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Original Research Article

Radiation dose in 320-slice multidetector cardiac CT: A single center experience of evolving dose minimization

Matthew K. Tung MBBS (Hons)[a,b],
James D. Cameron MBBS, MD, BE (Elec), MEngSc, FIEAust, CPE (Biomed), FCSANZ[a,b,*],
Joshua M. Casan MBBS (Hons), B Med Sci (Hons)[a,b],
Marcus Crossett B App Sc (Medical Radiations)[c], *John M. Troupis MBBS, FRANZCR*[a,b,c],
Ian T. Meredith BSc (Hons), MBBS (Hons), PhD, FRACP, FACC, FCSANZ, FSCAI[a,b],
Sujith K. Seneviratne MBBS, FRACP, FCSANZ[a,b]

[a] *Monash Cardiovascular Research Center, MonashHEART, Monash Medical Center, 246 Clayton Road, Clayton 3168, Australia*
[b] *Monash University Department of Medicine (MMC), Melbourne, Australia*
[c] *Diagnostic Imaging, Southern Health, Melbourne, Australia*

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ABSTRACT

Background: Minimization of radiation exposure remains an important subject that occurs in parallel with advances in scanner technology.
Objective: We report our experience of evolving radiation dose and its determinants after the introduction of 320-multidetector row cardiac CT within a single tertiary cardiology referral service.
Methods: Four cohorts of consecutive patients (total 525 scans), who underwent cardiac CT at defined time points as early as 2008, are described. These include a cohort just after scanner installation, after 2 upgrades of the operating system, and after introduction of an adaptive iterative image reconstruction algorithm. The proportions of nondiagnostic coronary artery segments and studies with nondiagnostic segments were compared between cohorts.
Results: Significant reductions were observed in median radiation doses in all cohorts compared with the initial cohort ($P < .001$). Median dose-length product fell from 944 mGy · cm (interquartile range [IQR], 567.3–1426.5 mGy · cm) to 156 mGy · cm (IQR, 99.2–265.0 mGy · cm). Although the proportion of prospectively triggered scans has increased, reductions in radiation dose have occurred independently of distribution of scan formats. In multiple regression that combined all groups, determinants of dose-length product were tube output, the number of cardiac cycles scanned, tube voltage, scan length, scan format, body mass index, phase width, and heart rate (adjusted $R^2 = 0.85$, $P < .001$). The proportion of nondiagnostic coronary artery segments was slightly increased in group 4 (2.9%; $P < .01$).
Conclusion: While maintaining diagnostic quality in 320-multidetector row cardiac CT, the radiation dose has decreased substantially because of a combination of dose-reduction protocols and technical improvements. Continued minimization of radiation dose will increase the potential for cardiac CT to expand as a cardiac imaging modality.

* Corresponding author.
E-mail address: james.cameron@monash.edu (J.D. Cameron).
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1. Introduction

Cardiac CT guidelines have been published which describe the appropriate clinical indications for the use of this noninvasive imaging modality along with strategies to optimize radiation dose.[1,2] Radiation exposure and concerns over its potential risks are a main limitation to the expanding use of cardiac CT and coronary CT angiography (CTA).[3] New developments in scanner design and imaging techniques have therefore focused not only on improving image quality but also on reducing the radiation dose to the patient.

The advent of 320-multidetector row cardiac CT (320-MDCT) has increased the z-axis coverage sufficiently to scan from cardiac apex to base in a single rotation, thereby potentially obtaining a full cardiac reconstruction in a single cardiac cycle, obviating the need for reconstruction from multiple rotations in multiple cardiac cycles.[4–6] Besides eliminating misalignment artifact, this can theoretically be expected to decrease radiation dose through decreased imaging rotations and slice overlap while also opening up the prospect of dynamic cardiac CT through single-cardiac cycle flow and perfusion studies.

