Reduced Axial Scan Length Coronary Calcium Scoring Reduces Radiation Dose and Provides Adequate Clinical Decision-Making Before Coronary CT Angiography

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Abbreviations: computed tomography (CT), coronary computed tomography angiography (CCTA), full scan length (FSL), reduced scan length (RSL), dose length product (DLP), computed tomography dose index (CTDI), milliampere (mA), kilovolts-peak (kVp), Walter Reed National Military Medical Center, Bethesda (WRNMMC-B), coronary artery calcium (CAC), computed tomography angiography (CTA)

ABSTRACT
Extensive coronary artery calcium (CAC) diminishes the accuracy of coronary computed tomography angiography (CCTA). Many imagers adjust CCTA acquisition parameters depending on a pre-CCTA Agatston CAC score to optimize diagnostic accuracy. Typical pre-CCTA CAC imaging adds considerably to radiation exposure, partially attributable to imaging beyond the area known for highest CAC, the proximal coronary arteries. We aimed to determine whether a z-axis reduced scan length (RSL) would identify the majority of CAC and provide adequate information to computed tomography angiography providers relative to a standard full-scan length (FSL) pre-CCTA noncontrast CT. We retrospectively examined 200 subjects. The mean CAC scores detected in RSL and FSL were 77.4 (95% CI 50.6 to 104.3) and 93.9 (95% CI 57.3 to 130.5), respectively. RSL detected 81% of the FSL CAC. Among false negatives, with no CAC detected in RSL, FSL CAC severity was minimal (mean score 2.8). There was high concordance, averaging 88%, between CCTA imaging parameter adjustment decisions made by 2 experienced imagers based on either RSL or FSL. CAC detected and decision concordance decreased with increasing CAC burden. CAC detected was lower, and false negatives were more common in the right coronary artery owing to its anatomic course, placing larger segments outside RSL. Axial scan length and effective dose decreased 59% from FSL (24 cm/2.1 mSv) to RSL (5.6 cm/0.45 mSv). This retrospective study suggests that RSL identifies most CAC, results in similar CCTA acquisition parameter modifications, and reduces radiation exposure. Our colleagues corroborated these results in a recently published prospective study.

INTRODUCTION
Coronary computed tomography angiography (CCTA) is a well-established noninvasive method to evaluate coronary pathology; however, the accuracy of CCTA varies depending on the amount and location of calcified plaques in the coronary arteries (1). A high coronary artery calcium (CAC) score is often associated with a nondiagnostic CCTA (2, 3). Beam hardening in densely calcified coronary arteries causes decreased sensitivity and specificity of CCTA in patients with high CAC. To counteract this, in many CCTA examinations, imagers perform a pre-CCTA-gated noncontrast computed tomography (CT) for identification and scoring of CAC, and then they use this information to adjust CCTA parameters to optimize acquisition parameters (eg, dose, gating) (4–6). One meta-analysis suggests that careful pre-CCTA planning is crucial in patients with CAC score ≥400 to ensure diagnostic accuracy (7).

Radiation doses of a standard pre-CCTA CAC scoring, covering the entire heart, are typically 1–3 mSv (8, 9), whereas the radiation dose of CCTA is typically 2–8 mSv (10). Therefore, performing a standard pre-CCTA CAC scoring exposes patients who are undergoing CCTA to considerable radiation. One approach to minimize patient radiation exposure in cardiac CT is to limit the scan length in the z-axis (ie, the craniocaudal dimension) (5). A typical scan length for CAC scoring is from the carina through the diaphragm (8). However, the majority of coronary artery calcifications occurs in the proximal to mid portions of the coronary...
arteries (11, 12), so CT exposure above and below the proximal to mid-coronary arteries often yields little diagnostic information but adds to the radiation dose (6).

Therefore, we sought to assess whether CAC as assessed from scans with reduced scan length (RSL), shortened in the z-axis to include only the proximal and mid-coronary arteries, would aid in the identification of the majority of coronary artery calcification and provide adequate information to computed tomography angiography imagers of patients referred for CCTA compared with CAC assessed using standard full scan length (FSL).

**METHODS**

**Overview**

We retrospectively simulated RSL in 200 patients by conducting a postprocessing truncation of a set of standard FSL images. Clinicians viewed both RSL and FSL scans and determined a CAC score for each. We calculated the percentage of FSL CAC detected in RSL. To help recoup decreased detection of CAC in RSL, linear regression equations were derived to attempt to predict FSL CAC scores from RSL CAC scores. We also replicated the decision-making process of adjusting CCTA parameters to identify whether RSL would result in similar decisions when compared with standard FSL. Finally, we estimated the radiation dose savings that could be expected by implementing RSL CAC scoring protocol in routine clinical practice.

