European Journal of Radiology 85 (2016) 1829–1834

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Single source dual-energy computed tomography in the diagnosis of gout: Diagnostic reliability in comparison to digital radiography and conventional computed tomography of the feet

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ARTICLE INFO

Article history:
Received 5 July 2016
Accepted 6 August 2016

Keywords:
Crystal arthropathy
Gout
Dual-energy ct
Single source dual-energy

ABSTRACT

Objectives: To investigate the diagnostic value of single-source dual-energy computed tomography (SDECT) in gouty arthritis and to compare its capability to detect urate depositions with digital radiography (DR) and conventional computed tomography (CT).
Methods: Forty-four patients who underwent SDECT volume scans of the feet for suspected gouty arthritis were retrospectively analyzed. SDECT, CT (both n = 44) and DR (n = 36) were scored by three blinded readers for presence of osteoarthritis, erosions, and tophi. A diagnosis was made for each imaging modality. Results were compared to the clinical diagnosis using the American College of Rheumatology (ACR) classification criteria.
Results: The patient population was divided into a gout (n = 21) and control (n = 23) group based on final clinical diagnosis. Osteoarthritis was evident in 15 joints using CT and 30 joints using DR ($p = 0.165$). There were 134 erosions detected by CT compared to 38 erosions detected by DR ($p < 0.001$). In total 119 tophi were detected by SDECT, compared to 85 tophi by CT ($p = 0.182$) and 25 tophi by DR ($p < 0.001$). SDECT had best diagnostic value for diagnosis of gout compared to DR and conventional CT (sensitivity and specificity for SDECT: 71.4% and 95.7%, CT: 71.4% and 91.3% and DR: 44.4% and 83.3%, respectively). For all three readers, Cohen's kappa for DR and conventional CT were substantial for all scoring items and ranged from 0.75 to 0.77 and 0.72–0.76, respectively. For SDECT Cohen's kappa was good to almost perfect with 0.77–0.84.
Conclusions: SDECT is capable to detect uric acid depositions with good sensitivity and high specificity in feet, therefore diagnostic confidence is improved. Using SDECT, inter-reader variance can be markedly reduced for the detection of gouty tophi.

1. Introduction

Gout is an inflammatory arthropathy presenting with acute arthritis in early disease. Later stages are associated with joint destruction, tophus formation, renal insufficiency and possibly cardiovascular diseases [1]. Several publications have shown that dual-energy computed tomography is a useful and reliable diagnostic tool for diagnosis of chronic tophaceous gout [2–5]. In most of these studies, however, patients were examined in the so-called dual source mode on CT scanners equipped with two X-ray tubes. Different solutions have been developed to per-

Abbreviations: SDECT, single source dual-energy computed tomography; CPPD, calcium pyrophosphate dehydrate; MSU, monosodium urate; US, ultrasound; PCSCT, photon-counting spectral computed tomography; DR, digital radiography; ESR, erythrocyte sedimentation rate; CRP, c-reactive protein; DLP, dose-length-product; $CTDI_{vol}$, volume computed tomography dose index; ROI, region of interest; MIP, smaximum intensity projections; TJ, intertarsal joints; TMT, tarsometatarsal joints; MTP, metatarsophalangeal joints; PIP, proximal interphalangeal joints; DIP, distal interphalangeal joints.

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http://dx.doi.org/10.1016/j.ejrad.2016.08.004
0720-048X/

form dual-energy imaging on single source dual-energy computed tomography (SDECT) systems. [6–8]

In most cases, the diagnosis of gout is established by clinical presentation with acute arthritis on the first metatarsophalangeal joint (podagra) and supported by the presence of hyperuricemia without need for further diagnostic tests [9]. However, gout can resemble or coexist with other diseases such as rheumatoid arthritis, septic arthritis, osteoarthritis or other crystal-induced arthropathies such as calcium pyrophosphate dehydrate (CPPD) crystal deposition disease [9]. Besides, it is commonly known that the serum level of uric acid can be within normal limits in acute gouty arthritis [10]. The current standard of reference for the diagnosis of gout is joint aspiration showing monosodium urate (MSU) crystals in polarized light microscopy [11,12]. However, identification via puncture is not always possible [13], especially when small joints such as the metatarsophalangeal joints are affected. Recently, ultrasound (US) has been proposed as a viable alternative for the diagnosis of gout [2]; however, the detection of gout by US requires a skilled examiner.

Dual-energy computed tomography relies on the principle that tissues have different Hounsfield numbers at various kVp. This results in a specific dual-energy gradient for each material or tissue, which can be used to characterize biological tissues or crystals depositions [14–17]. Dual-energy computed tomography has been shown to identify chronic and tophaceous gout with high sensitivity and specificity [4,5], while sensitivity appears to be lower in early stage disease [3].

