Comparison of Image Quality and Radiation Dose of Coronary Computed Tomography Angiography Between Conventional Helical Scanning and a Strategy Incorporating Sequential Scanning

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Abstract

Radiation dose from coronary computed tomography angiography may be reduced using a sequential scanning protocol rather than a conventional helical scanning protocol. Here we compare radiation dose and image quality from coronary computed tomography angiography in a single center between an initial period during which helical scanning with electrocardiographically-controlled tube current modulation was used for all patients (n=138) and after adoption of a strategy incorporating sequential scanning whenever appropriate (n=261). Using the sequential-if-appropriate strategy, sequential scanning was employed in 86.2% of patients. Compared to the helical-only strategy, this strategy was associated with a 65.1% dose reduction (mean dose-length product of 305.2 vs. 875.1 and mean effective dose of 14.9 mSv vs. 5.2 mSv, respectively), with no significant change in overall image quality, step artifacts, motion artifacts, or perceived image noise. For the 225 patients undergoing sequential scanning, the dose-length product was 201.9 ± 90.0 mGy·cm, while for patients undergoing helical scanning under either strategy, the dose-length product was 890.9 ± 293.3 mGy·cm (p<0.0001), corresponding to mean effective doses of 3.4 mSv and 15.1 mSv, respectively, a 77.5% reduction. Image quality was significantly greater for the sequential studies, reflecting the poorer image quality in patients undergoing helical scanning in the sequential-if-appropriate strategy. In conclusion, a sequential-if-appropriate diagnostic strategy reduces dose markedly compared to a helical-only strategy, with no significant difference in image quality.

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Keywords

Coronary CT angiography; sequential scanning; diagnostic strategies; radiation dose

Introduction

Recent advances in computed tomography (CT), with improvement in spatial and temporal resolution, now enable accurate assessment of the coronary arteries in a minimally invasive way.[1–4] Along with other cardiac imaging modalities such as myocardial perfusion scintigraphy and invasive angiography, coronary CT angiography (CCTA) utilizes ionizing radiation to obtain images.[5–7] With increasing concern about potential risks of malignancy associated with the doses of radiation received by patients undergoing CCTA,[8] manufacturers of CT equipment have implemented approaches to reduce radiation exposure. Most CCTAs are performed utilizing a helical acquisition and image reconstruction using retrospective electrocardiographic (ECG) gating.[9] This technique requires that the x-ray tube remains on during the entire cardiac cycle even though only a few phases in diastole (when coronary artery motion is minimized) are typically required to adequately evaluate coronary artery stenosis. Efforts to decrease radiation doses have been achieved by modulating the current delivered according to the phase of the cardiac cycle.[10,11] As an attempt to further lower dose, a sequential or "step-and-shoot" approach, using prospective ECG triggering, was described in 2006,[12] and is now implemented in many newer scanners. Sequential scanning delivers x-rays only during diastole. Rather than having the patient table move at a constant rate as x-rays are continuously delivered, the table remains stationary while a brief pulse of x-rays is delivered to image a portion of the heart and then advances before a subsequent cardiac cycle initiates the next pulse. This method requires a slow heart rate (HR) and a regular rhythm to be applied successfully. This study compares radiation dose and several aspects of image quality between a strategy in which sequential scanning is employed whenever appropriate, referred to as "sequential-if-appropriate", and the traditional "helical-only" strategy, using ECG-synchronized tube current modulation (ESTCM).

Methods

We studied consecutive patients referred to a single outpatient laboratory for evaluation of known or suspected coronary artery disease by CCTA, prior to and after a scanner upgrade that enabled sequential scanning to be performed. Prior to the upgrade, all patients were imaged using a helical protocol. After the upgrade, patients were scanned sequentially, unless they had a HR > 65 beats per minute (bpm) or an irregular rhythm, in which case a retrospectively gated helical mode was employed. If not contraindicated, intravenous metoprolol tartrate was given to achieve a goal HR < 65 bpm. All patients had received a questionnaire addressing demographic and health status factors. Only patients with scans limited to the coronary arteries were considered for this analysis. Patients who underwent a scan with extended craniocaudal coverage, for example imaging of coronary artery bypass grafts or "triple-rule-out" studies, which would be expected to require a larger radiation dose, were excluded from this analysis. This retrospective study was approved by the institutional review board.

