The Role of Dual-Energy Computed Tomography in Musculoskeletal Imaging

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KEYWORDS

• Dual energy • Spectral • Computed tomography • DECT • Musculoskeletal

KEY POINTS

- Dual-energy computed tomography (DECT) can reduce beam hardening artifacts by synthesizing a virtual monochromatic image and enables detailed evaluation of prosthetic complications.
- DECT can display monosodium urate crystal deposition, which helps to make a correct diagnosis in atypical gout and precise therapeutic assessment.
- DECT iodine maps can delineate soft tissue inflammation of arthritis and may be beneficial for evaluating peripheral joints because of its high spatial resolution.

INTRODUCTION

Dual-energy computed tomography (DECT) enables material decomposition and acquisition of virtual monochromatic images by performing 2 exposures at different energy levels. Its development has led to several interesting image processing applications that have been applied to a range of clinical entities. Bone removal in DECT angiography may be useful for detecting aneurysms adjacent to the skull base.[1] Iodine maps for pulmonary embolism have shown perfusion defects in areas of vascular occlusion.[2] For musculoskeletal imaging, DECT has been used to create virtual noncalcium images, to diagnose and follow the progression of gout, to create iodine maps, and to examine tendons through material decomposition techniques. Furthermore, virtual monochromatic images have also been used in musculoskeletal imaging to reduce metal artifacts when imaging patients with arthroplasty. In this article, the authors review these musculoskeletal imaging techniques with some representative cases.

All subjects were examined in the authors' institution with dual-source DECT (SOMATOM Definition Flash; Siemens Healthineers, Forchheim, Germany), and all images were created on a commercial workstation (Syngo Dual Energy; Siemens Healthineers Erlangen, Germany).

VARIETY OF DUAL-ENERGY COMPUTED TOMOGRAPHY IMAGE ACQUISITION TECHNIQUES

There are several ways to acquire DECT data, including sequential acquisition, dual source, rapid kilovoltage switching, and double layer technology.[3–5]

Sequential acquisition requires 2 separate sequential scans at different energy levels. It needs only the most basic hardware, but the high radiation dose, long acquisition time, and misregistration limit its utility.[3,5]

Dual-source DECT carries 2 independent X-ray tubes orthogonally in one unit so that data from the 2 different energy levels can be obtained at

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the same time. This technology allows the current modulation in each tube and tin filter usage. Tin filter reduces unnecessary radiation exposure and emphasizes spectral separation between low- and high-energy X-ray beams. However, the cross-scatter radiation that occurs with 2 simultaneous radiographs may cause deterioration of the data.[5]

Rapid kilovoltage switching uses a single X-ray tube that switches rapidly between 2 different energy settings. The high temporal resolution limits motion artifacts, but adapting the tube current is difficult.[3] The radiation dose and long scanning time are the main disadvantages.[5]

Last, double layer technology uses 2 detector layers: lower-energy radiographs are absorbed by the superficial detector layer and higher-energy radiographs are absorbed by the deeper detector layer. This technology provides temporo-spatially matched dual-energy data while preserving a full field of view. However, a high radiation dose is required to compensate for poor soft tissue contrast.[3,5]

Currently, dual source (Siemens Healthineers) and fast kilovoltage switching (GE Healthcare) are the market-leading technologies, and most of the available clinical data related to DECT have been obtained using these techniques.

VIRTUAL MONOCHROMATIC IMAGES

For musculoskeletal radiologists, interpreting the images of patients with metallic prostheses for surgical and postsurgical complications, such as infection, metallic prosthesis loosening, and fracture, is a daily task. Recently, the importance of early diagnosis of adverse local tissue reactions in arthroplasty has been recognized.[6] MR imaging is ideal for detecting soft tissue pathologic condition, but higher magnetic field makes the effect of magnetic susceptibility of metal increased. Recently, advanced techniques, such as slice encoding for metal artifact correction and multiacquisition with variable-resonance image combination, have been available for metallic artifact reduction and dedicated to the better image quality.[7,8] Conventional CT also suffers image deterioration from beam hardening artifacts. Polychromatic radiographs from conventional CT include low-energy radiographs, which are responsible for beam hardening artifacts.[9] On the other hand, DECT allows creation of a virtual monochromatic energy image from which complications adjacent to metallic implants can be evaluated with less artifact (**Fig. 1**). Beam hardening can be eliminated by increasing X-ray energy, with the optimal virtual monochromatic energy reported as between 105 and 150 keV.[10–14] However, increasing the X-ray energy diminishes the soft tissue contrast that is important for evaluating soft tissue complications around surgical devices. Bamberg and colleagues[11] suggested that 105 keV may be the ideal energy for the evaluation of bone and soft tissue surrounding prostheses. If applicable, metal artifact reduction software added to DECT monochromatic images further reduces metallic artifacts.[10,15,16] Recently tailoring the monochromatic energy to the implant type has been recommended by Wellenberg and colleagues.[17] They suggested that stainless steel implants produced more severe artifacts and needed higher monochromatic energy settings for optimal artifact reduction than titanium implants.

VIRTUAL NONCALCIUM IMAGES

DECT virtual noncalcium (VNCa) images are an image processing technique that subtracts high-attenuation calcium from cancellous bone to depict several bone marrow lesions. As the representative lesion, bone marrow edema is a common pathologic condition in clinical usage. On MR imaging, bone marrow edema is detected as hypointensity on T1-weighted images and ill-defined hyperintensity on fluid-sensitive sequences. Although CT has high spatial resolution and allows retrospective reconstruction of images, MR imaging can diagnose occult or nondisplaced fractures more precisely by delineating the fracture line and surrounding bone marrow edema.[18,19] With the DECT VNCa technique, edema in bone marrow can be detected on grayscale or color-coded images. It is thought that color-coded maps are better for detecting attenuation changes in bone marrow edema.[20] Because Pache and colleagues[21] used VNCa images for acute knee trauma in 2010, several other studies have reported the validity of VNCa images for detecting bone marrow edema in subjects with trauma or fracture[21–28] (**Table 1**), particularly in vertebral fractures. The sensitivity and specificity of VNCa images for detecting bone marrow edema were acceptable except for the low specificity from a study of nondisplaced hip fractures.[25] In that study there were 3 false-positive cases, but their reference was not MR imaging, which is sensitive to bone marrow edema. Because of the visibility of bone marrow edema, a recent article showed that adding DECT VNCa to conventional bone reconstruction increased diagnostic sensitivity, specificity, and confidence in images of patients with fracture[29,30] (**Fig. 2**). Some limitations have also been reported. Bone marrow lesions adjacent to cortical bone could not be detected with VNCa images due to spatial averaging effects.[21] Wang and colleagues[23] also suggested that gas and