Miscellaneous and Emerging Applications of Dual-Energy Computed Tomography for the Evaluation of Pathologies in the Head and Neck

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KEYWORDS

• Computed tomography • Dual-energy • Head and neck • Monochromatic imaging

KEY POINTS

- Dual-energy computed tomography (DECT) scanning of the head and neck may have added value over single-source multidetector computed tomography, providing radiologists with a technology that has the potential to improve detection and characterization of benign and malignant abnormalities.
- Iodine quantification may represent an alternative imaging biomarker for differentiating head and neck tumors or monitoring their viability using DECT.
- DECT also allows for reduction of contrast material or radiation dose without compromising image quality or diagnostic accuracy.

INTRODUCTION

Multidetector computed tomography (MDCT) is a well-established method for characterizing and staging a large variety of head and neck lesions. Recent advances in MDCT have allowed for higher temporal and spatial resolution with greater anatomic coverage. Although the technical concept for dual-energy computed tomography (DECT) was originally described more than 4 decades ago, only more recently has it evolved into a multiparametric technique used increasingly in routine clinical practice[1,2] due to its quantitative imaging capabilities. The goal of this article is to briefly explain the technical principles of DECT, describe the most common postprocessing applications, provide an overview of its various clinical applications, and give an outlook on its abilities as a quantitative imaging technique.

BASIC PRINCIPLES OF DUAL-ENERGY COMPUTED TOMOGRAPHY

At x-ray energy spectra relevant to diagnostic imaging (70–150 kilovolt peak or kVp), the predominant interactions between photons and tissue

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matter are mainly represented by the Compton effect (x-ray photons scatter with fractional loss of x-ray energy) and the photoelectric effect (complete x-ray absorption with ejection of a photoelectron). In CT, the Compton effect accounts for a large component of the attenuation but is relatively independent of beam energy. In contrast, photoelectric absorption is highly energy dependent and is therefore key for spectral tissue characterization. Normally, there is a higher probability of photoelectric interactions when the exposed material has a high atomic number. Carbon, oxygen, and nitrogen usually mainly interact with x-ray photons by Compton scattering due to their relatively low atomic number, whereas the photoelectric effect occurs more frequently with higher Z elements such calcium and iodine.[3] When biological tissues containing these materials are penetrated by photons at different energy levels, they can be characterized on the basis of the change in x-ray attenuation at the different energies used.

At higher x-ray tube voltages (eg, 140 kVp), linear attenuation values measured for iodine and calcium are similar. This phenomenon is due to the stronger weighted attenuation coefficient of mass density at higher potentials. In contrast, at lower tube potentials (eg, 80 kVp), the attenuation coefficient is stronger for iodine rather than calcium, which therefore allows for separation and identification of these materials. However, there is also increased x-ray beam tissue absorption at lower potentials, which results in higher image noise.[4]

Currently available DECT systems allow for simultaneous image acquisition using different x-ray energies, most commonly at 80 and 140 kVp. However, peak energies used for image acquisition are not pure monochromatic x-rays beams but polychromatic spectra of photons with various energy levels. Therefore, peak tube voltage (kVp) is typically used to refer to the maximum energy reached by the photons present in each of the spectra (**Table 1**).

Four main different approaches for DECT imaging are currently used, and they vary depending on the manufacturer. These approaches are discussed in the detail in a separate article in this issue but will be briefly reviewed here. The first system consists of 2 x-ray tubes operating at 2 different energies with their relative opposing detectors aligned perpendicularly or nearly perpendicularly ("dual-source DECT"). The second system uses a single x-ray tube that rapidly switches between 2 different energies together with its corresponding detector ("fast-kVp switching DECT"). The third system consists of a single x-ray source, in which the beam is prefiltered and split into high- and low-energy spectra before reaching the patient ("twin-beam DECT"). Finally, the fourth type of system uses one x-ray source and one detector, the latter composed of 2 scintillation layers placed directly on top of each other ("dual-layer DECT"), with scintillation layers that are closer to the source absorbing low-energy photons, and deep layers capturing high-energy photons. Independent of the technical realization, DECT is essentially considered dose-neutral compared with standard single-energy CT.[5]

One of the goals of DECT imaging is to combine the increased iodine attenuation of the low-kVp spectrum with the lower image noise of the high-kVp spectrum in order to obtain an image with highest contrast and lowest noise possible. So far, several DECT postprocessing algorithms have been developed for this purpose.

Table 1
Different energy levels (expressed in kiloelectron volt) adopted in virtual monoenergetic image to better depict various head and neck structures and abnormality

Reference Material	Energetic Level (keV)[a]	Miscellaneous Potential Clinical Applications (eg,)
Iodine	40–60	Tumor enhancement and delineation; vascular anatomy; bleeding point of hemorrhage
Soft tissues	65–70	Best SNR and CNR for head and neck evaluation (similar image quality of single-energy MDCT)
Calcium	~80	Definition of atherosclerotic plaque calcifications; evaluation of perivascular space
Metal hardware/ implants	90–150	Minimizing beam hardening artifacts; evaluating malposition, loosening or disruption of metal implants

[a] keV values may change according to type of DECT approach or platform used. Furthermore, they represent target values based on those recently reported in the scientific literature.