Applications of Dual-Energy Computed Tomography for Artifact Reduction in the Head, Neck, and Spine

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KEYWORDS

- Dual-energy CT • Beam-hardening artifact reduction • Virtual monochromatic imaging
- Virtual subtraction imaging

KEY POINTS

- Conventional single-energy computed tomography, using a polychromatic energy beam, is susceptible to beam-hardening artifacts as well as photon-starvation effect, which can degrade image quality in the setting of implanted metallic hardware, dense osseous structures, and dense intravenous iodinated contrast.
- Dual-energy computed tomography, by analyzing the changes in attenuation of soft tissues at disparate energies, allows for the creation of virtual monochromatic images, which can significantly improve diagnostic image quality by reducing beam-hardening artifact.
- Dual-energy computed tomography, through the process of material decomposition, can be used to virtually eliminate osseous structures as well as intravenous iodinated contrast, allowing for improved visualization of the adjacent soft tissues of interest.

INTRODUCTION

The use of computed tomography (CT) scanning in medical imaging has become ubiquitous, with an estimated 85 million CT scans performed in 2011 alone.[1] Traditional single-energy CT is able to offer exquisite anatomic detail with high contrast and spatial resolution of the structures of the neck and spine. However, despite optimization of modern single-energy CT techniques, technical challenges remain that can significantly degrade the diagnostic quality of these examinations. Especially troublesome is the evaluation of soft tissue structures adjacent to postoperative metallic hardware, dense bony structures, and in the presence of dense contrast within central venous anatomy at the level of the thoracic inlet.

Metallic artifact, in the setting of a polychromatic CT beam, results from the phenomena of beam hardening and photon starvation.[2] Beam hardening occurs as the lower-energy photons of a polyenergetic beam are preferentially absorbed by high atomic number substances, including dense metallic implants. The resultant beam is subsequently composed of only higher-energy photons, resulting in lower tissue contrast immediately adjacent to the metallic implants. The absolute number

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of photons in the resultant beam is also significantly decreased as photons are attenuated by the dense metallic implants. Consequently, an insufficient number of photons are able to reach the detector to provide adequate signal, resulting in significant noise within the adjacent soft tissues, termed the photon-starvation effect.

PRINCIPLES AND STRATEGIES FOR ARTIFACT REDUCTION

The advent of dual-energy CT (DECT) has offered radiologists an additional tool with which to combat and minimize the beam-hardening and photon-starvation artifacts associated with the presence of high atomic number materials, including implanted metal, dense intravenous contrast within central venous structures at the thoracic inlet level, and inherently dense bony structures. Whether through the use of dual-source, fast-kilovoltage switching, or dual-layer detection technology, DECT analyzes the changes in attenuation of different materials at 2 disparate energy levels, and subsequently uses a process termed material decomposition to generate monochromatic DECT images.[3] The methodology of image reconstruction varies based on the acquisition method, with single-source fast-kilovoltage switching images constructed from projection space data, whereas dual-source CT (where high-energy and lower-energy acquisitions are not coincident with each other in a helical acquisition) uses image domain material decomposition.[4] A more in-depth discussion of different DECT systems and DECT postprocessing can be found 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 Principles, Approaches to Scanning, Usage, and Implementation - Part 2," in this issue).

Virtual Monochromatic Series

In both techniques, the differential attenuation detected at lower-energy and higher-energy spectra can be used to generate mass density maps of the imaged tissues from which monochromatic images can be synthesized, and that are accurate for a wide range of atomic numbers. Monochromatic images can thus be generated for multiple different photon energy levels, to simulate how an image would look if the x-rays produced were solely of that single chosen energy level.[5] *Of considerable interest is the ability of the radiologist to choose a virtual monochromatic image (VMI) at an optimal energy level that yields the best contrast-to-noise ratio while minimizing beam-hardening artifact*. Although lower-energy imaging remains susceptible to metallic artifact (thought to be related to additional factors, such as photon starvation and nonlinear partial volume averaging), multiple studies have demonstrated virtual elimination of streak artifact adjacent to postoperative implants by using higher-energy monochromatic energies of greater than approximately 95 keV.[3,6–8]

It is not only the higher-energy VMIs that provide diagnostic benefit, however. Lower-energy monochromatic images still maintain superior tissue contrast, which can be of particular benefit in traditionally difficult to visualize regions, such as the posterior fossa, where evaluation of the parenchymal soft tissues is of primary importance. VMIs with energies in the 65-keV to 75-keV range can provide maximal signal-to-noise and contrast-to-noise ratios in the brain, while diminishing beam-hardening and streak artifacts associated with a polychromatic beam.[9] Thus, VMIs created from DECT data have the potential to markedly reduce beam-hardening artifacts and ameliorate the concomitant photon-starvation effect that degrades evaluation of the head, neck, and spine associated with a polychromatic beam. This can markedly improve the diagnostic evaluation in the setting of postoperative metallic implantation, as well as within inherently problematic areas to image, such as the posterior fossa.

Material Decomposition

The process of material decomposition also allows for the identification of tissue composition within the acquired images. This allows for the creation of material-specific images, which can show the distribution and concentration of a given material within the imaged soft tissues, and consequently also allows for the virtual elimination of the contributed attenuation of the selected material.[3] These subtraction images can allow for the formation of virtual images of the head and neck with materials such as iodinated contrast or osseous structures eliminated, improving visualization of the soft tissues immediately adjacent to these dense materials.[10] This demonstrates clinical applicability in the virtual elimination of intravenous contrast and improved visualization of the intracranial vasculature adjacent to dense osseous structures, such as the skull base.

ARTIFACT-REDUCTION STRATEGIES

In this section, different clinical applications and artifact-reduction strategies are discussed. At