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One-mSv CT colonography: Effect of different iterative reconstruction algorithms on radiologists' performance☆

Cheong-Il Shin[a,b], Se Hyung Kim[a,b,*], Jong Pil Im[c], Sang Gyun Kim[c], Mi Hye Yu[d], Eun Sun Lee[e], Joon Koo Han[a,b,f]

[a] Department of Radiology, Seoul National University Hospital, Republic of Korea
[b] Department of Radiology, Seoul National University College of Medicine, Republic of Korea
[c] Department of Radiology, Department of Internal Medicine and Liver Research Institute, Seoul National University College of Medicine, Republic of Korea
[d] Department of Radiology, KonKuk University Medical Center, Republic of Korea
[e] Department of Radiology, Chung-Ang University Hospital, Republic of Korea
[f] Department of Radiology, Institute of Radiation Medicine, Seoul National University Medical Research Center, Republic of Korea

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ABSTRACT

Purpose: To analyze the effect of different reconstruction algorithms on image noise and radiologists' performance at ultra-low dose CT colonography (CTC) in human subjects.
Materials and methods: This retrospective study had institutional review board approval, with waiver of the need to obtain informed consent. CTC and subsequent colonoscopy were performed at the same day in 28 patients. CTC was scanned at the supine/prone positions using 120/100 kVp and fixed 10 mAs, and reconstructed using filtered back projection (FBP), adaptive statistical iterative reconstruction (ASIR), and model-based IR (Veo) algorithms. Size-specific dose estimates (SSDE) and effective radiation doses were recorded. Image noise was compared among the three datasets using repeated measures analysis of variance (ANOVA). Per-polyp sensitivity and figure-of-merits were compared among the datasets using the McNemar test and jackknife alternative free-response receiver operating characteristic (JAFROC) analysis, respectively, by one novice and one expert reviewer in CTC.
Results: Mean SSDE and effective radiation dose of CTC were 1.732 mGy and 1.002 mSv, respectively. Mean image noise at supine/prone position datasets was significantly lowest with Veo (17.2/13.3), followed by ASIR (52.4/38.9) and FBP (69.9/50.8) ($P < 0.0001$). Forty-two polyps in 25 patients were reference polyps. For both readers, per-polyp sensitivity of all 42 polyps was highest with Veo reconstruction (81.0%, 64.3%), followed by ASIR (73.8%, 54.8%) and FBP (57.1%, 50.0%) with statistical significance between Veo and FBP for reader 1 ($P = 0.002$). JAFROC analysis revealed that the figure-of-merit for the detection of polyps was highest with Veo (0.917, 0.786), followed by ASIR (0.881, 0.750) and FBP (0.750, 0.746) with statistical significances between Veo or ASIR and FBP for reader 1 ($P < 0.05$).
Conclusion: One-mSv CTC was not feasible using the standard FBP algorithm. However, diagnostic performance expressed as per-polyp sensitivity and figures-of-merit can be improved with the application of IR algorithms, particularly Veo.

1. Introduction

CT colonography (CTC) has been shown to be a useful screening examination in the detection of adenomatous polyps and occult colorectal cancers [1]. A potential impediment to screening CTC, however, is the concern over radiation to patients undergoing a screening examination [2,3]. Although the true risk of very low levels (<10 mSv) of intermittent radiation for adults is unknown and largely theoretical [4], patients, referring physicians, and government administrative agencies remain concerned about radiation exposure. Therefore, radiologists have attempted to decrease radiation dose as much as possible while maintaining an acceptable level of image quality [5–21]. Reducing the tube current (milliampere-seconds) may be the simplest method to effectively reduce radiation dose as there is a linear relationship between milliampere-seconds and radiation dose. Indeed, low-dose CTC

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* Corresponding author at: Department of Radiology, Seoul National University Hospital, 101, Daehak-ro, Jongno-gu, Seoul 03080, Republic of Korea. Fax: +82 2 743 6385.
E-mail address: shkim7071@gmail.com (S.H. Kim).

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using lower milliampere-seconds has gained acceptance [5–7,9], even with tube currents as low as 10 mAs [6,7,15,18]. Even further dose reduction may be obtained with the reduction of tube voltage (i.e., peak voltage), resulting in a dose reduction to the power of 2.4 ~ 2.8 [12,14,20,22]. In addition, at a lower tube voltage, the average energy of the X-ray beam more closely approaches the k edge of iodine, leading to increased attenuation of tagged residual fluid with oral contrast material on CTC [20], which in turn results in increased contrast between the tagged fluid and submerged polyp. Recently, Chang et al. reported that 100 kVp CTC showed a significant decrease in radiation dose, yet with only a minimal decrease in three-dimensional image quality compared with 120 kVp, although they did not analyze radiologist's performance on 100 kVp CTC [12].

Iterative reconstruction (IR) algorithms also play a role in dose reduction by decreasing the amount of quantum noise that can be observed with standard filtered back projection (FBP) reconstruction algorithms [10,11,14–21]. In fact, studies that have evaluated the image quality acquired with hybrid types of IR algorithms demonstrated that a radiation dose reduction of approximately 50% in CTC examinations was possible while preserving image quality, although a certain amount of image noise and artifacts were still present [10,11,14–21]. Recently, the next generation of IR algorithms, full model-based IR, was developed by different vendors to focus on data restoration and noise reduction using a model-based process [11,14,17–19,21]. It applies a model- or knowledge-based approach that yields improved image quality and minimal image noise through the iterative minimization of the penalty-based cost function [11,14,17–19,21]. Thus, application of this new IR technique may have the potential to overcome the poor image quality observed at low voltage CTC with FBP reconstruction. According to a recent article, ultra-low kVp (80 kVp) CTC reconstructed with full knowledge-based IR algorithm was demonstrated to reduce radiation dose by 71% while showing similar radiologists' performance to that at standard 120 kVp CTC [14]. However, the previous article used an anthropomorphic pig phantom of which the results may not be directly applicable to human subjects [14].