CCTA examinations were performed on a single Lightspeed VCT/VCT XT scanner (GE Healthcare, Milwaukee, WI). All patients received a 2 plane scout, a calcium score, a timing bolus and either sequential scanning (SnapShot Pulse, GE Healthcare) or helical scanning with ESTCM (SnapShot Segment or SnapShot Burst, GE Healthcare) for coronary angiography. Image acquisition was performed from the tracheal bifurcation to the diaphragm. Scanning parameters included 64×0.625 mm detector configuration, gantry rotation time of 350 ms, and tube voltage of 100 or 120 kVp. Nearly all studies were performed with a voltage of 120

kVp. A lower voltage of 100 kVp was used rarely if the patient was very thin (roughly 3% of the cases). Maximum tube current was determined based on the patient's weight (250 – 275 mA for 95 – 140 lbs, 300 – 400 mA for 140 – 200 lbs, 450 – 600 mA for 200–230 lbs, and 600 – 800 mA for > 230 pounds). Variations of current settings within an individual weight category were determined by the experience of the technologist. For helical scans, ESTCM was performed with maximum tube current applied between 40% and 80% of the R-R interval; minimum tube current was 150 mA in the vast majority of cases, but increased to up to 400 mA at the technologist's discretion in very obese patients. For sequential scans, the x-ray window was set at 75% of the R-R interval with x-ray padding between 0 and 200 ms based on heart rate variability determined by the technologist at the time of scanning. Either small or medium scan field of view was utilized in patients depending on general patient body habitus.

CCTA images were reconstructed at 0.6 mm using a standard reconstruction algorithm and transferred to a 3D workstation (Advantage Workstation, GE Healthcare) for evaluation. Images were reviewed in all 3 planes and multiple phases as available, utilizing double oblique views. Optimal multiplanar reformat, maximum intensity projection, and/or curved multiplanar reformat images were generally constructed with commercial available software (CardIQ, GE Healthcare).

Effective dose of radiation in populations of patients was estimated by multiplying the dose-length product (DLP) of the CCTA sequence by the European Guidelines on Quality Criteria conversion factor of 0.017 mSv•mGy^{-1}•cm^{-1}.[13]

Image quality was evaluated by 2 readers (M.R.P. and A.J.E.) experienced in reading CCTA. Four criteria – noise artifact, stair-step artifact, motion or blur artifact, and overall image quality – were each assessed using a 5 point scale (Table 1, Figure 1). Each reader received the 75% phase reconstruction and images available as constructed above in the optimal phase for interpretation. In this way each reader was blinded to the scan protocol utilized; had all phases of reconstruction been provided, it would have been clear which patients had undergone sequential scanning due to the limited number of phases. Readers were also blinded to scan and reconstruction information such as tube current, peak kilovoltage, and phase. Image manipulation was possible utilizing the 3D workstation. A third blinded reviewer (A.P.) measured the noise level, reported as the standard deviation of the CT number in Hounsfield units (HU), at 2 regions of interest: the air anterior to the patient as well as that of the descending aorta. The latter was measured at the largest chest diameter and the region of interest was chosen to be just smaller than the size of the aorta itself.

Statistical analysis was performed using Stata 8.2 and 10.1 for Windows (Stata Corp., College Station, TX). Comparisons of radiation dose, quality, and noise were performed using two-sample t-tests assuming either equal or unequal variance as appropriate. Results are reported as mean ± standard deviation along with the 95% confidence interval. Comparisons of baseline characteristics, beta blocker use, and heart rate were performed using chi-squared tests, *t*-tests, or Mann-Whitney *U* tests as appropriate. A two-tailed p value < 0.05 was deemed significant. Inter-rater agreement of image quality was examined with kappa statistics. Bias corrected, quadratic weighted kappa coefficients were used and the confidence intervals were estimated using 1,000 bootstraps. Agreement was classified as follows: fair ($\kappa = 0.21 – 0.40$), moderate ($\kappa = 0.41 – 0.60$), substantial ($\kappa = 0.61 – 0.80$), and almost perfect ($\kappa = 0.81 – 1.00$).[14]

Results

261 patients underwent CCTA after the adoption of the sequential-if-appropriate strategy, including 225 patients (86.2%) imaged using sequential scanning and 36 patients (13.8%) imaged using helical scanning with ESTCM (Figure 2). 138 consecutive coronary artery scans

performed using a helical-only strategy, prior to the technology upgrade, were identified for comparison. Thus, 399 total (174 helical and 225 sequential) CCTA studies were examined. A value for anterior air noise is missing for 2 patients in whom large body habitus precluded measurement. Therefore, 397 patients were used in this analysis. There were no significant between-group differences in patient characteristics, as elicited in self-reported questionnaires, or in coronary artery calcium scores (Table 2). A small number of items in the questionnaires were left blank and the % of responders is indicated in Table 2. Table 3 contains details on beta blocker administration and its impact on patient HRs.

