Dual-Energy Computed Tomography

Advantages in the Acute Setting

Patrick D. McLaughlin, MB BCh BAO, FFR RCSI, FRCPC*,
Paul Mallinson, FRCPC, Pedro Lourenco, MD, Savvas Nicolaou, MD, FRCPC

KEYWORDS

• Dual energy • Computed tomography • Trauma • Gout • Uric acid • Marrow edema

KEY POINTS

- The fundamental principle of dual-energy (DECT) and spectral CT imaging is that certain materials with a high atomic weight have significantly higher attenuation values when exposed to an x-ray beam of low rather than high mean kV values.
- Dual-energy (DECT) and spectral CT post processing allows for material specific display and subtraction. Material specific identification of uric acid crystals can greatly benefit patients who present with acute articular pain and acute flank pain.
- Material specific subtraction of calcium allows for accurate detection of bone marrow hemorrhage and edema. Material specific subtraction and quantification of iodine allows more accurate characterization of abdominal incidentalomas.
- Image quality optimization is possible using energy specific display techniques.

INTRODUCTION

Since its first public unveiling in 1973, computed tomography (CT) has played a profound role in medical diagnosis, greatly enhancing the depth of understanding of many disease processes. Academic and industry collaboration has resulted in unparalleled evolution of CT technology and techniques over the past 40 years. The first CT system produced by Electric and Musical Industries produced one 80 × 80-pixel axial image after 5 minutes of scanning, whereas state-of-the-art CT technology today can acquire 1200 axial images of 512 × 512 pixels in 1 second, representing an increase in efficiency of 1.5 billion percent.[1]

The concept of acquiring 2 sets of CT images with different x-ray spectra to enhance material differentiation was conceived and tested only 5 years after the initial public unveiling of CT.[2] Original attempts at dual-energy imaging involved the acquisition of 2 separate, contemporaneous CT scans and clinical results were greatly impacted by variability in phase of contrast enhancement, patient motion, limited spatial resolution, instability of CT attenuation values, and postprocessing difficulties. These limitations were addressed with the introduction of dual-source CT in 2006 and in the subsequent 9 years dual-energy CT (DECT) has regained clinical significance and widespread application.[3] Today, several CT vendors have implemented DECT with different technical approaches, and integration into the diagnostic pathways of emergency medicine continues to grow. For in-depth

Disclosures: P.D. McLaughlin – Speaker, Innovations Conference 2014 (Siemens Healthcare).
Department of Radiology, Vancouver General Hospital, University of British Columbia, 899 West 12th Avenue, Vancouver V5Z 1M9, Canada
* Corresponding author.
E-mail address: mclaughlin.paddy@gmail.com

Radiol Clin N Am 53 (2015) 619–638
http://dx.doi.org/10.1016/j.rcl.2015.02.016

information regarding the technical characteristics of single-source fast kV switching, single-source dual-layer detector, and dual-source implementations of DECT, the reader is directed to an excellent summary of the topic by Marin and colleagues.[4]

The fundamental principle of DECT and spectral CT imaging is that certain materials can have significantly higher or lower attenuation values when exposed to an x-ray beam of different mean kV values. Elements with a high atomic number (Z), such as iodine, xenon, and calcium (Z = 53, Z = 54, and Z = 20), attenuate a greater proportion of low kV rather than high kV photons due to photoelectric effect. The photoelectric effect occurs because the k-edge of these elements (I = 33 keV, Xe = 34.6 keV, Ca = 4.03 keV) is more closely matched to the mean energy of the low-kV source. Elements such as hydrogen, oxygen, carbon, and nitrogen, os which the human body primarily consists, have low atomic numbers (Z = 1, Z = 8, Z = 6, and Z = 7) and therefore attenuate low kV and high kV photons in a more equal manner given that neither beam is sufficiently matched to their very low k-edge values. This characteristic and reproducible behavior provides the basis for material differentiation achieved by postprocessing software that maps different tissues according to their unique dual-energy index (DEI).[5]

$$DEI = \frac{x_{80} - x_{140}}{x_{80} + x_{140} + 2000},$$

In parallel with the aforementioned technical advances, the medical community has witnessed an exponential increase in the use of CT in the acute care setting over the past 20 years. A retrospective study conducted in the United States involving 1.29 billion weighted emergency department visits found that CT use in the emergency department has increased from 3% of visits in 1996 to 14% of visits in 2007.[6] This study found that increased CT usage has been driven primarily by expanded indications in patients with acute flank pain, acute abdominal pain, trauma, and acute chest pain. The unique demands that are placed on CT in the emergency and trauma settings play well to the strengths of DECT. In our experience, the ability of DECT to successfully differentiate densely organized uric acid crystals or uric acid–containing calculi from calcium-containing compounds is pivotal to the management of many patients presenting to the emergency department. The manipulation of dual-energy data to enhance, quantify, and subtract iodine-based contrast agents is an exciting and rapidly evolving field of research with great potential to increase diagnostic yield over single-energy CT (SECT) in the setting of acute chest and abdominal pain and also to help reduce the number of costly follow-up examinations of abdominal incidentalomas. The aim of this article is to inform and update emergency radiologists in respect of the clinically relevant benefits that DECT contributes over conventional CT in the emergency setting using practical imaging examples. The relevant scientific literature will be summarized and limitations of the technique also will be emphasized to provide the reader with a rounded concept of the current state of technology.

GOUT

Clinical Characteristics

Gout is the most common crystal-induced arthritis. It is characterized by extracellular fluid saturation, with the final product of purine metabolism, uric acid, which densely precipitates into rodlike crystals within soft tissues after binding with sodium ions to form monosodium urate (MSU) ($NaC_5H_3N_4O_3$ H_2O). Deposition of MSU crystals within articular and synovial soft tissues as well as ligaments and tendons can result in well-described clinical manifestations, including recurrent attacks of acute inflammatory arthritis, chronic arthropathy, and importantly, from the perspective of DECT imaging, macroscopic accumulation of MSU crystals in the form of tophaceous deposits.[7]

Patients typically present to the emergency department with severe pain, redness, warmth, and swelling of a joint. Maximal severity of the attack is usually reached within 12 to 24 hours with complete resolution of pain almost always occurring within a few days to several weeks, even in untreated individuals. When a patient presents to the emergency department with suspected gout, a definitive diagnosis should be sought given the clinical and laboratory overlap with septic arthritis.[8] Acute monoarticular gout can cause fever, leukocytosis, and elevated erythrocyte sedimentation rate and therefore can be clinically indistinguishable from acute septic arthritis.[9]

At least 80% of initial attacks of gout involve a single joint, most frequently the first metatarsophalangeal joint and second most commonly the knee. A potential explanation for preferential involvement of the lower limb and in particular the first metatarsophalangeal joint is temperature. A reduction of temperature by 2°C, from 37 to 35°C has been shown in in vitro studies to lower the solubility point of urate from 6.8 to