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Research article

Dual-energy CT in patients with colorectal cancer: Improved assessment of hypoattenuating liver metastases using noise-optimized virtual monoenergetic imaging

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A R T I C L E I N F O

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A B S T R A C T

Purpose: To assess the value of the noise-optimized virtual monoenergetic imaging (VMI+) technique on quantitative and qualitative image parameters in patients with hypoattenuating liver metastases from colorectal cancer (CRC) at abdominal dual-energy CT (DECT).

Materials and Methods: Fifty-three consecutive patients (mean age, 70.3 ± 11.4 years; range, 44–86 years) with histologically proven, hypoattenuating liver metastases from CRC were retrospectively included in this IRB-approved study. DECT datasets were reconstructed as standard linearly-blended M_0.6 image series, traditional virtual monoenergetic images (VMI), and noise-optimized VMI+ series. VMI and VMI+ reconstructions were obtained at energy levels ranging from 40 to 100-keV with 10-keV increments. Signal attenuation of liver parenchyma and liver metastases was measured to calculate signal-to-noise (SNR) and contrast-to-noise (CNR) ratios. Each image series was subjectively rated by three blinded radiologists with regard to image quality, lesion delineation, and image noise using a five-point Likert scale.

Results: Quantitative image quality parameters peaked at 40-keV VMI+ (SNR, 8.1 ± 3.4; CNR, 6.5 ± 2.6) with statistically significant differences in comparison with standard reconstructions and all traditional VMI series ($P \leq 0.001$). Qualitative image analysis revealed best rating scores for 60-keV VMI+ series (median, 5) with significant differences compared to linearly-blended M_0.6 and all traditional VMI series ($P \leq 0.001$). Lesion delineation showed significantly superior ratings for 40-keV VMI+ series compared to all other reconstructions (median, 5) ($P \leq 0.001$).

Conclusion: Low-keV VMI+ reconstructions demonstrate significantly increased quantitative and qualitative image quality parameters in patients with hypoattenuating liver metastases from CRC in comparison with standard reconstructions and traditional VMI series at abdominal DECT. Best lesion delineation can be achieved at 40-keV VMI+.

1. Introduction

Colorectal cancer (CRC) is the second most common cancer entity in Europe [1]. Approximately 18–25% of patients with CRC show metastatic disease at the time of initial diagnosis with primary localization in the liver or lung [2]. Nevertheless, the clinical outcome of these patients has improved over time due to advanced screening and prevention options, more effective systemic therapy strategies, an increased number of patients undergoing surgical resection, and local ablative therapies [1,3–5].

In early staging, therapy planning, and follow-up examinations, abdominal computed tomography (CT) represents the standard imaging

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modality for the detection of liver metastases in patients with colorectal cancer [2]. A detailed analysis of liver metastases in terms of segmental spread and localization to adjacent vessels is mandatory, as liver resection remains the only potential curative therapy [6,7].

Recent developments in dual-energy CT (DECT) have emphasized its usefulness in oncological imaging, particularly the introduction of a noise-optimized virtual monoenergetic imaging algorithm (VMI+). VMI+ reconstructions are generally based on a regional spatial frequency split technique of the high and the low energy datasets [8]. The main goal of such reconstructions is to increase the iodine signal attenuation at low-keV levels, while simultaneously reducing image noise. Multiple studies demonstrated favorable results using the VMI+ algorithm in the field of oncology [9–11]. In addition, VMI + reconstructions of the liver have been shown to improve lesion conspicuity of hyper- and hypovascular liver lesions [12,13]. Quantitative assessment of liver lesions by means of DECT has further indicated an improved differentiation of focal liver lesions using virtual spectral curves [14].

However, the impact of VMI+ reconstructions on the assessment of hypoattenuating liver metastases in patients with CRC has not been investigated yet. The intent of our study was to evaluate VMI+ reconstructions in patients with hypoattenuating liver metastases from CRC focusing on quantitative and qualitative image analysis.

2. Materials and methods

2.1. Patient selection

This retrospective study was approved by the local ethics committee of our University hospital and written informed consent was not required. A radiologist with 4 years of experience in abdominal CT imaging scanned our Picture Archiving and Communication System (PACS) and Radiology Information System (RIS) for patients, who met inclusion criteria. Between April 2015 and December 2017, a total of 62 patients with histologically proven CRC and hypoattenuating liver metastases were enrolled. All patients with CRC were diagnosed with histological specimen from colonoscopy (n = 41) or surgery (n = 21), while liver metastases were detected with abdominal DECT (n = 62). For liver metastases confirmation, either ultrasound-guided (n = 20) or CT-guided (n = 42) fine needle biopsy was performed. Patients were excluded from abdominal DECT when allergies to iodinated contrast agent, age under 18 years, known or suspected pregnancy, and limited renal function (glomerular filtration rate < 45 ml/min) were identified. Exclusion criteria also consisted of severe motion artifacts (n = 3), as well as deviations from our common DECT (n = 1) and contrast material injection protocol (n = 5). We finally included 53 consecutive patients (mean age, 70.3 ± 11.4 years; range, 44–86 years) comprising 30 men (mean age, 70.6 ± 9.8 years; range, 44–86 years) and 23 women (mean age, 69.8 ± 13.9 years; range, 44–86). All patients diagnosed with hepatic metastases were divided into three subgroups. Subgroups consisted of patients demonstrating > 5, < 5, or solely singular liver metastases. The mean tumor size was measured in the longest axial diameter and summed up if more than one liver metastasis was present [15].

