Dual Energy Computed Tomography Applications for the Evaluation of the Spine

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KEYWORDS

• Dual-energy computed tomography • Spine • Osteoporosis • Bone marrow • Trauma
• Bone mineral density

KEY POINTS

- Dual-energy computed tomography (CT) is a rapid and relatively inexpensive tool used to recognize marrow edema associated with acute traumatic injuries to the spine.
- Dual-energy CT can assess marrow infiltration in patients who have contraindications to MR imaging.
- Cancellous bone mineral density measurement with dual-energy CT may be a sensitive biomarker for fracture risk in patients with osteoporosis.
- Monosodium urate deposition imaging with dual-energy CT is an accurate diagnostic technique that can be used to improve our understanding of the spinal manifestations of gout.

INTRODUCTION

The spinal column encompasses in close proximity materials with vastly differing x-ray attenuation characteristics (dense cortical bone, cancellous bone, cerebrospinal fluid and, in post-operative patients, surgical metallic instruments), traditionally rendering this part of the body challenging to image with computed tomography (CT).

Dual-energy CT enables material characterization and differentiation, based on high- and low-peak voltage acquisitions. Materials with equal or near equal attenuation at a certain single energy peak voltage may be differentiated by analyzing energy-dependent changes of their attenuation. This article provides an overview of the major novel indications of dual-energy CT in the evaluation of the diseases of the spinal column.

BONE MINERAL DENSITY IMAGING

Osteoporosis, or loss of bone mass and strength, is a major risk factor for disability. Dual x-ray absorptiometry is the most ubiquitous diagnostic tool to assess bone mineral density; however, it is unable to differentiate cortical and cancellous bone, with the latter being primarily affected by the disease. Single-energy CT provides excellent spatial resolution, but quantification is difficult owing to beam-hardening artifact, x-ray scatter, and the confounding effect of varying amount of fatty bone marrow.[1] Early studies using sequential dual-energy CT yielded improved accuracy, but were limited by motion and misregistration.[2,3] The advent of simultaneous dual-energy scanners allows for significant reduction in beam-hardening artifact and more accurate separation of bone and

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marrow attenuation.[4] Owing to the volumetric nature of the technique, measurement of trabecular bone mineral density can be achieved, providing a sensitive biomarker to predict fracture risk in postmenopausal women. Dual-energy CT acquisition has also been evaluated for use in radiation therapy planning to predict proton stopping power in the vicinity of the spine.[5]

BONE MARROW IMAGING

Unenhanced single-energy CT frequently yields equivocal results in patients with suspected osteoporotic vertebral compression fractures. MR imaging is the standard for the noninvasive assessment of marrow abnormalities and can depict bone marrow edema and hemorrhages, and may clarify the diagnosis in this situation. However, issues with access and safety screening may lead to delays in the final diagnosis and ultimate treatment; in addition, MR imaging is more costly. Patients with contraindications to MR imaging (such as certain implanted devices or noncooperative patients) may benefit from CT marrow imaging as an alternative way to determine the acuity of the fracture.

Recent studies have shown that bone marrow edema after acute trauma of the spine can be detected by using the so-called virtual noncalcium technique.[6,7] Virtual noncalcium dual-energy CT can accurately depict bone marrow edema in patients with osteoporosis with acute vertebral fractures, with good correlation with MR imaging.[8] In 1 study, dual-energy–based bone marrow edema visualization significantly improved the detection rate of acute fractures and was helpful for differentiating them from older fractures compared with single-energy CT images. The investigators also found that a significant number of MR examinations could be avoided using the virtual noncalcium information. This finding is promising in light of numerous studies indicating dose-equivalence of dual-energy acquisition as compared with standard CT scans.[9–11]

Seronegative spondyloarthritis is a chronic inflammatory rheumatologic disease with sacroiliitis as the earliest clinical finding. A recent study demonstrated that dual-energy CT scanning not only depicts findings of chronic sacroiliitis (ie, bone erosion and sclerosis), but also can detect and quantify the extent of marrow edema in the subchondral bone.[12,13]

CT scanning is the primary modality in cancer staging owing to its wide availability, relatively low cost, short scanning times, and consequent high patient tolerance. A major limitation of standard CT scanning is its lower sensitivity for the detection of nonlytic bone marrow infiltration in the axial skeleton, where visualization and measurement of bone marrow attenuation are severely hampered by the dense trabecular structure of the cancellous bone. A recent study has demonstrated that bone marrow images created from dual-energy CT scanning datasets of the spine have the potential to improve the sensitivity for the detection of diffuse bone marrow infiltration in patients with multiple myeloma, especially in cases with high-grade infiltration (**Fig. 1**).[14] It remains elusive how the presence of iodine-based contrast might affect the quality of this virtual noncalcium technique. Patients with multifocal nodular bone marrow involvement may also benefit from dual-energy CT–guided bone marrow sampling.

POSTOPERATIVE SPINE

Metallic instrumentation interferes with the quality of single-energy CT imaging because of beam hardening (owing to the preferential absorption of low energy or "soft" x-rays in the polyenergetic x-ray beam spectrum as x-rays pass through the body), photon starvation, and scatter artifacts (caused by their high x-ray attenuation coefficient). Despite advances in detector technology and optimized image reconstruction, artifacts from metal implants remain a problem. Dual-energy CT scanning, allowing for analysis of energy-dependent changes in the attenuation of different materials, has been proposed as a means to reduce beam-hardening metal artifacts by generating virtual monoenergetic images.[15–17] It has been demonstrated that reconstruction of images at higher extrapolated monoenergetic x-ray energies significantly diminishes (without completely eliminating) the artifacts radially projecting from the hardware, however, at the expense of diminished soft tissue contrast.[18] A recently published reconstruction technique combines the benefits of multiple reconstructed monochromatic datasets[19] by blending the superior soft tissue and iodine contrast conspicuity at lower energies and the reduced noise and metallic artifact at medium energy images. Dual-energy CT myelography and virtual myelography are other opportunities to reduce radiation dose and minimize artifact in patients with prior osteosynthesis.[20] The assessment of the postoperative spine in patients with metallic instrumentation and various measures to reduce metallic artifact is discussed in detail (See Eric Liao and Ashok Srinivasan's article, "Applications of Dual Energy CT for Artifact Reduction in the Head, Neck, and Spine," in this issue).