We report here our experience of progressive changes in radiation dose over an extended period of time at our center, aiming to demonstrate the key factors that facilitated dose minimization in a real-world clinical setting. We compared our initial experience after installation with 3 subsequent cohorts of consecutive patients after dose-reducing modifications in the operating system and after the introduction of an adaptive iterative image reconstruction algorithm.[7,8]

2. Methods

Four cohorts of consecutive patients (total 525) undergoing coronary CTA for clinical indications between September 2008 and July 2011 were prospectively analyzed. The initial CT system installed in our center was the Aquilion ONE 320-MDCT with V4.2 software. Initial indications for coronary CTA included ischemic-type chest pain of low-to-intermediate risk,[1] pediatric and adult congenital heart disease, planning before electrophysiology procedure, and planning before cardiac surgery. Characteristics of the initial 212 adult cases and 3 subsequent comparator groups referred for 320-MDCT are given in Table 1. Scans performed in children or for investigation of congenital cardiac conditions are not included in this analysis.

Cardiac CT was always performed with device settings as currently suggested by the manufacturer and according to predefined institutional clinical protocols with the use of 1 of the following 3 scan formats (Fig. 1): (1) prospectively electrocardiogram (ECG)-triggered phase window widths (no ECG dose modulation); (2) full cardiac cycle, ECG-based tube current modulation with prospectively defined diastolic acquisition window (70%–80% for heart rate [HR] <65 beats/min, 30%–80% for HR ≥65beats/min with a tube current of 100 mA during low tube current portions); and (3) full cardiac cycle retrospectively gated (no ECG dose modulation).

Scan format was determined by prespecified hospital protocol (including a protocol requirement in the initial cohort that patients referred from the emergency department for investigation of symptoms suggestive of ischemic chest pain should have full cardiac cycle imaging to allow for left ventricular functional assessment[9]). All subjects with a HR >60 beats/min received β-blockers with a single oral dose of 50 mg or 100 mg of metoprolol. If the HR remained >65 beats/min at the time of scan additional oral (50–100 mg) or intravenous metoprolol (5–10 mg) was administered. Oral ivabradine (5–10 mg) has also been used since June 2009. Sublingual glyceryl trinitrate (400 μg) was administered 1 minute before contrast injection. Contrast agent, 75 to 100 mL (Ultravist 370 at 370 g/cm^3; Bayer HealthCare) with 50 mL of saline flush was injected intravenously at a rate of 5 to 6 mL/s (median, 6 mL/s). Atrial fibrillation was not considered a contraindication to imaging, and patients with atrial fibrillation are included in the analyses.[10]

In April 2009 a supplier-mandated upgrade in operating software (to version 4.3) for the 320-MDCT occurred at which point 212 subjects (group 1) had been scanned at our site. The predominant effect of this operational update was to give an option to prevent arrhythmia rejection software from automatically increasing the number of cardiac cycles scanned. Use of arrhythmia rejection was at the discretion of the operating radiographer. The proportion of cases in which this option was disabled was not recorded. Group 2 consists of the initial 102 patients scanned after this operating system revision. Group 3 consists of 110 consecutive patients imaged after a second operating software update in October 2010 (version 4.61, including phaseXact, ConeXact, and VolumeXact+; Toshiba Medical Systems). Several aspects were affected by this update. First, the use of asymmetrical cone beam correction to decrease the exposure time facilitated a reduction in the duration of maximum tube current during ECG-based dose-modulated and prospective ECG-triggered imaging,[11,12] Second, a software modification of the volume truncation effect allowed a decreased scan length overall.[12,13] Although first-generation iterative reconstruction features were available in this upgrade, they were not used at our center.

Group 4 consisted of 101 consecutive patients scanned after a further operational update in July 2011 (version 4.74, including AIDR3D). This update involved the introduction of a new image reconstruction method and also improvements in advanced dose modulation. First, the reconstruction algorithm (AIDR3D; Toshiba Medical Systems) applied statistical remodeling and iterative optimization to prospectively reduce image noise and to enhance image quality from raw image data acquired with lower radiation doses. Second, the update in dose modulation (SureExposure3D; Toshiba Medical Systems) allowed optimization and setting of tube current at each point along the acquisition path of the scan on the basis of the scout images. Tube potential defaulted to 120 kV with tube current determined by expected standard deviation (SD) within the image as determined by SureExposure3D. When the tube current achieved maximum level, the tube potential was increased to 135 kV. When the tube current was <450 mA, the tube potential was decreased