**Patient Selection**

Data in this study were collected from 200 subjects, >50 years, who had had a CCTA performed at our institution between July 1, 2013 and December 31, 2014. Patients were included if they underwent a clinically indicated noncontrast CAC scan and subsequent CCTA. Patients of at least 50 years of age were selected based on experience that this cohort is more likely to have substantial CAC, which might influence CCTA scan parameters and is a cohort where many providers most commonly perform pre-CCTA calcium scans.

**CT Examination Protocol**

All imaging was conducted on a General Electric Discovery LightSpeed\textsuperscript{TM} CT750 HD 64 Slice scanner (GE Medical Systems, Waukesha, WI). Patients underwent CT imaging consisting of a noncontrast CAC scoring and subsequent contrast-enhanced CCTA in accordance with SCCT guidelines.

**FSL CAC Score Acquisition**

Following standard institutional protocol, FSL images were acquired from each research subject from the carina through the diaphragm and were stored in a picture archiving and communication software (PACS) system (AGFA version 6.4.0.5510, Mortsel, Belgium). CAC scoring was performed in accordance with the Agatston method (13) on a GE Advantage Workstation (GE Healthcare, Chicago, IL) for diagnostic imaging post processing. In total, 3 groupings of coronary arteries were analyzed for calcium, specifically the left coronary artery, the right coronary artery, and the right and left coronary arteries combined. Although left CAC in more precise anatomic locations was originally scored, all CAC scores from the left main, left anterior descending, and left circumflex coronary arteries were merged into an inclusive group for the purpose of this analysis. This decision was based on the assumption of large interobserver variability in accurate classification of CAC near the bifurcation of the left coronary artery system into one of its tributaries (ie, the distal left main or the proximal left anterior descending or proximal left circumflex).

**RSL CAC Score Calculations**

FSL images were postprocessed to generate RSL images. FSL image volume was truncated in the z-axis, from 1 cm below the carina to the greatest convexity of the right atrium, to produce RSL image volume. For each RSL image, Agatston CAC scores were generated. The same 3 groupings of coronary vessels were analyzed for calcium. See Figure 1 for a representative visual comparison between FSL and RSL. The proportion of the Agatston CAC score on FSL captured in RSL was assessed.

**Clinical Decision-Making**

FSL images from each research subject were interpreted in consensus by both a radiologist and a cardiologist, both board-certified with >10 years of clinical experience in the performance of cardiac CT. On a separate occasion, RSL images were randomly presented to the same 2 physicians for interpretation. The RSL and FSL images were presented to these interpreting physicians...
analyses were conducted using R Version 3.2.2 (R Core Team, Vienna, Austria). Continuous variables were reported as means with 95% confidence interval, and categorical variables were reported as a percentage.

Institutional Review and Research Setting

This retrospective study was approved with a waiver of informed consent by Walter Reed National Military Medical Center Bethesda (WRNMMC-B) Institutional Review Board (protocol #394857) in compliance with all applicable federal regulations governing the protection of human subjects. This assessment was conducted at WRNMMC-B, a moderate-sized tertiary care facility providing for Military Health System beneficiaries residing in the National Capital Region near Washington, D.C. No external funding was used in support of this research.

RESULTS

Research Subject Baseline Parameters

Images and clinical data from a total of 200 subjects (104 men and 96 women) were included in this study. The mean age, body mass index, and heart rate were 60 years, 29.3 kg/m², and 56 beats/min, respectively.

Ability of RSL to Detect FSL CAC

Table 1 describes the RSL and FSL CAC data sets. Among all research subjects where the FSL total CAC was >0, RSL detected 81.34% of FSL CAC. A stratified analysis showed that RSL detected 98.4% of FSL CAC in the left coronary artery. A stratified analysis of RSL’s ability to detect FSL CAC in the right coronary artery yielded different results than those seen in the left and total CAC analyses. Among the subjects where the FSL right CAC was >0, RSL detected 28.46% of CAC. As the FSL CAC burden increased, RSL detected progressively less of this CAC. Table 2 presents these results in more detail.