DLP was decreased by 65.1% using the sequential-if-appropriate strategy compared to the helical-only strategy (305.2 ± 301.2 mGy·cm and 875.1 ± 278.5 mGy·cm, respectively; p < 0.0001). The corresponding effective doses were 5.2 mSv and 14.9 mSv, respectively. Comparing scan protocols, DLP was 201.9 ± 90.0 mGy·cm for sequential scans and 890.9 ± 293.3 mGy·cm for helical scans (p<0.0001). This corresponds to effective doses for these 2 protocols of 3.4 mSv and 15.1 mSv, respectively, reflecting a dose reduction of 77.5%. There was no significant difference in dose between helical studies performed before and after the scanner upgrade (p = 0.23). Details of radiation dosimetry are shown in Table 4.

Image quality scores, across all 4 dimensions examined, were not significantly different between the sequential-if-appropriate and helical-only strategies. However, these scores were significantly greater among the sequential scans compared to the helical scans (Table 5). When considering only the helical protocol scans, quality was superior among those performed as part of a helical-only strategy than those from a sequential-if-appropriate strategy.

There was moderate agreement between readers for noise (κ = 0.53, 95% CI 0.45 – 0.61), moderate agreement for step (κ = 0.49, 95% CI 0.37 – 0.58), substantial agreement for blur (κ = 0.70, 95% CI 0.64 – 0.76), and substantial agreement overall (κ = 0.71, 95% CI 0.65 – 0.76). A disagreement of 2 or more points was seen in 0.7% of patients for noise, 5.3% for step, 5.0% for blur, and 4.5% for overall quality. A tabulation of the 2 reviewers' rankings for overall quality is found in Table 6.

The mean noise levels of the anterior air and descending aorta were significantly greater in the sequential-if-appropriate strategy than in the helical-only strategy, as well as in the sequential protocol compared to the helical protocol. However, there was not a significant difference between the studies of the helical-only strategy and the helical protocol studies of the sequential-if-appropriate strategy. Tube current was less in the sequential-if-appropriate strategy compared to the helical-only strategy, the sequential compared to the helical groups, and in the studies of the helical-only strategy compared to the helical protocol studies of the sequential-if-appropriate strategy. Table 7 summarizes image noise and tube current data.

Discussion

Procedures that utilize ionizing radiation are integral parts of medical diagnosis and treatment, and physicians should use them in accordance with the As Low As Reasonably Achievable (ALARA) philosophy.[5] CCTA using helical protocol is widely used with effective radiation doses approaching 20 mSv in some patient populations.[15–18] Some studies have demonstrated a reduction in radiation exposure by modulating the current during the cardiac cycle (lower current during systole).[10,11,19] Others have found a reduction by tailoring the current or voltage to body habitus.[20,21]

The recently published PROTECTION I study investigated strategies for dose reduction. Among 1965 scans, the median DLP was 885 mGy·cm. The DLP was reduced by 78% using a sequential protocol. A sequential protocol was applied in only 99 scans (6%) and was limited by technology availability. The authors estimated that an additional 51% of patients would

have qualified to be scanned using this protocol if all scanners were capable of sequential scanning.[9]

Sequential scanning has been shown to be a viable alternative with a low effective radiation dose.[22] Gutstein et al. analyzed helical scans to identify predictors of diagnostic image quality. HR $\geq$ 70 bpm, HR variation of $\geq$ 10 bpm, coronary artery calcium score $\geq$ 400 U, and body mass index (BMI) $\geq$ 30 were all predictors of patient unsuitability for sequential scanning.[15]

Recently several studies have compared radiation dose between sequential and helical protocols. Hirai et al. scanned 60 patients twice each using both protocols (4.1 mSv vs. 20.0 mSv, respectively). They found image quality to be similar with an excellent agreement in the reading of stenotic lesions of > 50% occlusion.[16,23] Shuman et al. retrospectively compared 50 patients using a sequential protocol to 50 patients using a helical protocol and found a 77% reduction in effective dose (4.2 mSv vs. 18.1 mSv, respectively) along with similar quality scores.[17] Earls et al. looked at a total of 203 patients and described an 83% dose reduction (2.8 mSv vs. 18.4 mSv) with improved image quality.[18] The largest investigation found in the literature comparing radiation dose of these 2 protocols was recently published by Earls and Schrack in which 1978 CCTAs were reviewed. They confirmed the reduced radiation dose for sequential protocol studies compared to helical protocol studies (3.1 mSv vs. 17.2 mSv, respectively).[24]

