Published in final edited form as:

Am J Cardiol. 2011 April 1; 107(7): 1093–1098. doi:10.1016/j.amjcard.2010.11.038.

Comparison of Radiation Dose and Image Quality of Triple-Rule-Out Computed Tomography Angiography Between Conventional Helical Scanning and a Strategy Incorporating Sequential Scanning

Eric D. Manheimer, MD^a, M. Robert Peters, MD^{b,c}, Steven D. Wolff, MD, PhD^{a,b,c}, Mehreen A. Qureshi, MD^d, Prashanth Atluri, MD^e, Gregory D.N. Pearson, MD, PhD^b, and Andrew J. Einstein, MD, PhD^{a,b}

^a Department of Medicine, Cardiology Division, Columbia University Medical Center, New York, NY

^b Department of Radiology, Columbia University Medical Center, New York, NY

^c Advanced Cardiovascular Imaging, New York, NY

^d Mid-Hudson Medical Group, Fishkill, NY

^e Department of Medicine, St. Luke's-Roosevelt Hospital, New York, NY

Abstract

Triple-rule-out computed tomography angiography (TRO CTA), performed to evaluate the coronary arteries, pulmonary arteries, and thoracic aorta, has been associated with high radiation exposure. Utilization of sequential scanning for coronary computed tomography angiography (CCTA) reduces radiation dose. The application of sequential scanning to TRO CTA is much less well defined. We analyzed radiation dose and image quality from TRO CTA performed in a single outpatient center, comparing scans from a period during which helical scanning with electrocardiographically controlled tube current modulation was used for all patients (n=35) and after adoption of a strategy incorporating sequential scanning whenever appropriate (n=35). Sequential scanning was able to be employed in 86% of cases. The sequential-if-appropriate strategy, compared to the helical-only strategy, was associated with a 61.6% dose decrease (mean dose-length product [DLP] of 439 mGy×cm vs 1144 mGy×cm and mean effective dose of 7.5 mSv vs 19.4 mSv, respectively, p<0.0001). Similarly, there was a 71.5% dose reduction among 30 patients scanned with the sequential protocol compared to 40 patients scanned with the helical protocol under either strategy (326 mGy×cm vs 1141 mGy×cm and 5.5 mSv vs 19.4 mSv, respectively, p<0.0001). Although image quality did not differ between strategies, there was a non-statistically significant trend towards better quality in the sequential protocol compared to the helical protocol. In conclusion, approaching TRO CTA with a diagnostic strategy of sequential

© 2010 Excerpta Medica, Inc. All rights reserved.

Corresponding Author: Andrew J. Einstein MD, PhD Telephone: 212-305-4275 Fax: 212-305-4648 andrew.einstein@columbia.edu
Mailing Address: Cardiology Division, Columbia University Medical Center, 622 West 168th Street PH 10-203A, New York, NY 10032.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Disclosures: Dr. Wolff serves as a paid consultant for GE Healthcare and is an owner of NeoSoft, LLC and NeoCoil, LLC.

scanning as appropriate offers a marked reduction in radiation dose while maintaining image quality.

Keywords

Triple-rule-out CT angiography; sequential scanning; diagnostic strategies; radiation dose

INTRODUCTION

Advancements in CT technology have made possible the imaging of not only the coronary arteries but also the entire thorax in a single breath-hold.¹⁻³ “Triple-rule-out” computed tomographic angiography (TRO CTA) is able to simultaneously evaluate for multiple potentially life-threatening conditions: acute coronary syndrome, aortic dissection, and pulmonary thromboembolism.¹⁻⁶ A survey of emergency departments found that only 18% are using TRO CTA in the evaluation of chest pain.⁷ A significant barrier to the more routine use of TRO CTA is the associated radiation dose, which is as much as 50% to 100% greater than in dedicated coronary computed tomographic angiography (CCTA) studies on account of the longer scanning length.¹⁻³ With increasing concern regarding radiation associated with medical imaging,⁸ scanning protocols have been developed to minimize radiation doses. Although numerous dose saving techniques have been described for dedicated CCTA⁹⁻¹⁵, the applicability of these techniques to TRO CTA is infrequently described in the literature. Dose lowering of TRO CTA has been demonstrated with electrocardiographically-synchronized tube current modulation (ESTCM)¹⁶ and 1 study found a 71% dose reduction using a sequential protocol compared to a helical protocol.¹⁷ Our study compared 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 ESTCM.