In the last few years, research efforts have been undertaken to develop and implement techniques allowing use of the dual-energy computed tomography imaging method on conventional CT scanners with one X-ray tube (single source). One solution is the rapid-kilo voltage-switching method, which uses a generator that allows fast switching between high and low tube voltage in 0.5 milliseconds during one rotation [7,18,19]. Another method for material decomposition on a single tube CT scanner is photon-counting spectral computed tomography (PCSCT). PCSCT uses a photon-counting detector to split the X-ray spectrum into separate energy bins, collecting different CT data in each energy bin for material decomposition [20].

Another solution is sequential data acquisition at two voltages on a conventional single-source CT scanner (single-source dual-energy computed tomography – SDECT) [6,21]. This can be accomplished either by using two different spiral scans in conjunction with a co-registration software to reduce motion artifacts or by scanning two different volumes one after the other with a wide area detector without the need for table movement, as used in our study. The benefit of this method is the possibility of tube current adaption between both scans for similar image noise and dose optimization. It has been shown in a recently established phantom model that SDECT is capable of detecting MSU crystal deposition [22]. Initial clinical results with SDECT in comparison with synovial fluid analysis in a small number of patients have been promising [23].

The aim of this study was to investigate the diagnostic accuracy of SDECT in suspected gout and to compare its diagnostic capabilities with conventional CT and digital radiography (DR) in the context of the clinical diagnosis of gout.

2. Methods

2.1. Study subjects

We retrospectively investigated 47 patients (30 men, 17 women) who underwent SDECT of one (n = 18) or both (n = 29) feet in the period from February 2011 to July 2013. All patients were referred to our institution with acute arthritis of the feet suspicious for gouty arthritis. Three patients had to be excluded from analysis because no clinical diagnosis by a rheumatologist to serve as standard of reference was available. The study was approved by the local ethics committee, and all patients gave written informed consent.

2.2. Clinical features

To compare the imaging findings with the clinical presentation we retrospectively collected the following items: serum uric acid, leucocytes, erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), creatinine, and final diagnosis made by referring rheumatologists using the American College of Rheumatology criteria [24]. Based on the rheumatologist's final diagnosis the patients were divided into group A (gout) or group B (other diseases, controls).

2.3. Single source dual-energy computed tomography (SDECT)

All patients underwent an SDECT on a 320-row CT scanner (Toshiba Aquilion ONE^{TM}, Toshiba Medical Systems Corporation, Japan) in the dual-energy volume scan mode with 16 cm z-axis coverage without table movement [25]. The low-energy scan was performed with 80 kVp and 90–110 mAs, the high-energy scan with 135 kVp and 15–20 mAs, resulting in an overall dose-length-product (DLP) of 24.1–30.5 mGy*cm, a volume computed tomography dose index ($CTDI_{vol}$) of 1.5–1.9 mGy and a calculated radiation dose for the patient of 0.019–0.024 mSv.

For conventional CT scoring, multi-planar images were reconstructed in all three planes from the 135 kVp-datasets in 0.5 mm slice thickness in a soft-tissue kernel. The SDECT scans were evaluated using dual-energy composition analysis software (Product Software Version 6.0, Toshiba Medical Systems Corporation, Japan) utilizing a co-registration algorithm to correct for potential motion influences between both datasets. We applied a gradient of 1.07 for MSU crystals and 0.60 for calcium and bone derived from our previous phantom test [22]. The resulting dual energy graph with the region of interest (ROI) for the gout differentiation is shown in Fig. 1. SDECT image reading was performed using a 3-dimensional reconstruction as well as cross-sectional images jointly visualized on one high-resolution monitor. Areas positive for uric acid deposition were automatically colored in red by the analysis software.

2.4. Scoring

Image interpretation was done by three readers with different experience (reader 1, a research student with no experience in musculoskeletal image reading, reader 2, a resident with 3 years of experience, and reader 3, an expert musculoskeletal radiologist with 12 years of experience). Before commencing scoring of images, reader 1 obtained proper training during a joint read session by all three readers. Five cases were scored in consensus (digital radiography, conventional CT and SDECT for each case), and results of this session were captured as a pictorial atlas for reference during the following individual read sessions. All three image modalities were pseudonymized separately. Each reader was blinded to clinical details, clinical diagnosis, other imaging modalities and other reader's scoring results. All three readers scored the conventional CT scans (n = 44) and DR (n = 36) for erosion, osteoarthritis, tophus, and final diagnosis, whereas the reconstructed SDECT images (n = 44) were only scored for MSU deposition and diagnosis of gout (yes/no). Each joint of the foot was examined separately and for each imaging modality, assigning "1" for the presence and "0" for the absence of each of the evaluated abnormalities. The following joints were examined: intertarsal joints (TJ), tarsometatarsal joints (TMT) 1–5, metatarsophalangeal joints (MTP) 1–5, proximal