In our study, there was a substantial reduction in effective radiation dose of 77.5% using the sequential protocol (3.4 mSv) compared to a standard helical protocol using ESTCM (15.1 mSv). The dose reduction in our study is similar to that found in other published studies, although additional recent reports suggest that helical protocols can be optimized futher, either by narrowing the window of maximal tube current[25], decreasing the minimal tube current to very low mA[25,26], or turning the x-ray tube off during parts of the cardiac cycle.[26]

Our expectation had been that quality for the sequential protocol images would be comparable or decreased compared to those of the helical protocol, due to the fewer cardiac phases available from which to obtain optimal images. However, the significant sparing in radiation exposure was not achieved at the expense of image quality. There was no significant difference in any aspect of image quality between the two scanning strategies, and the sequential protocol studies were read as having lesser degrees of noise, step, and blur artifacts as well as a greater overall quality than the helical protocol studies. While quality did not differ between the studies of the helical-only and sequential-if-appropriate strategies overall, the lower quality of the helical protocol scans of the sequential-if-appropriate strategy vs. scans of the helical-only strategy was not surprising, since in the sequential-if-appropriate strategy, patients were imaged using the helical protocol only if they had high HRs or irregular rhythms, which are detrimental to image quality. These higher HRs are evidenced in Table 3; the frequency of patients with cardiac rhythms other than normal sinus was not recorded.

A possible confounder for the finding of equivalent image quality between strategies is the slightly lower (by 2.2 bpm) post-metoprolol HR in the sequential-if-appropriate strategy. This could result in improved image quality, potentially causing a spurious finding of equivalence, although the difference in HRs was modest and barely statistically significant (p = 0.045). Another potential limitation of our study is that the BMI of the patients is not known, as this data was not recorded at the time of the scan. However, since there was no change in the referral population to our outpatient imaging center prior to and after the upgrade enabling sequential scanning, we would not expect a difference in body habitus of patients. As such, we would expect BMI to be similar between the sequential-if-appropriate and helical-only groups. Moreover, since BMI was not an indication to use one protocol over the other, we would not

expect a significant difference in body habitus between patients in the sequential-if-appropriate group scanned via the helical protocol and the sequential protocol.

Image noise in both the anterior air and descending aorta was significantly greater in the sequential-if-appropriate strategy than in the helical-only strategy, as well as in sequential scans compared to helical scans. This difference may be explained, at least in part, by the differences in applied tube current observed as there is an inverse relationship between noise and current. [27] With increased attention paid to minimizing radiation dose, the technologist was becoming more careful about using optimized tube currents with time. Accordingly, the mean tube current was 32 mA lower in the later sequential-if-appropriate scans than in the early helical-only scans. Another possible contributing factor is that the difference in noise may be related to the reconstruction algorithm. Nonetheless, despite an increase in measured image noise and lower applied tube current in the sequential protocol, blinded reads by experienced physicians found less artifact from noise interfering with image interpretability, and overall improved image quality, in the sequential strategy and scans.

Although a comparison between these 2 types of protocols has been discussed in the recent literature, our study is unique in 3 main regards: the size; the way we assessed quality; and our focus on diagnostic strategies rather than scanning protocols.

Our study is the largest published series of its kind. We analyzed a total of 399 patients (225 sequential protocol and 174 helical protocol). While a recent large study examined radiation exposure in 1978 patients, it did not discuss the effect of each protocol on image quality.[24] The next largest study to compare both radiation exposure and image quality was a study that included a total of 203 patients (121 sequential protocol and 82 helical protocol).[18] Furthermore, our criteria for inclusion were relatively broad, thus increasing the applicability of our findings to general outpatient practices.

To assess quality, we devised a unique grading scale that focuses on individual common artifacts and their effects on interpretability. Two experienced readers, who were blinded to the protocol used, assessed each study and assigned a score to each category. The published studies discussed above, in general, compared quality by assessing the diagnostic interpretability of the coronary artery segments as defined by the American Heart Association[16–18,20–23] or by the reading of stenoses[16] and did not look at each type of artifact individually. Even so, image quality data is not equivalent to evaluation of diagnostic accuracy efficacy.[28] Initial pilot studies suggest that sequential scanning has comparable diagnostic performance to conventional scanning[21], but randomized multicenter trials are needed.

