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Optimization of window settings for virtual monoenergetic imaging in dual-energy CT of the liver: A multi-reader evaluation of standard monoenergetic and advanced imaged-based monoenergetic datasets

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ABSTRACT

Objectives: To evaluate optimal window settings for display of virtual monoenergetic reconstructions in third-generation dual-source, dual-energy computed tomography (DECT) of the liver.

Methods: Twenty-nine subjects were prospectively evaluated with DECT in arterial (AP) and portal venous (PVP) phases. Three reconstructed datasets were calculated: standard linearly-blended (LB120), 70-keV standard virtual monoenergetic (M70), and 50-keV advanced image-based virtual monoenergetic (M50+). Two readers assessed optimal window settings (width and level, W/L), establishing a mean for each reconstruction which was used for a blinded assessment of liver lesions.

Results: The optimal W/L for M50+ were significantly higher for both AP (W = 429.3 ± 44.6HU, L = 129.4 ± 9.7HU) and PVP (*W* = 376.1 ± 14.2HU, *L* = 146.6 ± 7.0HU) than for LB120 (AP, *W* = 215.9 ± 16.9HU, *L* = 82.3 ± 9.4HU) (PVP, *W* = 173.4 ± 8.9HU, *L* = 69.3 ± 6.0HU) and M70 (AP, *W* = 247.1 ± 22.2HU, *L* = 72.9 ± 6.8HU) (PVP, *W* = 232.0 ± 27.9HU, *L* = 91.6 ± 14.4HU). Use of the optimal window setting for M50+ vs. LB120 resulted in higher sensitivity (AP, 100% vs. 86%; PVP, 96% vs. 63%).

Conclusions: Application of dedicated window settings results in improved liver lesion detection rates in advanced image-based virtual monoenergetic DECT when customized for arterial and portal venous phases.

1. Introduction

Dual-energy computed tomography (DECT) operates by obtaining two datasets at different tube voltages from the same anatomic region, and thus allows for material decomposition due to attenuation differences at different energy levels [1,2]. Virtual monoenergetic imaging (VMI) enables reconstruction of datasets at a desired virtual energy level (keV) [3]. Synthesized VMI datasets from DECT can be manipulated to optimal keV settings in order to attain the highest contrast-to-noise ratio (CNR) [4]. Prior studies reported that reconstruction at 70 keV resulted in the highest CNR and lowest image noise, thus improving liver lesion detection [2,5].

Recently, a noise-optimized advanced image-based monoenergetic algorithm (VMI+) was introduced with the goal of superior CNR values at even the lowest keV [6,7]. When viewing VMI+ datasets at low keV settings, the iodine attenuation is greatly increased and thus the W/L settings have to be manually adjusted in order to achieve an image impression similar to the standard

Abbreviations: VMI, virtual monoenergetic imaging; VMI+, advanced image-based monoenergetic algorithm; LB120, Standard linearly-blended; M70, 70-keV standard monoenergetic; M50+, 50-keV advanced image-based virtual monoenergetic.

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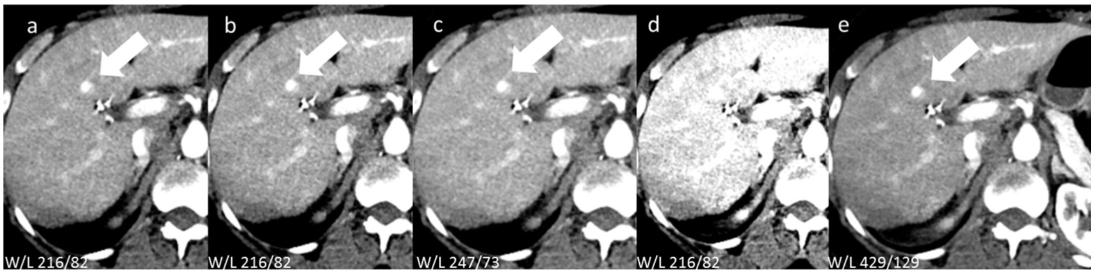

Fig. 1. Arterial Phase, hypervascular lesion. No differences in lesion detection are shown with reference standard LB120 W/L (a), M70 with a optimal LB120 W/L (b) and optimal M70 W/L (c). M50+ required to adjust the W/L for the identification of the lesion, from the optimal LB120 (d) to the optimal M50+ W/L (e).

settings used in polychromatic liver CT. As the experience with the VMI+ algorithm in imaging of the liver is scarce [6,8], no optimal window settings have been proposed yet to use this algorithm in routine DECT. Nevertheless, it has been shown that CT of the liver requires optimized window settings to maximize hepatic lesion detection [9–11].