2.2. DECT image acquisition

All examinations were performed on a 192-detector row, third-generation dual-source CT scanner in the dual-energy mode (SOMATOM Force, Siemens Healthcare, Forchheim, Germany). Scan parameters were equal for all abdominal DECT examinations and set as follows: tube A 90-kV/95-mAs, and tube B Sn150-kV/59-mAs using an additional tin filter, pitch 0.7, rotation time 0.5 s, and collimation 2 × 192 × 0.6 mm. All patients had undergone a single-phase DECT of the abdomen in portal-venous phase in craniocaudal direction. The scan started with a delay of 70 s during inspiratory breath-hold. Contrast material volume (Imeron 400; Bracco, Milan, Italy) was individually adjusted to the patients' habitus at a dose of 1.2 ml/kg body weight with a flow rate of 3 ml/s through an intravenous catheter inserted into an antecubital vein. Radiation exposure was controlled using an automatic tube current modulation system (CARE Dose 4D, Siemens). For radiation dose monitoring, the dose-length product (DLP) and volume CT dose index ($CTDI_{vol}$) were obtained from the patient protocol.

2.3. DECT image reconstruction

First, DECT raw data were automatically reconstructed using the standard linear-blending technique by applying a blending factor of 0.6 (M_0.6; 60% of the 90-kV and 40% of the 150-kV spectrum). Standard linearly-blended reconstructions were obtained to simulate conventional 120-kV single-energy image acquisition [16,17]. Image series were sent to a 3D multimodality workstation (syngo.via, Version VB10B; Siemens) and manually post-processed with a medium soft tissue convolution kernel (Qr40; Siemens) and a dedicated, third-generation iterative reconstruction algorithm (ADMIRE, strength level 3) [18]. In addition, monoenergetic reconstructions were calculated using the traditional VMI and noise-optimized VMI+ algorithm. For qualitative image evaluation we solely reconstructed VMI and VMI+ image series ranging from 40 keV to 80 keV, as the lesion conspicuity beyond 80 keV can be expected to be too low according to prior studies [11,19,20]. Images were reconstructed in transverse orientation at a section thickness of 3 mm and an increment of 1.5 mm.

2.4. Quantitative image analysis of DECT datasets

Quantitative image quality assessment was performed by a radiologist with four years of experience in oncological DECT imaging of the abdomen, who has neither been involved in data acquisition, nor qualitative image analysis. Signal attenuation in mean Hounsfield units (HU) was measured by scaling circular regions-of-interests (ROI) within the liver metastases and adjacent, unaffected liver parenchyma (100 mm^2). Areas of focal heterogeneity and tumor necrosis were spared. Image noise assessment, defined as the standard deviation (SD) of fat, included identical ROI measurements within the subcutaneous fat of the lower back (200 mm^2). Moreover, homogenous ROIs were placed within the psoas muscle to evaluate image contrast (150 mm^2). All measurements were repeated twice to avoid data inaccuracies. According to prior studies investigating the VMI and VMI+ algorithm in oncological settings, the signal-to-noise (SNR) and contrast-to-noise (CNR) ratio calculations were as follows [9,13,21]:

$$SNR = HU_{lesion}/SD_{fat}$$

$$CNR = (HU_{liver\ parenchyma} - HU_{liver\ lesion})/SD_{fat}$$

2.5. Qualitative image analysis of DECT datasets

For qualitative image evaluation, three blinded radiologists with 3 and 4 years of experience in abdominal CT reading subsequently analyzed DECT datasets. Observers were aware of the patients' medical history, but unaware of the reconstruction algorithm used. Standard linearly-blended (M_0.6), traditional VMI, and noise-optimized VMI+ reconstructions were rated in random order, while only one single image series was rated during each reading session. Moreover, readers were allowed to manually adjust the standard window settings as prior studies suggest different window configurations for the VMI+ algorithm [22]. Based on 5-point Likert-scales, the following quality criteria were assessed: Overall image quality (ranging from 1 = poor overall image quality to 5 = excellent overall image quality), lesion delineation (ranging from 1 = lesion cannot be ruled out to 5 = excellent lesion margin delineation), and image noise (ranging from 1 = enormous image noise to 5 = no relevant image noise perceivable).