The most unique aspect of our study is the analysis of 2 diagnostic strategies: helical-only vs. sequential-if-appropriate as determined by the patient's cardiac rate and rhythm. In the sequential-if-appropriate strategy, applied to 261 consecutive patients, the sequential protocol was appropriate in 86.2%. From the perspective of an outpatient cardiovascular imaging laboratory, this may be more useful then simply comparing sequential to helical protocols as the former is not suitable for all patients. Modern scanners are capable of both protocols and clinicians must utilize an algorithm to decide on one.

Acknowledgments

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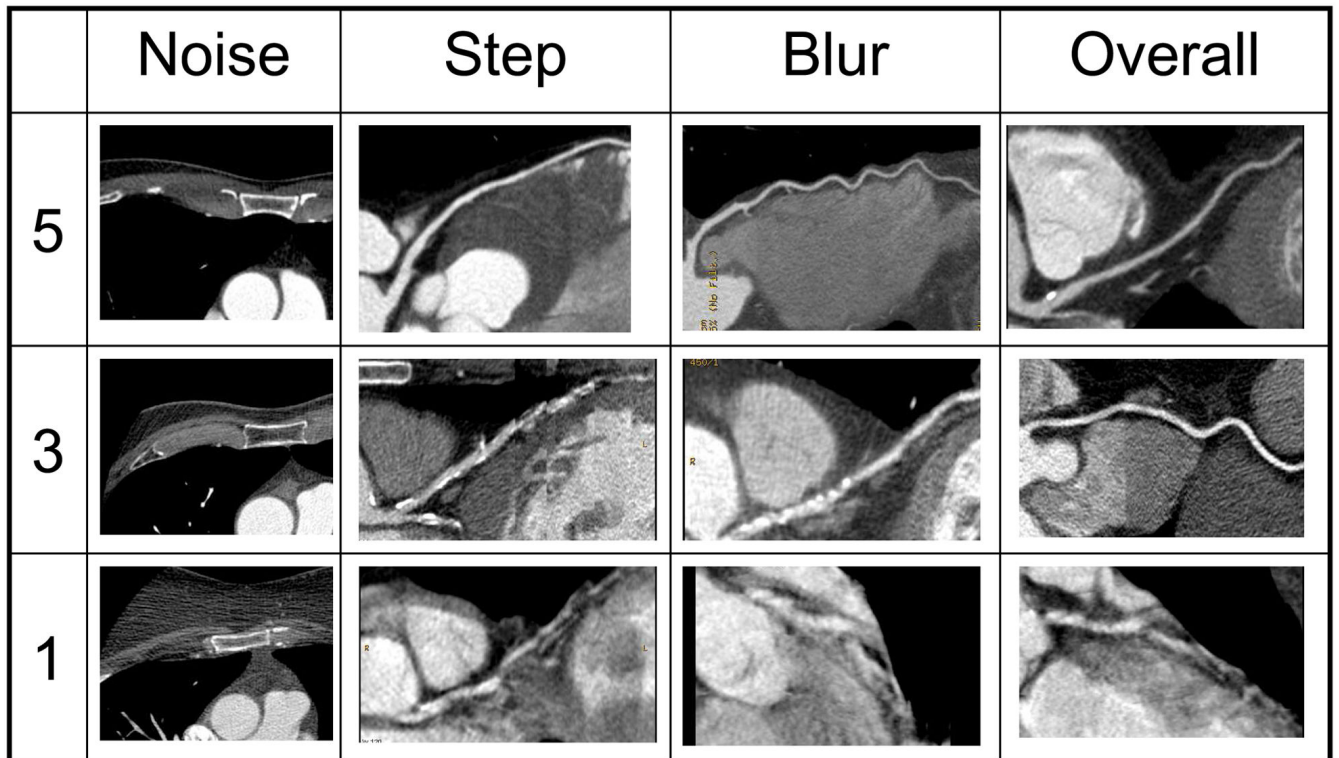
Figure 1.
Representative images reflecting highest, intermediate, and lowest levels of the four aspects of image quality considered (Table 1).
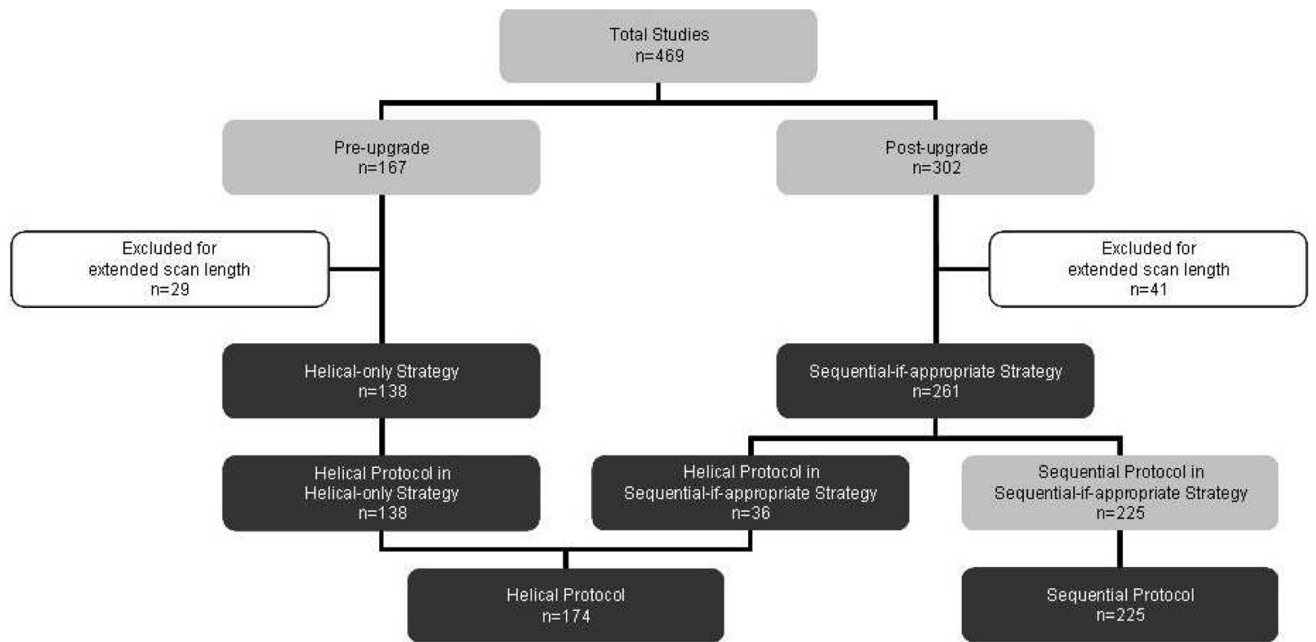
Figure 2.
Patient groups evaluated in the study. Statistical comparisons were made between groups represented by pairs of black boxes at the same horizontal level.

