Dual-Energy Computed Tomography Angiography of the Head and Neck and Related Applications

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KEYWORDS

- Dual-energy CT • Neurovascular • Bone-removal • Virtual non-contrast • Virtual monochromatic • "Spot-sign"

KEY POINTS

- Neurovascular dual-energy CT applications include automated bone removal, creation of virtual noncontrast, noncalcium, and monochromatic images, and metallic artifact reduction.
- Automated bone removal reduces interpretation time and potentially increases accuracy by improved depiction of neurovascular structures and abnormalities.
- Virtual noncontrast and iodine overlay images improve depiction of "spot sign" as a marker of active bleeding and to predict hematoma expansion and patient prognosis.
- Low keV virtual monochromatic images can be used to improve iodinated contrast attenuation and/or reduce contrast dose.
- High-keV virtual monochromatic images and other DECT-based metal artifact techniques can significantly reduce image degradation from aneurysm clips and coils.

INTRODUCTION

Dual-energy computed tomography (DECT) technology has become increasingly available on the high-end computed tomography (CT) platforms most common at large medical centers and teaching institutions with the potential for much wider adoption given its proposed capacity to improve CT diagnosis. For neuroimaging, the advantages of DECT lie in greater tissue characterization and differentiation than conventional CT, more akin to the capabilities of MR imaging in advanced neurodiagnostics. For neurovascular indications, increased accuracy, efficiency, and diagnostic confidence can be achieved, especially in the acute setting where CT remains the preferred imaging method or in patients with contraindications to MR imaging.

DECT tissue characterization is based on predictable attenuation differences of various materials when exposed to 2 different energy x-ray spectra and is discussed in detail in the first 2 articles in this issue (see Reza Forghani and colleagues' article, "Dual Energy CT: Physical Principles, Approaches to Scanning, Usage, and Implementation - Part 1"; and Reza Forghani and colleagues' article, "Dual Energy CT: Physical

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Principles, Approaches to Scanning, Usage, and Implementation - Part 2" in this issue). If using a dual-source DECT system, mixed or blended images are created from weighted averages of the high- and low- peak kilovoltage (kVp) image data to simulate traditional single-source CT images. However, the changes in tissue attenuation between these 2 datasets can be mathematically correlated to expected characteristic changes of constituent basis materials such as iodine, calcium, and water. The degree to which the expected characteristic attenuation differences for the basis materials are observed when mathematically comparing the high- and low-energy data sets enables an estimation of the relative percentage of the various basis materials on a voxel-wise basis. This material decomposition can then be used to create material-selective or tissue-weighted image reconstructions such as bone- or calcium-subtracted images, iodine overlay, and virtual noncontrast (VNC) images. Virtual monochromatic (monoenergetic) images can also be derived from this material decomposition. By reconstructing images reflecting the lower or higher energies within the polychromatic x-ray spectra used for CT acquisition, accentuation of iodine contrast enhancement or reduction of metallic artifact from aneurysm coils or clips can be achieved, respectively. This article provides an illustrative overview of the key applications of DECT technique for neurovascular imaging and their clinical utility.

FUNDAMENTAL PRINCIPLES OF DUAL-ENERGY COMPUTED TOMOGRAPHY ACQUISITION, MATERIAL CHARACTERIZATION, AND POSTPROCESSING

Dual-Energy Computed Tomography Acquisition and Material Characterization

The various commercially available DECT scanners and different methods for acquiring images are discussed in detail in the first 2 articles of this issue and will not be reviewed here. A detailed discussion of DECT principles and material characterization can also be found in the first 2 articles in this issue, but will be briefly reviewed here (see Reza Forghani and colleagues' article, "Dual Energy CT: Physical Principles, Approaches to Scanning, Usage, and Implementation - Part 1"; and Reza Forghani and colleagues' article, "Dual Energy CT: Physical Principles, Approaches to Scanning, Usage, and Implementation - Part 2" in this issue). Tissue characterization in both conventional and DECT is based on the differential x-ray photon attenuation from the various materials that are encountered during medical scanning, including different soft tissues, fluids, and bone, as well as exogenous materials such as metal and contrast agents. In the energy range used in medical imaging, x-ray attenuation is attributable primarily to photoelectric absorption (PEA) and photon scatter (Compton effect). The likelihood of PEA depends on an element's K-edge, atomic number, and the incident photon energy. The K-edge is the binding energy of the atom's innermost electron shell. At energies slightly above the K-edge of an element, the probability of PE absorption is sharply increased. Therefore, at energies just above the K-edge, there is a sharp increase in attenuation followed by a rapid decline with increases in energy away from the K-edge. Furthermore, PEA is proportional to the cube of the atomic number (Z^3) and inversely proportional to the cube of the incident photon energy ($1/E^3$). Therefore, elements with a higher Z have a much higher likelihood of PEA, which can be exploited using DECT approaches.

Compton effect is the decrease in energy of an incident photon scattered by its interaction with outer shell electrons of a particular atomic material. The likelihood of this event is proportional to the number of outer shell electrons, which relates both to electron density of the given element and to the physical density of the overall material. The likelihood of the Compton effect does not change with the atomic number and shows little energy dependence, in contrast to PEA.

In DECT, attenuation data are gathered from materials exposed to 2 different polychromatic x-ray beams, enabling evaluation and characterization of the energy-dependent attenuation characteristics of different materials and tissues. In general, the elements constituting most soft tissues in the body, such as hydrogen, carbon, oxygen, and nitrogen, have low atomic numbers and typically demonstrate little energy-dependent changes in their attenuation. Elements with higher atomic numbers such as iodine, on the other hand, demonstrate significant energy dependency of their attenuation that can be exploited using DECT approaches.

Dual-Energy Computed Tomography Postprocessing

The imaging datasets acquired by DECT can be used to calculate effective atomic numbers, for 2- or 3-material decomposition, and to create virtual monochromatic images. The postprocessing tools and different DECT reconstructions are discussed in detail in multiple accompanying articles in this issue but are briefly reviewed here as well.

Calculation of effective atomic number

When dealing with materials composed of more than one element, a useful tool is to calculate an