The aim of this study was to determine whether there is a need to alter window settings when applying the VMI+ algorithm for DECT of the liver. In addition, we determined optimal window settings for each image reconstruction algorithm and assessed differences in diagnostic performance regarding liver lesions detection.

2. Materials and methods

This prospective study recruited volunteer subjects with one or more liver lesions reported on a prior MRI performed clinically. The local institutional review board approved this prospective, single-center study which was Health Insurance Portability and Accountability Act compliant. All subjects gave written informed consent.

2.1. Dual Energy CT technique

All CT examinations were performed on a 3rd-generation dual-source CT scanner (SOMATOM Force; Siemens Healthcare, Forchheim, Germany). Images were acquired in dual-energy mode during arterial as well as portal phases after the administration of an intravenous contrast material bolus. Subjects were examined in a supine position and initial anterior-posterior and lateral scout images were obtained for planning of the scan. The DECT arterial and portal phase images were acquired using the following parameters: pitch, 0.7; collimation, $2 \times 64 \times 0.6$ mm for both detectors; field of view, 350 mm; tube A was operated at 100 kVp with a reference tube current of 180 mAs; tube B was operated at 150 kVp equipped with an optimized integrated tin filter (Selective Photon Shield II, SPS II, Siemens) and a reference tube current of 90 mAs. Automated real-time anatomical tube current modulation (CareDose 4D, Siemens) was activated in all acquisitions.

Parenchymal attenuation was achieved by injecting a total of 0.625 gI/kg body weight [12] of non-ionic iodinated contrast material (Omnipaque 350 mgI/ml, GE Healthcare, Milwaukee, USA) at a flow rate of 4.0 mL/s followed by a 50 mL saline flush by using an automated dual-syringe power injector (Stellant D CT Injection System, Medrad, Inc., Warrendale, PA) through a 20-gauge needle placed in a superficial vein in the antecubital fossa. A lower limit of 100 mL of contrast media for subjects weighing less than 60 kg and an upper limit of 130 mL for subjects weighing more than 85 kg was used to target a mean amount of 120 mL. The timing of scan initiation was determined using a dedicated bolus tracking software application (CareBolus, Siemens) with the region of interest (ROI) placed in the abdominal aorta just below the diaphragmatic dome and a trigger threshold level of 100HU for the tracking scan (120 kV, 23 mAs) with a 20-s delay for the arterial phase and 70-s delay for the portal phase [13]. All scans covered a scan field ranging from the diaphragm to the iliac crest during breath-hold.

2.2. Image reconstructions and post-processing technique

From the arterial and portal phase images, three series were reconstructed using a standard DECT soft tissue kernel (Qr36), for a total of six datasets per subject. The first series was calculated to approximate typical clinical routine single-energy polychromatic 120-kV images and was reconstructed using vendor-recommended standard settings as a linearly blended image (LB120) by merging 70% of the 100-kV and 30% of the 150-kV spectra. The second and third image series were reconstructed as a virtual monoenergetic image by using commercially available DECT software approved for clinical use (Mono+; Siemens Healthcare) on a dedicated post-processing system (Syngo.Via, version VA30A; Siemens). Although this algorithm allows for image reconstruction at energy levels ranging from 40 to 190 keV, a standard virtual monoenergetic (VMI) dataset at 70 keV (M70), and a noise-optimized VMI+ reconstruction at 50 keV (M50+) were calculated, based on the recommendations of prior studies evaluating image quality [2,3,14,15]. All image datasets were reconstructed as transverse oriented image slices with a slice thickness of 2.5 mm.

2.3. Parenchymal and vascular attenuation

Considering that subjective W/L settings selection is influenced by organs attenuation, the mean HU of the aorta and liver were recorded. Each image dataset was assessed by a single reader (XXX) who was not a radiologist but was familiar with Region of Interest (ROI) measurements by CT. This reader placed three 1-cm ROIs at consecutive anatomical levels over the liver periphery avoiding large vessels, and aorta at the level of the superior mesenteric artery origin for each of the six datasets. The attenuation (mean HU) was recorded for each of the measurements.

2.4. Optimal window settings

In order to establish the optimal width and level settings for each image dataset, two independent readers assessed each image dataset separately on a standard clinical PACS viewing system (IMPAX v.6.5, Agfa-Gevaert Group, Mortsel, Belgium). The two readers had 2 years (XXX) and 8 years (XXX) of experience in CT imaging respectively. Each reader was asked to manually adjust the width and level settings for each image dataset until the most visually appealing appearance was achieved, particularly in regard to liver lesion assessment. The two readers recorded the width and level settings for the linearly-blended (LB120), M70, and M50+ image datasets at both arterial and portal venous phase timing in random order and in different reading sessions to avoid recall bias. Only a single image series per subject was randomly assigned to