Table 1

5 Point Scales for Evaluation of Image Quality

Noise
5	None – Noise not at all interfering with image interpretability
4	Mild – Epicardial vessels well seen, small branch vessels not easy to interpret
3	Moderate – Epicardial vessels well seen, small branch vessels uninterpretable
2	Severe – Epicadial vessel interpretability affected
1	Non-diagnostic – Large vessel(s) uninterpretable due to excessive noise

Step (Stair-step) Artifact
5	None – No translation within any coronary arteries between slabs
4	Mild – Minimal translation with minimal effect on coronary artery interpretation
3	Moderate – Moderate translation with moderate effect on coronary artery interpretation
2	Severe – Single slab misregistration resulting in missing coronary artery segment (s)
1	Non-diagnostic – Multiple slab misregistrations resulting in multiple segments of missing coronary arteries

Motion (Blur) Artifact
5	None – No motion artifact
4	Mild – Minimal adverse effect on coronary artery assessment
3	Moderate – Moderate adverse effect on coronary artery assessment
2	Severe – Multiple segments uninterpretable, typically including at lease one proximal coronary artery
1	Non-diagnostic – Large segments of all three major coronary arteries uninterpretable

Overall Image Quality
5	Near perfect
4	Excellent
3	Good
2	Fair
1	Poor

Table 2

Comparison between groups of patient characteristics. Entries represent number (percentage) for categorical variables and mean for continuous variables.

