European Journal of Radiology 108 (2018) 7–12

Contents lists available at ScienceDirect

European Journal of Radiology

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

Research article

Dual-energy computed tomography colonography using dual-layer spectral detector computed tomography: Utility of virtual monochromatic imaging for electronic cleansing

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ARTICLE INFO

Keywords:
CT colonography
Colon cancer
Dual-energy CT
Dual-layer spectral detector CT
Electronic cleansing

ABSTRACT

Objective: To assess the utility of virtual monochromatic imaging (VMI) using a dual-layer spectral detector CT for electronic cleansing in fecal-tagging CT colonography (CTC).

Methods: This study included 35 patients who underwent fecal-tagging CTC with a dual-layer detector spectral CT scanner. Conventional images at 120 kVp and VMI at 40, 50, and 60 keV were reconstructed. Quantitative image quality parameters, i.e., tagging density and image noise, were compared and the visual image quality was scored on a four-point scale. We recorded the number of the colon segments with appropriate tagging density (≥300 HU) for each patient and used these data to compare the reconstructions. In addition, electronic cleansing performance was semi-quantitatively assessed using a four-point scale.

Results: The mean tagging density on VMI was significantly higher than that on conventional 120 kVp images. The number of colon segments with appropriate tagging density on VMI were significantly higher than that on conventional 120 kVp images. There was no significant difference among the reconstructed images with respect to image noise. Scores for subjective image quality and electronic cleansing performance on VMI were significantly higher than those on conventional 120 kVp images.

Conclusion: With dual-layer spectral detector CT, VMI can yield significantly better fecal-tagged CTC image quality and improve electronic cleansing performance.

1. Introduction

Computed tomography colonography (CTC) is a reliable, minimally invasive method for the rapid evaluation of clinically relevant lesions in the entire colon [1]. Previous studies have demonstrated comparable performance of CTC and optical colonoscopy for the detection of polypoid neoplasms [2,3]. Moreover, CTC was recently shown to be useful for the pre-operative evaluation of patients with colorectal cancer [4]. Both colonoscopy and CTC typically require bowel preparation with laxative cleansing to enable thorough assessment of the colonic wall. However, bowel preparation can be onerous and is often poorly tolerated by patients undergoing colon examination. To overcome these issues, electronic cleansing techniques for CTC which entail virtual subtraction of the tagged fecal materials with use of oral contrast agents, were developed [5]. Tagging density depends on various factors (e.g., the amount of oral contrast agents, timing of administration, and method of bowel preparation), which may directly influence the electronic cleansing results and image quality [6].

Dual-energy CT enables the use of virtual monochromatic imaging (VMI) reconstruction at arbitrary X-ray energies (keV) based on the high- and low-energy X-ray spectra datasets. Taking advantage of the greater contrast enhancement in lower keV images [8–10], a few researchers have suggested the feasibility of VMI generated from tube-based dual-energy CT systems for electronic cleansing of CTC images [7]. However, this strategy is not fully established possibly because of the increased image noise at lower keV and increased radiation dose

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https://doi.org/10.1016/j.ejrad.2018.09.011
Received 1 June 2018; Received in revised form 31 July 2018; Accepted 10 September 2018

associated with dual-energy imaging using tube-based dual-energy CT systems. In addition, the systems require a pre-scan determination of the use of the dual-energy mode.

Recently, a dual-layer spectral detector CT, has become commercially available [8–10]. This system employs detector-based dual-energy technique and simultaneously measures high- and low-energy projection data in the two detector layers at the same spatial and angular location. This approach allows VMI in the projection domain without the need for temporal and angular interpolation, which may theoretically yield an accurate beam-hardening correction and anticorrelated noise cancellation in photoelectric and Compton scatter images [11]. With this scanner, dual-energy data is always available using a routine scan protocol that enables retrospective on-demand dual-energy analysis, including VMI. Using VMI, tagging density can be freely calibrated to an appropriate level after scanning. Therefore, we hypothesized that VMI can improve the image quality and electronic cleansing performance of fecal-tagging CTC in patients who have insufficient tagging density.

The purpose of this study was to assess the utility of VMI using a dual-layer spectral detector CT for electronic cleansing of fecal-tagging CTC.