False Negatives with Detection of CAC in FSL and No Detection in RSL

In 3.5% of research subjects (n = 7), FSL showed total CAC, which was not detected with RSL. Among these 7 examinations, the average total CAC in FSL was 2.9 and the maximum was 9. In 2.5% of subjects (n = 5), FSL showed left CAC, which was not detected with RSL. Among the 5 examinations where RSL did
not detect left CAC, the average FSL left CAC in FSL was 2.2
and the maximum was 4. In 10% of subjects (n = 20), FSL
showed total CAC, which was not detected with RSL. In these
20 examinations, the average FSL right CAC was 64.6 and the
maximum was 653.

**Subsequent CCTA Parameter Decision-Making**

Comparison

There was overall high concordance between the CCTA parame-
ter manipulation decisions based on RSL and FSL interpretation
(Table 3). The highest discordance occurs for individuals with
higher CAC scores. Figure 2 shows that with CAC scores
> 0, concordance rapidly falls to near 50% and kVp concordance decreases
to ~75% in the upper quartiles of CAC.

**Radiation Reduction**

See Table 4 for differences in scan length and radiation dose
between FSL and RSL.

**DISCUSSION**

In this study, we retrospectively examined the clinical feasibility
of using a pre-CCTA CAC score with RSL in the z-axis with the
intention of reducing patient radiation exposure. Our study
shows multiple important findings including:

1. RSL detects most CAC seen in FSL;
2. RSL results in a small percentage of false-negative CAC
examinations and is highly predictive of FSL CAC scores;
3. RSL CAC scans result in similar decision-making regarding
parameter adjustment for subsequent CCTA; and
4. RSL CAC scans may significantly reduce patient radiation
exposure if used clinically.

Among all research subjects where FSL total CAC was >0,
RSL detected >80% of FSL CAC. As the burden of CAC increased
to >1000, the percent detection dropped to ~65%. Similar results
were seen in the left coronary arteries, where RSL detected >98%
of FSL CAC with a similar decreased detection efficiency of
~90% as the CAC burden increased >1000. Very different results
were seen in the right coronary artery with RSL detecting <30%
of FSL CAC, with detection efficiency decreasing to ~10% as the
CAC burden increased >1000.

False negatives (ie, detection of CAC on FSL without detec-
tion on RSL) were infrequent, particularly in the total and left
coronary artery analyses. In these false negatives, the magnitude
of the undetected CAC score never exceeded an Agatston score
of 9, a generally very small quantity. False negatives were the
most frequent in the right coronary artery, where they occurred
in 10% of research subjects. In these false negatives, a larger
magnitude of undetected CAC was observed, on average an
Agatston score of ~65 and in the most extreme case was 653.

As described in the previous paragraphs, when compared
with RSL of the total and left CAC, the RSL right CAC score shows
a markedly greater percentage of underdetection of CAC, and a
higher percentage of false negatives with larger burdens of CAC
was not observed. The right coronary artery has a more inferior
(ie, caudal) origin along the aortic root than the left main

**Table 2. Percentage of Full Scan Length Coronary Artery Calcium Detected in Using Reduced Scan Length**

| Coronary Artery | FSL CAC > 0 | FSL CAC > 100 | FSL CAC > 200 | FSL CAC > 1000 |
|-----------------|-------------|---------------|---------------|---------------|
| Both left and right coronary artery systems | 81.34% | 78.87% | 70.95% | 65.42% |
| Left coronary arteries | 98.44% | 98.32% | 90.41% | 89.60% |
| Right coronary artery | 28.46% | 15.57% | 13.24% | 10.56% |

* Separate analyses were conducted to independently analyze the left coronary artery system, the right coronary artery, and the right and left coronary
to combined.

**Table 3. Percentage Concordance between Decisions for Coronary Computed Tomography Angiography (CCTA)**

Parameter Adjustments Based on Full Scan Length (FSL) and Reduced Scan Length (RSL)

| Parameter | Concordance (%) | Average Change Based on FSL | Average Change Based on RSL | Major Discrepancies |
|-----------|-----------------|----------------------------|----------------------------|---------------------|
| mA        | 71% (P = .7277) | 97.18                      | 82.09                      | 0                   |
| kVp       | 87.5% (P = .8383) | 20                         | 18.97                      | 1                   |
| Padding   | 96% (P = .1306) | 50                         | 61.1                       | 1                   |
| Gating    | 99% (P < .001)  | N/A                        | N/A                        | N/A                 |
| High definition | 89% (P = .0190) | N/A                        | N/A                        | N/A                 |