Category	% with data available	Helical-only Strategy (n=138)	Sequential-if-appropriate Strategy (n=261)	P Value	Helical Protocol (n=174)	Sequential Protocol (n=225)	P Value
Age	100	57.2	57.7		60.0	57.1	
Male gender	100	98 (71.0%)	179 (68.6%)	0.62	121 (69.5%)	156 (69.3%)	0.97
Diabetes	98.5	7 (5.1%)	21 (8.2%)	0.25	12 (6.9%)	16 (7.3%)	0.88
Smoking	77.7	50 (42.4%)	97 (50.5%)	0.16	66 (46.2%)	81 (48.5%)	0.68
Dyspnea	97.7	26 (19.1%)	64 (25.2%)	0.17	41 (23.8%)	49 (22.5%)	0.75
Abnormal ECG	94.0	26 (19.7%)	45 (18.5%)	0.78	36 (21.7%)	35 (16.8%)	0.23
Abnormal stress test	92.5	23 (18.0%)	44 (18.3%)	0.95	31 (19.1%)	36 (17.4%)	0.67
Angioplasty	95.2	10 (7.6%)	24 (9.7%)	0.49	12 (7.2%)	22 (10.3%)	0.29
Coronary stent	96.7	11 (8.2%)	16 (6.4%)	0.52	14 (8.2%)	13 (6.1%)	0.41
Prior cardiac surgery	97.5	0 (0%)	5 (2%)	0.10	1 (0.6%)	4 (1.8%)	0.28
Indication for CCTA	100			0.058			0.19
screening		42 (30.4%)	69 (26.1%)		47 (27.0%)	63 (28.0%)	
chest pain		28 (20.3%)	61 (23.4%)		37 (21.3%)	52 (23.1%)	
dyspnea		6 (4.4%)	23 (8.8%)		14 (8.1%)	15 (6.7%)	
abnormal ECG		7 (5.1%)	10 (3.8%)		10 (5.8%)	7 (3.1%)	
abnormal stress test		18 (13.0%)	15 (5.8%)		20 (11.5%)	13 (5.8%)	
aortic aneurysm		0 (0%)	1 (0.4%)		0 (0%)	1 (0.4%)	
blank		28 (20.3%)	73 (28.0%)		36 (20.7%)	65 (28.9%)	
others		19 (4.8%)	10 (3.8%)		10 (5.8%)	9 (4.0%)	
Coronary calcium score	98.2	148.4	190.4	0.51	153.8	192.7	0.39

Table 3

Heart rate (HR) and beta blocker use. Entries represent mean values, while values in parentheses represent range for continuous variables and percentages for counts.

	Helical-only Strategy (n=138)	Sequential-if-appropriate Strategy (n=261)	P Value	Helical Protocol (n=174)	Sequential Protocol (n=225)	P Value	Helical Protocol in Sequential-if-appropriate Strategy (n=36)	Sequential Protocol in Sequential-if-appropriate Strategy (n=225)	P Value
Initial HR (bpm)	68.0 (40–113)	66.7 (40–108)	0.34	70.9 (40–113)	64.5 (40–94)	<0.001	80.6 (58–108)	64.5 (40–95)	<0.001
HR after any metoprolol (bpm)	63.1 (40–113)	60.9 (40–102)	0.045	65.6 (40–113)	58.8 (40–79)	<0.001	74.4 (58–102)	58.8 (40–79)	<0.001
End HR $\geq$ 75	8 (6.5%)	18 (7.0%)	0.69	22 (13.8%)	4 (1.8%)	<0.001	14 (38.9%)	4 (1.8%)	<0.001
Change in HR in those given beta blockers (bpm)	11.2	9.2	0.037	11.1	8.8	0.026	10.9	8.8	0.34
Beta blocker use	70 (50.7%)	161 (61.7%)	0.035	93 (53.5%)	138 (61.3%)	0.11	23 (63.9%)	138 (61.3%)	0.77
Beta blocker dose (mg)	4.1	6.7	0.001	5.3	6.2	0.070	9.6	6.2	0.048

Table 4

Radiation doses by group: Dose-Length Product (mGy·cm) and Effective Dose (mSv)

	DLP (Mean)	DLP (SD)	DLP (95% CI)	Estimated Effective Dose (mSv)	P Value
Sequential-if-appropriate Strategy vs.	305.2	301.2	268.5 – 341.9	5.2	<0.0001
Helical-only Strategy	875.1	278.5	828.3 – 922.0	14.9	
Sequential Protocol vs.	201.9	90.0	189.3 – 214.5	3.4	<0.0001
Helical Protocol	890.0	293.3	847.0 – 934.7	15.1	
Helical Protocol in Sequential-if-appropriate Strategy	951.1	342.3	835.3 – 1066.9	16.2	0.23
vs.					
Helical Protocol in Helical-only Strategy	875.1	278.5	828.3 – 922.0	14.9	

Table 5

Image Quality Scores (see Table 1 for descriptions of scores 1 through 5). SD denotes standard deviation. CI denotes confidence interval.

