Dual-Energy CT in Neuroimaging

- Image contrast in CT is mostly dependent on elements with high atomic weight, such as calcium, iron, and iodine.
- The concentrations of these elements can be calculated from dual-energy x-ray data based on their characteristic attenuation patterns.
- Dual-energy CT may be helpful in neuroimaging to:
  - Differentiate between hemorrhage and iodinated contrast agents in brain parenchyma.
  - Improve CT angiography images by differentiating between calcified plaque and iodinated contrast.
  - Lessen artifacts due to metal clips and coils.

Standard methods for CT employ a single polychromatic beam of x-rays with peak energy in the range of 120–140 kVp. At these energies, the penetration of x-rays is relatively high, and the resulting images have a high signal-to-noise ratio. However, it is not possible to discriminate between attenuation due to elements such as iodine and calcium without performing both an unenhanced and a contrast-enhanced image.

Both Compton scattering (scattering of x-rays with little absorption) and the photoelectric effect (absorption) play a role in x-ray imaging. Compton scattering predominates in the 120–140 kVp energy range. Absorption (attenuation) is greater at lower x-ray energies and is dependent on the energy required to displace a k-shell electron, which differs from one element to another. Such differences make it possible to determine the contributions of elements such as iodine and calcium.

The advantages of using dual-energy CT were postulated in the 1970s, but image acquisition has only recently become sufficiently fast to overcome problems of patient movement and misregistration of images. Two different technologies are now in clinical use for dual-energy CT. One method employs two orthogonal x-ray beams that are set at different energies (kVp) and two separate detectors. The second method uses rapid kVp switching from a single x-ray source and a detector composed of two scintillation layers. Both methods enable near simultaneous acquisition of images at both energy levels. The two energy levels are typically set at 80 and 140 kVp.

Complex material differentiation algorithms have been developed to analyze dual-energy CT data and create images that highlight the presence of elements such as iodine from contrast material and calcium. Alternatively, they can be used to remove the contributions of these elements. For example, removal of calcium enables clear visualization of vasculature that would otherwise be obscured by bone or calcified plaque, and removal of iodine creates virtual non-contrast images. Consequently, a single dual-energy CT scan can be employed instead of two consecutive standard CT scans while maintaining image quality with no additional radiation exposure.

One advantage of dual-energy CT in neuroimaging is that it can differentiate between hemorrhage and iodine staining in the brain. Other potential benefits include the provision of superior image quality for CT angiography and minimization of streak artifacts due to metals or dense bony structures.
Intracerebral Hemorrhage

Early recognition of the presence of hemorrhage, particularly after ischemic stroke therapy, is important for patient management. For this reason, non-contrast CT scans are routinely performed within the first 24 hours after intra-arterial therapy. However, interpretation of these images can be challenging because iodinated contrast material can stain brain parenchyma, a common occurrence after intra-arterial contrast administration. In addition, extravasation into the subarachnoid space can result from intra-arterial stroke therapy with mechanical devices.

Single-energy CT cannot differentiate between hemorrhage and hyperattenuation in the brain due to contrast enhancement. However, dual-energy CT plus a three-material decomposition algorithm to obtain virtual non-contrast images and iodine overlay images can differentiate between hemorrhage and contrast staining with a high degree of accuracy (Figure 1), although the analysis may be confounded by diffuse calcification in the parenchyma or metal streak artifacts. This method is also useful in cancer patients who have recently received intra-venous

Figure 1. Intracerebral Hemorrhage vs. Iodine Staining. A simulated single-energy image (A), acquired as a part of a dual-energy CT, shows a diffuse hyperdensity (arrow) in the right sub-insular region after intra-arterial therapy for acute stroke. This hyperdensity may represent contrast staining from the intra-arterial treatment, or hemorrhagic conversion of the stroke. Panels (B) and (C) present the iodine overlay image and virtual non-contrast image, respectively, from the same dual-energy CT. As can be seen, the area of hyperdensity is localized to the iodine overlay image, likely representing contrast staining (B). No areas of hyperdensity are identified on the VNC image (C) suggesting there is no intracranial hemorrhage. This is confirmed by the 24 hour follow-up non-contrast CT (D) which demonstrates near-complete washout of the hyperdensity property of water-soluble contrast without evidence of parenchymal edema to suggest hemorrhage. Any hemorrhagic component in this hyperdensity would have persisted for days.
contrast to monitor response to therapy and head trauma patients to monitor for further bleeding after an intra-cerebral hemorrhage.

