European Journal of Radiology 83 (2014) 1759–1764

Contents lists available at ScienceDirect

European Journal of Radiology

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

Quantitative analysis of the dual-energy CT virtual spectral curve for focal liver lesions characterization

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ARTICLE INFO

Article history:
Received 6 May 2014
Received in revised form 6 July 2014
Accepted 7 July 2014

Keywords:
Dual-energy computed tomography
Quantitative analysis
Focal liver lesions
Spectral curve

ABSTRACT

Objective: To assess the usefulness of the spectral curve slope of dual-energy CT (DECT) for differentiating between hepatocellular carcinoma (HCC), hepatic metastasis, hemangioma (HH) and cysts.
Methods: In total, 121 patients were imaged in the portal venous phase using dual-energy mode. Of these patients, 23 patients had HH, 28 patients had HCC, 40 patients had metastases and 30 patients had simple cysts. The spectral curves of the hepatic lesions were derived from the 40–190 keV levels of virtual monochromatic spectral imaging. The spectral curve slopes were calculated from 40 to 110 keV. The slopes were compared using the Kruskal–Wallis test. Receiver operating characteristic curves (ROC) were used to determine the optimal cut-off value of the slope of the spectral curve to differentiate between the lesions.
Results: The spectral curves of the four lesion types had different baseline levels. The HH baseline level was the highest followed by HCC, metastases and cysts. The slopes of the spectral curves of HH, HCC, metastases and cysts were 3.81 ± 1.19, 1.49 ± 0.57, 1.06 ± 0.76 and 0.13 ± 0.17, respectively. These values were significantly different ($P < 0.008$). Based on ROC analysis, the respective diagnostic sensitivity and specificity were 87% and 100% for hemangioma (cut-off value ≥ 2.988), 82.1% and 65.9% for HCC (cut-off value 1.167–2.998), 65.9% and 59% for metastasis (cut-off value 0.133–1.167) and 44.4% and 100% for cysts (cut-off value ≤ 0.133).
Conclusion: Quantitative analysis of the DECT spectral curve in the portal venous phase can be used to determine whether tumors are benign or malignant.

1. Introduction

Computed tomography (CT) is a widely used imaging modality for detecting and diagnosing liver tumors [1]. The lesion morphology and contrast enhancement patterns provide fundamental clues for characterizing liver tumors [2]. However, numerous cases require further imaging or histopathological exams to confirm the diagnosis [3–5]. Quantitative assessment of focal liver lesions is a useful tool for the qualitative diagnosis of liver lesions [6,7]. For example, perfusion CT can measure tissue hemodynamic parameters, which have high clinical value for the differential diagnosis of liver tumors. However, a high radiation dose is one of the major limitations of CT perfusion in clinical practice [8].

Dual-energy CT (DECT) was considered a promising new development in CT that had the potential to improve lesion detection and characterization beyond levels currently achievable with conventional CT [9]. Spectral imaging was recently introduced into clinical DECT imaging. Studies indicate that DECT has the potential to improve lesion detection [1,10], enhance image quality [11], reduce hardening artifacts [12] and substitute non-contrast images with virtual non-contrast [9]. Iodine map, virtual unenhanced and monochromatic images can improve lesion characterization and affect evaluation of the response to therapy and detection of oncology-related disorders [13].

Theoretically, a series of monochromatic images of various keV levels could be calculated by scanning at two different energy levels [9]. This technique can measure and analyze the chemical composition of lesions or tissues by means of the dual-energy index (DEI), which characterizes the spectral behavior of materials [14]. DECT has potential to address some of the issues related to dual acquisition because images provide virtual spectral curves (VSCs) [15].

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http://dx.doi.org/10.1016/j.ejrad.2014.07.009
0720-048X/

The X-ray attenuation coefficient of the tissue at different energy levels could be presented as a VSC. The aim of our study was to investigate the ability of DECT VSCs to differentiate between hepatocellular carcinoma (HCC), metastasis, hepatic hemangioma (HH) and simple liver cysts by quantitative analysis of spectral curve characteristics.

2. Materials and methods

The study was not supported by any technical or financial sponsor. All co-authors are hospital physicians who have no conflicts of interest with Siemens or other institutions and claim ownership of all research data and results. This prospective study was approved by the institutional ethics committee of our hospital, and informed consent forms were obtained from all of the patients.

