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Impact of filter convolution and displayed field of view on estimation of coronary Agatston scores in low-dose lung computed tomography

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A B S T R A C T

Background: Coronary artery calcification (CAC) may be quantified on low-dose computed tomography (CT) of the lung (LDCT). This study aims to evaluate the effects of filter convolution (FC) and displayed field of view (dFOV) in a Toshiba 320-row CT scanner in quantifying CAC, and to compare the CAC scores obtained by LDCT with standard cardiac CT.

Methods: Fifty subjects (52 to 85 years, mean 68.5, 36 males) with visible CAC underwent both standard cardiac CT and LDCT. CAC scores were obtained from standard cardiac CT using conventional FC12(22) (FC12 with 22-cm dFOV) and four different LDCT protocols: FC02(22), FC02(40), FC08(22), and FC08(40). CAC scores obtained by each LDCT protocol were compared with those obtained by standard cardiac CT.

Results: CAC scores obtained by all four LDCT protocols were well correlated with those by standard protocol (Pearson's coefficient = 0.978 to 0.987, $p < 0.001$; kappa = 0.731 to 0.836, $p < 0.001$). CAC scores obtained by FC08(22) showed the best agreement with standard cardiac CT (kappa = 0.836, $p < 0.001$). Under fixed dFOV, CAC scores in FC08 were significantly higher than in FC02 ($p < 0.001$). Under fixed FC, CAC scores were significantly higher in 22-cm dFOV than in 40-cm dFOV ($p \leq 0.006$).

Conclusions: Both FC and dFOV have significant impact on CAC scoring. To obtain reliable data, consistent parameters should be employed when quantifying CAC using LDCT. In a Toshiba 320-row CT scanner, CAC scores obtained by FC08(22) agree well with standard cardiac CT.

1. Introduction

Cardiac disease and malignant neoplasms account for the top two causes of death worldwide [1,2]. Coronary artery disease (CAD) causes significant patient morbidity and mortality with a substantial financial burden, whereas lung cancer constitutes around 20% of all malignancies and is the leading cause of cancer death worldwide [1]. Smoking and age are common risk factors for both lung cancer and CAD [3–5]. Both are potentially detectable using computed tomography (CT), although the conventional approach for scanning methods and protocols differ. Low-dose computed tomography (LDCT) has been recommended for lung cancer screening in high-risk groups [5–7] as it may reduce lung cancer mortality by up to 20% [7].

The presence and extent of coronary artery calcification (CAC) detected on CT are independent predictors of cardiovascular events [8–10]. A CAC score of >100 is predictive of cardiac death events, independent of standard risk factors and high-sensitivity C-reactive protein levels [11,12]. Furthermore, CAC scores can be used to reclassify persons at intermediate risk into either high or low risk, using empirically derived cutoff values of 615 and 50, respectively [13].

Early detection of lung cancer and CAD is critical in promoting healthcare. Devising a reliable and clinically feasible diagnostic modality for simultaneous detection of lung nodules and CAC on LDCT is an

Abbreviations: FC, filter convolution; dFOV, displayed field of view; CT, computed tomography; LDCT, spiral non-gated low-dose lung computed tomography; BHC, beam hardening correction; CAC, coronary artery calcification; CAD, coronary artery disease; ECG, electrocardiography; FC02(40), LDCT with FC02 and 40-cm dFOV for chest imaging; FC02(22), reconstructed cardiac imaging with FC02 and 22-cm dFOV from LDCT raw data; FC08(40), LDCT with FC08 and 40-cm dFOV for chest imaging; FC08(22), reconstructed cardiac imaging with FC08 and 22-cm dFOV from LDCT raw data; FC12(22), standard cardiac CT with FC12 and 22-cm dFOV..

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attractive strategy, and may benefit individuals in the screening population by reducing both cost and radiation exposure. A number of studies have described the clinical value and importance of CAC detection using non-electrocardiography (ECG)-gated chest CT or LDCT [14–23]. Some authors advocate visual assessment and categorization of CAC, a simple method requiring no special computer program or processing time [15,23,24]. However, radiologists may require some training before assessment. The Society of Cardiovascular Computed Tomography (SCCT) and Society of Thoracic Radiology (STR) recently published the 2016 SCCT/STR guidelines for CAC scoring of non-contrast non-cardiac chest CT scans, and recommended that, if feasible and in patients ≥40 years, CAC should be evaluated and reported on all non-contrast chest CT examinations (class I) and should at least be visually estimated as none, mild, moderate or severe (class I). It is also considered reasonable to perform ordinal assessment of CAC (class IIa) or Agatston CAC scoring (class IIb) [25]. However, the filter convolution (FC) and displayed field of view (dFOV), which may affect CAC quantification, were not specified in most of these studies.

Different terminologies are used by various manufacturers for the reconstruction property that determine the sharpness or smoothness of CT images. These include "algorithm" in General Electric, "reconstruction filter" in Philips, "Kernel" in Siemens, "filter convolution" in Toshiba and "image filter" in Hitachi [26,27]. In our Toshiba 320-row CT scanner, FC can be classified as having beam hardening correction (BHC) (labeled FC01 to FC09) or not (labeled FC11 to FC19). BHC is an iterative correction algorithm that is applied to reduce beam hardening artifacts, which occur between two high-contrast structures [27]. As an example, FC02 and FC12 have the same reconstruction algorithm, except that BHC is used in FC02 and not in FC12. Within the same group, FC algorithms with higher numbers represent sharper kernel filters and have stronger edge enhancement [26–28]; therefore, FC08 produces sharper but noisier images than does FC02. For standard cardiac CT, the conventional algorithm is FC12 with a 22-cm dFOV for the heart, as Agatston Scoring is currently only validated without BHC. For LDCT of the lung, FC02 and FC08 are the protocols recommended in the operation manual [27].