2. Materials and methods

2.1. Study population and bowel preparation

Our study included 35 patients (17 women and 18 men; mean age, 69.1 ± 14 years; age range, 39–88 years) who underwent fecal-tagging CTC between January and December 2017. All patients had suspected or confirmed colorectal cancer (30 colorectal cancer and 5 non-colorectal cancer) and were referred for CTC for clinical reasons based on the guidelines [1]; the indications were preoperative evaluation (n = 26), incomplete colonoscopy including obstructing colorectal cancer (n = 6), and others (n = 3). The final diagnoses of the 5 patients with non-colorectal cancer were colon diverticulum (n = 2) and colon lipoma, colonic endometriosis, and no apparent abnormalities (n = 1 each). Exclusion criteria were CT acquisition parameters less stringent than those described below or non-diagnostic CTC examination including severe breath-hold artifacts and metal artifacts. Ionic iodine-based (n = 26) or barium sulfate-based (n = 9) contrast agents were used for fecal-tagging. For ionic iodine-based contrast imaging, full-cathartic bowel preparation with polyethylene glycol-electrolyte (PEG) lavage solution and contrast agent bowel preparation solution, called PEG-C method, were used [12]. On the day before the procedure, patients were allowed a low-residue meal and ingested 34 g of magnesium citrate (Magcorol P, Horii Pharmaceutical Ind. Ltd., Osaka, Japan) at 8 pm. On the day of the examination, between 9 a.m. and 11 a.m., patients were given 1000–1800 mL of PEG (MoviPrep; EA Pharma, Tokyo, Japan), followed by 200 mL of PEG plus 10 mL of diatrizoate meglumine and diatrizoate sodium (concentration, 370 mgI/mL; Gastrografin; Bayer, Osaka, Japan) for tagging of residual fluid (about 3 h prior to CTC). For barium sulfate-based contrast imaging, patients were administered 32 mL of 25% barium sulfate suspension (ColomforT Oral Suspension, Fushimi Pharmaceutical Co. Ltd., Marukame, Japan) before low-residue meals on three occasions and ingested 34 g of magnesium citrate for minimum laxative cleansing at 8 pm on the day prior to CTC. The patient characteristics are summarized in Table 1.

This study retrospectively investigated the utility of VMI using dual-energy data generated from dual-layer spectral detector CT in routine clinical practice. The study was approved by the institutional review board, and the requirement for informed consent of patients was waived.

2.2. CTC protocol and image reconstruction

All patients were examined using a dual-layer spectral detector CT scanner (IQon Spectral CT; Philips Healthcare, OH, USA). CTC was performed in the supine position as per the standard protocol. A balloon-tipped silicone catheter was inserted via the rectum and carbon dioxide was insufflated using an automated device (PROTOCO2L; Bracco Diagnostics Inc., NJ, USA) to maximum patient tolerance or an equilibrium pressure of 20–22 mmHg. The scan parameters were as follows: tube voltage, 120 kVp; detector configuration, 64 × 0.625 mm (detector collimation); gantry rotation time, 0.5 s; and helical pitch (beam pitch), 0.797. The tube current was determined by automatic exposure control (Dose Right Index = 19; Philips Healthcare). The spectral-based image data were post-processed on a dedicated workstation (Spectral Diagnostic Suite; Philips Healthcare) to generate VMI at three different energy levels (60, 50, and 40 keV) with a spectral level of 3 and compared with conventional images at 120 kVp reconstructed using a hybrid iterative reconstruction (iDose [4]; Philips Healthcare) of level 3. The image reconstruction section thickness and section interval were 5.0 and 5.0 mm for routine axial image reconstruction and 0.5 and 0.5 mm for 3-dimensional (3D) image reconstruction, respectively. The original 0.5–mm axial images were processed using a commercially available image-processing workstation (Ziostation2; Ziosoft, Tokyo, Japan) for 3D volume-rendered image reconstruction. The workstation was operated by a board-certified radiologist. The acquisition parameters are summarized in Table 2.

Table 1
Demographic and clinical characteristics of the study population.

Sex (male/female)	18/17
Age (years)	69.1 ± 14
Body weight (kg)	56.2 ± 11.3
Body mass index (kg/m^2)	22.3 ± 3.6
Diagnosis (Colorectal cancer / Non-colorectal cancer)	30 / 5

Data are presented as mean ± standard deviation.

2.3. Quantitative image quality analysis

Two board-certified radiologists with 5 and 13 years of experience in CTC independently performed the quantitative analysis of reconstructed 5-mm transverse images. The tagging density on conventional image and each VMI was measured by placing the regions of interest (ROIs) in six colorectal segments (cecum, ascending colon, transverse colon, descending colon, sigmoid colon, and rectum; excluding the segments with no visible tagged fluid). The average of the attenuation values by the 2 observers was calculated for all measurement sites. Successful tagging was defined as tagging density ≥ 300 Hounsfield unit (HU), as reported previously [13]. The number of colon segments with appropriate tagging density (≥ 300 HU) was recorded for each patient. Image noise was also measured by placing the ROIs on the erector spinae muscles at the mid-descending colon level on conventional image and each VMI. The standard deviation of CT attenuation in the ROI corresponds to image noise. Image noise was compared between the conventional image and each VMI.

Table 2
Imaging parameters of CTC protocol.

Detector collimation (mm)	64 × 0.625
Tube voltage (kVp)	120
Tube current	3D auto-modulation (dose right index = 19)
Gantry rotation time (s)	0.5
Helical pitch	0.797
$CTDI_{vol}$ (mGy)	Mean 6.9 (range, 4.8–10.8)
Section thickness/interval (mm)	5.0/5.0 for routine axial and 0.5/0.5 for 3D images