Therefore, the purposes of our study are to assess the feasibility of ultra-low dose CTC with a reduction in both kVp and mAs, and to assess the effect of two different IR algorithms including a full model-based IR algorithm on radiologist's performance at ultra-low dose CTC in human subjects.

2. Materials and methods

This retrospective study was approved by the Institutional Review Board of our institute and informed consent was waived. Part of the data of this study was obtained from another prospective study investigating the effect of different iterative reconstruction methods on computer-aided diagnosis of ultra-low dose CTC, which has been previously published [23]. The acquisition method of the datasets are described in detail in the prior prospective study [23].

2.1. Patients

From a search of our medical database between January 2013 and July 2013, 41 patients underwent therapeutic colonoscopy for polypectomy based on the results of the prior examination with same-day CTC. Thirteen patients were excluded from the study owing to refusal of involvement in this study ($n = 11$) or as they had more than 10 polyps ($n = 2$). Therefore, 28 patients (M:F = 24:4; mean age, 61.9 years; range, 39–75 years) who underwent CTC and colonoscopy sequentially on the same day comprised our study population.

2.2. Bowel preparation and fecal tagging for CT colonography

For bowel preparation, all patients were instructed to avoid foods that were rich in fiber, seeded fruits and seaweed two days prior to the examination. One day prior to the CTC examination, patients were allowed a regular breakfast but only rice porridge for lunch. Dinner was not allowed. For fecal tagging, 25 mL of a non-ionic, water-soluble, iodinated contrast agent (Omnipaque™ 300, GE healthcare, Cork, Ireland) was ingested with two cups of water the night prior to the exam with another 25 mL in the early morning of the exam day. Thereafter, colonic cleansing was performed with 250 mL of a magnesium citrate solution (Magcorol solution®, Taejoon Pharm Co., Ltd., Seoul, Korea), containing 19.2 g of magnesium citrate and four tablets of 5 mg bisacodyl.

2.3. Ultra-low dose CT colonography

All patients were instructed to insert a bisacodyl suppository in their rectum to evacuate any remaining residual fluid 30 min prior to CT scanning. Then, a dedicated CT technician carefully insufflated the patient's colon using a small, flexible, rectal tube and an automated CO_2 delivery system (PROTOCO2L, E-Z-EM, Westbury, NY). To achieve a sufficient amount of colonic distension, abdominal digital radiographs were acquired. When the colonic distension was considered not to be sufficient, further insufflation was performed. CT images were acquired successively, first in the supine and then in the prone position. CT scanning was performed with a 64-channel multi- detector row CT (MDCT) (Discovery™ CT750HD, GE Healthcare, Milwaukee, WI, USA) without intravenous contrast agents. Acquisition parameters for CTC were: detector configuration, 64 × 0.625 mm; pitch, 1; gantry rotation time, 0.5 s; slice thickness, 1.25 mm; reconstruction increment, 1.25 mm; tube voltage, 120 kVp in the supine and 100 kVp in the prone position; tube current, 10 mAs; matrix, 512 × 512, with a field of view to fit. Three different reconstruction algorithms were used to reconstruct the raw data using a standard soft tissue kernel and FBP, adaptive statistical iterative reconstruction (ASIR; GE Healthcare, Wis, USA) at 60% section mode, and model-based iterative reconstruction (MBIR; Veo®, GE Healthcare, Wis, USA). Reconstruction with Veo took approximately 1 h per acquisition (2 h per patient), with real time reconstruction for ASIR and FBP.

Volume CT dose index ($CTDI_{vol}$), size specific dose estimates (SSDE), and dose-length products (DLP) were recorded for each image series acquired. SSDE was calculated by multiplying $CTDI_{vol}$ with a conversion factor according to the patient's size as recommended by the American Association of Physicists in Medicine [24]. Effective dose (ED) was estimated by multiplying DLP with a conversion coefficient for the abdomen ($k = 0.015$ mSv/mGy cm) according to the European working group guidelines on quality criteria for CT [25].

2.4. Optical colonoscopy

Same-day therapeutic colonoscopy was performed after CTC within a 4-h interval. Prior to therapeutic colonoscopy, all patients were instructed to take 2 L of a polyethylene glycol solution (Colyte-F®, Taejoon Pharm., Seoul, Korea) during 1 h for additional bowel preparation. Colonoscopic examinations were performed by one of two board-certified gastroenterologists (J.P.I and S.K.K with 12 and 14 years of experience, respectively) who were unblinded to the results of the prior CTC examination. All patients underwent intravenous sedation using 5 mg of midazolam hydrochloride. The location, shape, and size of all identified polyps were recorded. Polyp sizes were measured using 8 mm-long biopsy forceps. The endoscopists were asked to capture colonoscopic images of all polyps prior to polyp removal. Specimens of most lesions were