To our knowledge, this is the first study to investigate the effects of different FC and dFOV on CAC scores. We aim to compare the reliability of different LDCT protocols in measuring CAC, using standard cardiac CT as the gold standard. We hypothesize that different FC and dFOV may significantly affect CAC quantification, and thus an algorithm appropriate for CAC assessment should be identified.

2. Methods

2.1. Participants

This study was approved by the Institutional Review Board of our institution (approval number #100-4675A3), and informed consent was obtained from all subjects. Inclusion criteria were subjects 45 to 85 years old with visible coronary artery calcification on routine chest CT images. Subjects were excluded if they had coronary stents or coronary artery bypass grafts, difficulties in breath-holding or maintaining a supine position, hemodynamic instability, pregnancy, severe tachycardia, cardiac arrhythmia, pacemaker implantation or other metallic devices in the thorax that may produce artifacts to interfere with CAC measurement.

Over 15 months, 50 subjects (36 males, aged 52 to 85 years, mean 68.5) were enrolled. Each subject underwent both a 320-row non-enhanced LDCT and a standard cardiac CT using the same 320-row CT scanner and on the same day. Of the 50 subjects, 30 had hypertension, 14 had diabetes mellitus, 11 had hypercholesterolemia, and 10 had a history of smoking. Body mass index values ranged from 17.26 to 34.02 (mean 24.8 ± standard error 3.5) kg/cm^2. Heart rates during standard cardiac CT ranged from 46 to 95 (mean 71.0 ± standard error 10.8) beats per minute. The clinical diagnoses of the 50 subjects included CAD (n = 18), aortic dissection or aneurysm (n = 6), lymphoma (n = 6), lung nodule or lung cancer (n = 18), bronchiectasis (n = 1) and pneumonitis (n = 1).

2.2. CT scanning protocols and images reconstruction

All CT scans were performed on a wide volume 320-row CT scanner at 320 × 0.5 mm detector configuration, with a fixed tube voltage of 120 kVp, 16-cm coverage and gantry rotation time of 350 ms (Aquilion One, Model: TSX-301A, Toshiba Medical System Corporation, Japan). ECG-gated standard cardiac CT using protocol FC12(22) (FC12 with a 22-cm dFOV) (Fig. 1A) and four different LDCT protocols FC02(40), FC02(22), FC08(40) and FC08(22) (Fig. 1B to E) were applied to each subject (Table A1 and Fig. A1). Standard cardiac CT was used as a gold standard for CAC scoring. Hybrid algorithms with 50% filtered back projection (FBP) and 50% adaptive iterative dose reduction (AIDR 3D) at standard level were applied in the standard cardiac CT and LDCT in all subjects.

2.2.1. Non-ECG-gated spiral LDCT of chest

LDCT examinations were performed with 120 kVp, 3-mm slice thickness, 20–45 mAs, 0.5-second gantry rotation, and a pitch of 1.5. The entire chest was imaged in a single breath-hold without ECG gating, using a data collection diameter of 40 cm and scanning from the lung apex to the posterior costophrenic angle. The raw data were reconstructed into 512 × 512 matrix chest images with a 40-cm dFOV using FC02 and FC08. Cardiac images were then reconstructed from raw data using a 22-cm dFOV from carina to heart base in contiguous 3-mm slice thickness.

2.2.2. Prospectively ECG-gated standard cardiac CT

Prospective ECG-gated standard cardiac CT from the carina to the cardiac apex (12–16 cm) was performed in a single breath-hold. Cardiac images at 75% of the interval between two R waves on ECG (R-R interval) were obtained using protocol FC12(22), tube voltage 120 kVp, 512 × 512 matrix and contiguous 3-mm slice thickness. The tube current-time product for standard cardiac CT was 66 mAs.

2.3. Measurement of coronary artery calcification (CAC)

Image data from selected reconstruction filters were transferred to an offline workstation (Vitreafx V. 2.0.2, Vital Images, Inc. USA) for calculation of CAC. Regions of interest containing calcified plaques in each coronary artery were encircled manually by a dedicated radiological technologist, and a computer-driven measurement of the lesions was automatically obtained. All calcifications ≥130 Hounsfield Units (HU) were considered potential coronary calcification according to the conventional definition of the Agatston score, along with the requirement of three contiguous pixels [29]. An Agatston score was obtained by the sum of scores of each calcification, defined as pixel area multiplied by a weighted density factor (1: 130–199 HU, 2: 200–299 HU, 3: 300–399 HU, 4: >399 HU) [29]. Total calcium scores were obtained from the summation of calcium scores from the left main coronary artery, right coronary artery, left circumflex coronary artery, and left anterior descending coronary artery, with the branches considered a part of the main vessel and ramus intermedius as part of left anterior descending coronary artery, if present [13].

2.4. Estimation of effective radiation dose

After CT, the dose-length product (DLP) shown in the dose report for each patient was recorded. The effective radiation dose in mSv was estimated from the extended DLP multiplied by a conversion factor of 0.014 mSv/mGy-cm [30]. The same conversion factor was used for both men and women.

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