		Mean	SD	95% CI	P Value
Noise	Sequential-if-appropriate Strategy vs.	4.4	0.6	4.3 – 4.5	0.66
	Helical-only Strategy	4.4	0.6	4.4 – 4.5	
	Sequential Protocol vs.	4.5	0.5	4.4 – 4.5	0.036
	Helical Protocol	4.3	0.6	4.2 – 4.4	
	Helical Protocol in Sequential-if-appropriate Strategy vs.	4.0	0.7	3.8 – 4.3	0.0004
	Helical Protocol in Helical-only Strategy	4.4	0.6	4.4 – 4.5	
Step	Sequential-if-appropriate Strategy vs.	4.2	0.7	4.1 – 4.2	0.25
	Helical-only Strategy	4.1	0.7	4.0 – 4.2	
	Sequential Protocol vs.	4.3	0.6	4.2 – 4.3	<0.0001
	Helical Protocol	4.0	0.8	3.8 – 4.1	
	Helical Protocol in Sequential-if-appropriate Strategy vs.	3.5	1.0	3.1 – 3.8	0.0001
	Helical Protocol in Helical-only Strategy	4.1	0.7	4.0 – 4.2	
Blur	Sequential-if-appropriate Strategy vs.	4.2	0.9	4.1 – 4.3	0.23
	Helical-only Strategy	4.1	1.0	3.9 – 4.3	
	Sequential Protocol vs.	4.4	0.7	4.3 – 4.5	<0.0001
	Helical Protocol	3.9	1.1	3.7 – 4.1	
	Helical Protocol in Sequential-if-appropriate Strategy vs.	3.2	1.0	2.9 – 3.5	<0.0001
	Helical Protocol in Helical-only Strategy	4.1	1.0	3.9 – 4.3	
Overall	Sequential-if-appropriate Strategy vs.	4.0	0.9	3.9 – 4.1	0.15
	Helical-only Strategy	3.8	1.0	3.7 – 4.0	
	Sequential Protocol vs.	4.1	0.7	4.0 – 4.2	<0.0001
	Helical Protocol	3.7	1.1	3.5 – 3.9	
	Helical Protocol in Sequential-if-appropriate Strategy vs.	3.1	1.1	2.8 – 3.5	0.0003
	Helical Protocol in Helical-only Strategy	3.8	1.0	3.7 – 4.0	

Table 6

Overall quality assessment scores for observer 1 vs. observer 2 (1=poor, 2=fair, 3=good, 4=excellent, 5=near perfect)

		Observer 2					
		1	*2*	*3*	*4*	*5*	*Total*
Observer 1	*1*	**5**	4	7	1	0	*17*
	2	4	**10**	10	2	0	*26*
	3	0	8	**26**	18	0	*52*
	4	0	1	20	**113**	18	*152*
	5	0	0	7	72	**73**	*152*
	Total	*9*	*23*	*70*	*206*	*91*	***399***

Table 7

Anterior Air Noise, Descending Aorta Noise, and Tube Current. SD denotes standard deviation, CI denotes confidence interval, HU denotes Hounsfield units.

		Mean	SD	95% CI	P Value
Anterior Air Noise (HU)	Sequential-if-appropriate Strategy vs. Helical-only Strategy	16.8 / 15.5	3.7 / 4.5	16.3 – 17.3 / 14.7 – 16.2	0.0019
	Sequential Protocol vs. Helical Protocol	17.1 / 15.4	3.8 / 4.3	16.6 – 17.6 / 14.8 – 16.0	<0.0001
	Helical Protocol in Sequential-if-appropriate Strategy vs. Helical Protocol in Helical-only Strategy	15.1 / 15.5	3.2 / 4.5	14.0 – 16.2 / 14.7 – 16.2	0.62
Descending Aorta Noise (HU)	Sequential-if-appropriate Strategy vs. Helical-only Strategy	36.7 / 32.1	8.5 / 8.2	35.7 – 37.8 / 30.7 – 33.4	<0.0001
	Sequential Protocol vs. Helical-only Protocol	37.4 / 32.2	8.4 / 8.1	36.3 – 38.5 / 30.9 – 33.4	<0.0001
	Helical Protocol in Sequential-if-appropriate Strategy vs. Helical Protocol in Helical-only Strategy	32.5 / 32.1	7.9 / 8.2	29.8 – 35.1 / 30.7 – 33.4	0.79
Tube Current (mA)	Sequential-if-appropriate Strategy vs. Helical-only Strategy	445.3 / 477.4	122.3 / 67.7	430.4 – 460.2 / 466.0 – 488.8	0.0044
	Sequential Protocol vs. Helical Protocol	433.7 / 485.7	116.3 / 87.1	418.4 – 449.0 / 472.7 – 498.8	<0.0001
	Helical Protocol in Sequential-if-appropriate Strategy vs. Helical Protocol in Helical-only Strategy	517.8 / 477.4	135.2 / 67.7	472.0 – 563.5 / 466.0 – 488.8	0.013