**Fig. 1:** 58-year-old female presenting to the emergency department with altered mental status. Noncontrast head CT imaging (top left) shows hyperattenuating findings in the right parietal lobe (yellow arrows). The finding is visible on the calcium map (top right) but not on the virtual non-calcium image (bottom left), indicating that this finding represents calcium rather than acute hemorrhage. Matching the conventional grayscale finding to the calcium can be facilitated by a color overlay of the calcium map onto the original grayscale image (bottom right).

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Fig. 2: 56-year-old female presenting with acute right upper and lower extremity weakness. On the non-contrast head CT (first column), small foci of hyperattenuation are seen at infarct sites in the parieto-occipital regions bilaterally (red arrows) and in the left cerebellar hemisphere (yellow arrows). These areas of hyperattenuation are visible on calcium maps (second column) and absent on virtual non-calcium images (third column), indicating that they likely represent calcification rather than hemorrhage. As expected, choroid plexus calcifications are also absent on the virtual non-calcium images. Color overlays of the calcium maps on the grayscale images are also shown (fourth column).
Fig. 3: 59-year-old female with acute left-sided facial droop and weakness. CTA imaging (top left) shows a large hematoma centered in the right frontal lobe (red arrows), with intraventricular extension. Parenchymal and intraventricular hemorrhage is not visualized on the iodine map (top right), except for a tiny focus in the central portions of the right frontal lobe hematoma (yellow arrows), consistent with a CTA spot sign and indicating active hemorrhage. This finding is absent on the virtual non-contrast image (bottom left), whereas hemorrhagic findings are visible. Color overlay of the iodine map onto the grayscale head CTA image conspicuously demonstrates a punctate focus of iodinated contrast within the large acute intracerebral hematoma. A small portion of an incidental right frontal convexity meningioma (green arrows) extends into the plane of these images; because it contains calcium in addition to enhancing soft tissue components, the meningioma is visible on both the iodine map and the virtual non-contrast image.

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Fig. 4: Head CT imaging (top left) in a patient who experienced intraoperative aneurysm rupture during coiling of a basilar tip aneurysm shows extensive hyperattenuation in the subarachnoid spaces, including the basal cisterns, and within the midbrain. The iodine map (top right) shows high iodine content in the hyperattenuating midbrain finding (yellow arrows) and a few areas of lower iodine content in the suprasellar cistern and left ambient cistern. On the virtual non-contrast image (bottom left), there is artificially reduced attenuation at the midbrain finding, indicating that the midbrain finding consists almost entirely of iodinated contrast, while most of the suprasellar cistern contents are hyperattenuating and therefore represent predominantly hemorrhage intermixed with a small amount of contrast. Superimposing a color overlay of the iodine map on the conventional grayscale image (bottom right) aids differentiation of areas that are predominantly contrast from those that are predominantly hemorrhage.

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Fig. 5: 94-year-old female who presented with stroke and underwent thrombectomy. On CT imaging (left column), hyperattenuation in the left basal ganglia (yellow arrows) and in the upper cerebral sulci (red arrows) could represent either hemorrhage or contrast. These areas of hyperattenuation are conspicuously present on the iodine maps (middle column) and absent on virtual non-contrast images (right column), indicating that they represent contrast staining/leakage rather than hemorrhage.

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Fig. 6: 51-year-old male with a recent left cerebral infarct being evaluated for hemorrhagic conversion after having received intravascular contrast. On the head CT image (top left), there is extensive left cerebral hyperattenuation (yellow arrows), with involvement of cortex. There is high signal in these locations on the iodine map (top right) but low signal on the virtual noncontrast image (bottom left). Color overlay of the iodine map (bottom right) shows that the iodine content matches the hyperattenuating areas, consistent with contrast staining rather than hemorrhagic transformation.

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Conclusion

Dual-energy CT can be a useful neuroimaging approach in multiple emergent neurovascular scenarios, and familiarity with this increasingly prevalent technique would likely benefit emergency radiologists, neuroradiologists, and other physicians interpreting head CT and CTA studies.
References