* P-values were calculated using the McNemar chi-square with 1 degree of freedom. Average CCTA parameter changes are based on both FSL and RSL.
The number of major CCTA imaging parameter decision-making discrepancies are presented, defined as differences of > 100 for mA, 20 for kVp, and 50
milliseconds for padding.
coronary artery and it travels in a more inferiorly oriented course along the pericardium than the other major coronary artery branches. We postulate that the more inferior origin and course of the right coronary artery subsequently position its proximal and mid portions closest to being off of the inferior margin of RSL, and thus results in greater underdetection of CAC in the right coronary artery than in the other major coronary vessels. Furthermore, previous studies suggest that unlike in the left coronary arteries where CAC is concentrated in the proximal portions of the arteries, the right coronary artery has a more uniform distribution or even distally concentrated distribution (16).

There was overall high concordance in decision-making regarding imaging parameter adjustment based on FSL and RSL CAC scores for the subsequent CCTA. In total, 4 of the 5 parameters (ie, kVp, padding, choice of prospective/retrospective gating, and use of high definition) evaluated showed >87% concordance, with the remaining parameter (ie, mA) showing 70% concordance. Concordance dropped as FSL CAC score increased. For the imaging parameters which were continuous variables (ie, mA, kVp, and padding), the average magnitude of the differences in the changes was minimal. In addition, the number of large discrepancies (ie, ΔkVp > 20, ΔmA > 100, Δpadding > 50 milliseconds) was minimal.

Our results show a reduction in axial scan length and a directly proportional reduction in radiation dose of ~60% from FSL (~14.5 cm and ~1.1 mSv) to RSL (~5.9 cm and ~0.45 mSv). Given that the mean effective radiation dose of CCTA is typically between 2 and 8 mSv (10), this result represents a noteworthy decrease in dose to the combined imaging sequence of a CAC score followed by CCTA.

Our study has several important limitations. First, this study involved patients undergoing only CAC scoring before CCTA and

### Table 4. Differences in Scan Length and Radiation Dose between FSL and RSL

| Parameter | Axial (z) Scan Length (cm) | Computed Tomography Dose Index (mGy) | Dose Length Product (mGy-cm) | Effective Dose (mSv) [Calculated Using k = 0.014 mSv/(mGy-cm)] |
|-----------|---------------------------|--------------------------------------|-----------------------------|---------------------------------------------------------------|
| FSL       | 14.54 ± 0.24              | 5.42 ± 0.09                          | 79.96 ± 1.92                | 1.12 ± 0.03                                                   |
| RSL       | 5.85 ± 0.17               | 2.18 ± 0.06                          | 32.08 ± 1.03                | 0.45 ± 0.01                                                   |
| Change    | −8.69 ± 0.22              | −3.24 ± 0.09                         | −47.88 ± 1.55               | −0.67 ± 0.02                                                  |

All values are reported using ±95% confidence intervals.
thus our results should not be extrapolated to CAC scoring for coronary artery disease screening. Second, our examination was restricted to a single medical center, a single scanner platform, and age >50 years, and thus, these results may not be broadly generalizable to other patient populations, CT scanners, or age groups. Although our study incorporated a large sample size of 200 subjects, many of these subjects showed very low CAC scores, with 81 subjects showing CAC scores of 0 and additional 78 subjects showing CAC scores of <100. As defined in the goals of our research, the objectives were to determine the percentage of CAC detected and whether similar CCTA parameter adjustment decision-making occurred based on the amount of CAC detected. It is outside the scope of our examination to determine whether the RSL CAC score as a stand-alone value is predictive of acute coronary syndrome events. Finally, this study was a retrospective examination aimed primarily at hypothesis generation; however, our results were prospectively corroborated in a recently published prospective clinical trial—the Focused field of view calcium scoring prior to coronary CT angiography (FOCUS-CTA; ClinicalTrials.gov Identifier: NCT02972242) (17).

**CONCLUSION**

RSL noncontrast CT scan identifies the majority of CAC and is associated with similar post-CAC decision-making regarding parameter adjustment for subsequent CCTA. These results are hypothesis generating and should be assessed, along with other CAC reduction methods, in prospective comparative studies.

**DISCLOSURE**

Conflicts of Interest/Funding: We deny any financial or other relationships that may pose a relevant conflict of interest. No funding was used in support of this research.

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