Dual-Energy Computed Tomographic Applications for Differentiation of Intracranial Hemorrhage, Calcium, and Iodine

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KEYWORDS

- Dual-energy CT • Intracranial hemorrhage • Calcification • Iodine staining • Iodine map
- Calcium overlay maps • Material decomposition • Virtual non-contrast images

KEY POINTS

- Dual-energy computed tomography (CT) uses the energy-dependent attenuation of different elements to allow decomposition of materials on a voxel-by-voxel basis.
- Dual-energy CT (DECT) material decomposition can accurately differentiate between calcification and hemorrhage for any indeterminate hyperdensity in the brain.
- In patients who have previously received intra-arterial or intravenous iodinated contrast, DECT can differentiate intracranial hemorrhage from contrast.

INTRODUCTION

Computed tomography (CT) remains an important tool in neuroimaging despite the advent and popularity of MR imaging, due in part to its wide availability, rapid acquisition, and high spatial resolution. Limited ability to differentiate materials with similar x-ray attenuation is an important limitation of this modality, whereby images are typically acquired using a single peak kilovoltage (kVp) that produces a polychromatic spectrum. Dual-energy CT (DECT) offers the ability to exploit the energy-dependent attenuation of different elements to allow decomposition of materials on a voxel-by-voxel basis. Emerging applications of this powerful technique in neurologic imaging include differentiation of intracranial calcification versus hemorrhage, postprocedure iodine staining versus hemorrhagic transformation, and bland versus tumoral hemorrhage, among others.

MATERIAL DECOMPOSITION PRINCIPLES

Attenuation of radiographs used in diagnostic imaging is dependent on 2 major interactions: the photoelectric effect and Compton scattering. The photoelectric effect is highly dependent on the atomic number (Z) of the element and energy of the x-ray beam (E) and dominates at lower energies with a spike of photon absorption near the

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K-edge. Compton scattering, on the other hand, is dependent on electron density and has little energy dependence. The CT attenuation value used in clinical imaging relies on a combination of these 2 interactions and is therefore a function of the atomic number and electron density of the material being measured as well as the energy spectrum of the x-ray beam used for measurement.

Conventional CT uses a single peak voltage (kVp) and thus performs a measurement with a single energy spectrum, while DECT enables measurements using 2 different energy spectra. Measurement using a single spectrum does not allow the differentiation or decomposition of materials, because the attenuation coefficient is not unique to a material but is dependent on the energy of the x-ray beam and concentration of each material. For example, a lower concentration of a higher Z material (ie, iodine) may have the same attenuation as higher concentration of a lower Z material (ie, calcium) at a given energy. However, measurement at 2 different energies may be able to distinguish between these 2 materials because their total attenuation (which is a sum of their photoelectric and Compton scattering components) will not be the same at both energies.

DECT exploits the energy-dependent attenuation differences of elements to allow the decomposition of a mixture of materials in each voxel. The most widely available systems use 2 distinct energy spectra, using either a single source that rapidly switches between 2 energy levels, typically 80 and 140 kVp (GSI; GE Healthcare, Waukesha, WI, USA), or 2 orthogonally oriented imaging chains each operated at a different peak voltage, either 80 and 140 kVp (SOMATOM Flash; Siemens, Forchheim, Germany) or 80 and 150 kVp (SOMATOM Force; Siemens). Other implementations include a multilayer detector system (IQon Spectral CT; Philips, Andover, MA, USA) that allows detection of low and high energy at different layers, and photon-counting systems under development that allow separation of incident radiograph into multiple energy bins.

The attenuation coefficient of a mixture of materials can be modeled as a combination of photoelectric effect and Compton scattering, or as the linear combination of attenuation coefficient of individual basis materials (excluding the k-edges). The latter method is of interest in material decomposition because it allows for the calculation of the concentrations of the 2 known materials in a voxel, using available data on energy-dependent mass attenuation coefficient of standard materials. Two-material decomposition assumes the presence of only 2 basis materials, and models other constituents as a combination of the 2. Two-material decomposition is the most straightforward implementation and is practical when decomposition of 2 materials is the question of clinical interest (eg, iodine vs hemorrhage). Two-material decomposition algorithm can be performed before reconstruction using projection data or after reconstruction of 2 sets of different energy images. Three-material composition algorithm allows the determination of the mass fraction of 3 known materials based on assumption of conservation of mass.[1] Detailed description of dual-energy principles and methods can be found in separate articles in this issue as well as a recent review by McCollough and colleagues.[2]

DUAL-ENERGY COMPUTED TOMOGRAPHIC IMAGE POSTPROCESSING

Commercial software is available from each of the major DECT vendors that allows for postprocessing of images and analysis. Software packages differ in their implementation and terminology, but in general, vendor-specific workstations are used for postprocessing, qualitative analysis, and construction of material-specific images sent to PACS for clinical interpretation. In addition to material-specific images, a mixed image using a combination of high- and low-energy data is often created to simulate a conventional CT image performed at 120 kVp. Each material has a characteristic ratio of attenuation at high and low energies, and a threshold often referred to as the dual-energy ratio or iodine ratio can be specified in the postprocessing workflow to achieve the best separation of 2 materials. In 2-material decomposition, pairs of basis material images can be generated, each displaying the distribution of one of the specified materials (eg, water-calcium, water-iodine, calcium-iodine). The pixels attributable to a specific material are sometimes color coded and displayed as material-specific images (ie, calcium-overlay, iodine-overlay), removed from the image to produce subtraction images (ie, virtual noncalcium, virtual noncontrast), or superimposed on conventional images in a sliding scale.

DIFFERENTIATION OF HEMORRHAGE AND CALCIFICATION

Intracranial hemorrhage and calcification can both appear hyperdense on conventional polychromatic CT and can have overlapping attenuation coefficients depending on their respective concentrations. Although the 2 can usually be differentiated based on clinical history, location, morphology, and density characteristics, diagnostic dilemmas