CT Angiography

Conventional catheter angiography remains the gold standard for assessing the vasculature of the head and neck, mainly because of its superior spatial and temporal resolution. However, it is invasive and associated with risk of permanent neurologic complications. CT angiography is a safer alternative, but it does not clearly display the vasculature near the base of the skull and cervical vertebrae due to difficulties separating bone and blood vessels. These problems have been partly overcome in single-energy CT using manual post-processing for bone removal, although it is a time-consuming process associated with misregistration due to patient movement between and during the enhanced and unenhanced scans. With dual-energy CT, automated material differentiation can remove most head and neck bones, as well as calcified plaque from the image, to improve blood vessel delineation, although the bone subtraction algorithm is not always effective around the vertebral artery. Thus, the vasculature near the skull base that is only poorly visualized using single-energy CT can be seen clearly with dual-energy CT (Figure 2), but the bone subtraction algorithm and single-energy CT may provide better vessel integrity.

Carotid endarterectomy or stenting is commonly used to improve blood flow to the brain. However, heavy calcification is considered a relative contraindication to carotid stenting, and it is essential to quantify the calcium burden prior to treatment. Single-energy CT methods are available for this purpose, using data from both an unenhanced examination and a contrast-enhanced scan to examine the vasculature. Dual-energy CT requires only one scan because a three-material differentiation algorithm can be used to calculate the distribution of both calcium and iodine and display them in color-coded images (Figure 3).

Beam Hardening and Metal Streak Artifacts

The high density of bone in the posterior fossa causes streaks and shadows in adjacent soft tissues because the bone absorbs the lower energy photons, resulting in beam hardening. Although these effects are reduced by various built-in features in CT scanners and specialized computer algorithms, they still pose a problem in single-energy CT. Metallic objects, including maxillofacial and dental hardware and aneurysms clips, result in severe metal streak artifacts due to incomplete attenuation profiles. Dual-energy CT data can be processed to ameliorate these problems (Figure 4).

As a result, single-energy CT angiography is not suitable for evaluating patients with metal clips or endovascular coils for treatment of aneurysms. However, a recent study using rapid kVp switching dual-energy CT together with a metal artifact reduction algorithm has shown that this method enables good visualization of coiled aneurysms and the surrounding vasculature in most cases (Figure 4). This method is not always adequate to visualize aneurysms near the skull base. Similar consideration may apply to other hardware used for reconstruction after facial fractures.
Figure 3. Dual-energy CT of head and neck in a 73-year-old male acquired at 80 kVp and 140 kVp shows partially calcified plaque (arrow) in interior carotid artery with mild associated stenosis. Post-processing of the imaging data provides an iodine overlay image showing iodine in orange (A), a virtual non-contrast image by iodine subtraction (B), a monoenergetic image extrapolated to 140 keV (C), and plaque characterization obtained using a hard plaque application algorithm that differentiates iodine (blue) from calcium (red) (D).

Figure 4. Dual-energy CT in a patient with a coil-embolized aneurysm. Monoenergetic reconstruction at 64 keV (which matches the mean energy of standard 120 kVp) shows severe metal artifact (A). Monoenergetic reconstruction at 140 keV reduced the metal artifact and enables better visualization of the surrounding brain parenchyma and vasculature (B).
Scheduling
Dual-energy CT is offered at Mass General Imaging facilities on the main campus in Boston. Referring physicians may request this modality, or radiologists can choose it depending on the patient’s circumstances. If requested, dual-energy CT should be specified in the instructions associated with the scan. Appointments can be made through ROE (inside Partners network) or ROE Portal (outside Partners network) or by calling 617-724-XRAY (9729).

Further Information
For further information on dual-energy CT applications in neuroimaging, please contact Raj Gupta, MD, PhD, Neuroimaging Division, Department of Radiology, Massachusetts General Hospital, at 617-643-4592.

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References


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