From March 2013 to December 2013, 170 patients with known or suspected liver tumors or cysts underwent upper-abdominal contrast-enhanced multiphase CT scanning. The patients were included in the study if the lesion type was confirmed by histological results, CT follow-up studies or sufficient imaging evidence. Forty-nine (28.82%) of the 170 patients were excluded from the study for the following reasons: (a) Eight patients with suspected hepatic metastases were excluded due to lack of histological results and sufficient imaging evidence. (b) Nineteen patients were excluded due to other types of liver lesions, including focal nodular hyperplasia ($n = 5$), abscess ($n = 8$), tuberculosis ($n = 3$), and hepatic adenoma ($n = 3$). (c) Seventeen patients were excluded due to atypical CT manifestations and no follow-up examinations. (d) The evidence was inadequate for a diagnosis of cysts ($n = 5$). Multilocular, mural nodularity, irregular thickness of the septa, and typical enhancement pattern in the solid portion of cystic hepatic lesion were excluded. A total of 121 patients (age range, 38–82 years; mean age, 55 years) were included in our study, including 79 men (age range, 42–82 years; mean age, 59 years) and 42 women (age range, 38–69 years; mean age, 54 years). The characteristics of all of the patients are summarized in Table 1. Twenty-three patients had HH (mean diameter, 4.9 cm; diameter range, 2.3–15.6 cm). Twenty-eight patients had HCC (mean diameter, 4.4 cm; diameter range, 2.1–12.3 cm). Forty patients had hepatic metastases (mean diameter, 3.1 cm; diameter range, 1.3–8.7 cm). Thirty patients had simple cysts (mean diameter, 2.9 cm; diameter range, 1.2–6.9 cm). The diagnosis of HH was made after postoperative histological exam ($n = 12$) or typical CT signs with follow-up MR exam confirmation ($n = 11$). HCC was diagnosed via histology after surgery ($n = 11$), needle biopsy ($n = 13$), or a combination of typical CT and MR signs and a history of liver cirrhosis and alpha-fetoprotein levels > 500 ng/mL ($n = 4$). All of the cases diagnosed as metastasis had a history of primary carcinoma. The primary malignancies in these patients included gastric ($n = 12$), colon ($n = 13$), lung ($n = 8$) and pancreatic ($n = 3$) and esophageal carcinomas ($n = 4$). Of these 40 metastasis cases, 13 were confirmed by post-surgery histology, 21 by needle biopsy and 6 by typical CT manifestations and 6-month follow-up observations. MR confirmed the 30 cases of simple cysts.

2.1. CT protocol

All liver CTs were performed using a 128-slice DECT scanner (Somatom Definition Flash, Siemens Medical Systems, Forchheim, Germany). Unenhanced and contrast-enhanced liver CT at the arterial (30 s) and delay (180 s) phases were performed using the standard-of-care scan protocol of our hospital, whereas CT at the portal venous (70 s) phase was performed using dual-energy mode with a tin filter and tube voltages of 80 and 140 kVp. The standard-of-care and dual-energy scan protocols for the portal venous phase are described in Table 2. Iopromide (Ultravist 300 mg I/ml; Schering, Guangzhou, China) was injected into the antecubital vein at a dose of 1.5 ml/kg and a rate of 3 ml/s via a 22-gauge intravenous catheter.

For each dual-energy CT dataset, a series of three 1.5-mm thick images were reconstructed using a kernel of D30. Two of the series were acquired with a polychromatic spectrum of 80 and 140 kVp, and a linear mixture of the 80 and 140 kVp images was acquired at the vendor default mixture ratio of 0.5. The polychromatic 80 and 140 kVp images were uploaded to a commercial workstation (Multi-Modality WorkPlace, Siemens Healthcare, Forchheim, Germany) to calculate the monochromatic spectral images. For each patient, 16-keV levels of the virtual monochromatic spectral (VMS) imaging sequences were calculated from 40 to 190 keV with 10-keV intervals. The default mixed images were considered to be simulated 120-kVp images and were used for routine image review and diagnosis.

2.2. Quantitative analysis of VSCs

To generate a spectral curve for each lesion, the CT values for the liver parenchyma and lesion were obtained in two steps. In the first step, a circular region of interest (ROI) was placed on the simulated 120-kVp venous phase images to determine the CT values of the liver parenchyma and lesion. The ROI was placed on the regions of the lesion with the most significant enhancement in the portal venous phase. The ROI on the liver parenchyma and lesion was placed at the same transverse slice, and care was taken to avoid blood vessels or inhomogeneous areas. A screenshot was obtained to record the position of the ROI. In the second step, an ROI with the same location and size as that on the screenshot stored in the first step was placed on the monochromatic images. The CT values of the different keV levels were recorded and stored. To ensure consistency, all of the measurements were performed three times in 3 consecutive slices, and average values were calculated. An abdominal radiologist (X.H.Q.) with 5 years of experience performed the quantitative measurement.

After the CT values of the monochromatic images were exported to the Excel sheet, the spectral curve was plotted and observed for each case. To quantitatively analyze the spectral curve, the slope of the spectral curve was calculated with the following formula: slope = $(ROI_{40} - ROI_{110})/70$. In the formula, ROI_{40} and ROI_{110} represent the ROI measurement of the 40 and 110 keV monochromatic images, respectively.

Table 1
Patient characteristics and radiation exposure.

Parameter	HCC	Metastasis	Liver cyst	HH
Sex ratio (men/women)	16/12	27/13	21/9	15/8
Age (year)[a]	57.2 ± 12.8	59.6 ± 13.5	54.5 ± 15.5	51.2 ± 11.3
Radiation exposure for portal venous phase				
Dose-length product (mGy cm)[a]	265.26 ± 67.71	287.34 ± 43.15	283.21 ± 45.46	273.47 ± 69.25
Effective dose (mSv)	3.99 ± 1.01	4.31 ± 0.63	4.25 ± 0.69	4.13 ± 1.04

HH, hepatic hemangioma; HCC, hepatocellular carcinoma.
[a] Data are expressed as the mean ± standard deviation (SD).