METHODS

We studied consecutive patients referred to a single outpatient laboratory for TRO CTA. Prior to July, 2007 all patients were imaged using a helical protocol. After this date, a scanner upgrade enabled sequential scanning to be performed. Patients were scanned sequentially, unless they had an irregular rhythm or HR>65 beats per minute (bpm), in which case a conventional retrospectively gated helical mode was employed. If appropriate, an intravenous beta blocker was given to achieve a goal HR<65 bpm.

A single Lightspeed VCT/VCT XT scanner (GE Healthcare, Milwaukee, WI) was used for all examinations. All patients received a 2 plane scout, calcium scoring scan, timing bolus and either helical scanning with ESTCM (SnapShot Segment or SnapShot Burst, GE Healthcare) or sequential scanning (SnapShot Pulse, GE Healthcare). Image acquisition was performed craniocaudally from above the aortic arch to the diaphragm. Scanning parameters included 64×0.625 mm detector configuration and a gantry rotation time of 350 ms. Almost all studies were performed with a voltage of 120 kVp. Voltages of 100 kVp and 140 kVp were used in 1 and 2 cases, respectively, as influenced by body habitus. 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 lbs) with variation within a weight category as 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 almost all 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

determined by the technologist at the time of scanning and set between 0 and 200 ms, depending on heart rate variability. The contrast bolus protocol consisted a 24 second infusion at a weight-based rate and was identical for helical and sequential scans. Patients < 170 lbs received 72 cc (3 cc/s), patients 171-250 lbs received 96 cc (4 cc/s), and patients > 251 lbs received 120 cc (5 cc/s). A wide reconstruction field of view was used to enable visualization of all structures on the same images.

CCTA images were reconstructed with slice thickness of 0.6 mm using a standard reconstruction algorithm. Images were transferred to a 3D workstation (Advantage Workstation, GE Healthcare) for evaluation, and reviewed in all 3 planes and multiple phases as available, utilizing double oblique views. Optimal maximum intensity projection, multiplanar reformat, 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 dose-length product (DLP) of the CCTA sequence by the European Guidelines on Quality Criteria conversion factor of 0.017 mSv/(mGy×cm).¹⁸

Image quality was assessed by focusing on the coronary arteries. The pulmonary arteries and aorta are large vessels that are relatively immobile and with little to no calcium. Because patient movement or poor contrast timing would have a more significant effect on the quality of the smaller, more mobile coronary arteries than the larger vessels, the quality of the former was used as an indicator of overall quality. Two readers (M.R.P. and A.J.E.), experienced in reading CT angiograms, graded 4 criteria of quality – noise artifact, stair-step artifact, blur or motion artifact, and overall image quality – each assessed using a 5 point scale, as previously described.¹² Each reader received the 75% phase reconstruction and images available as constructed above in the optimal phase(s) for interpretation. In this way each reader was blinded to the scan protocol; had every phase of reconstruction been provided, it would have been obvious which patients had undergone sequential scanning due to the limited number of phases. Readers were also blinded to scan and reconstruction information such as phase and tube voltage and current. Image manipulation was possible utilizing the 3D workstation. A third reviewer (E.D.M.) measured the noise level, reported as the standard deviation of the CT number in Hounsfield units (HU), measured in air anterior to the patient and in the descending aorta at the largest chest diameter.

Coronary artery image quality of the TRO CTA studies were compared to those of 399 dedicated coronary artery studies reported previously.¹² These CCTAs were performed in the same laboratory, during the same time period, using the same CT scanner, interpreted by the same readers, and evaluated using the same criteria.

Statistical analysis was performed using Stata 8.2 (Stata Corp., College Station, TX). Comparisons of radiation dose, quality, and noise were performed using 2-sample t-tests. Results are reported as mean±standard deviation along with 95% confidence interval. Comparisons of baseline characteristics, indication, tube current, voltage, beta blocker use, and heart rate were performed using chi-squared tests, t-tests, or Mann-Whitney two-sample rank-sum tests as appropriate. A 2-tailed p value <0.05 was deemed significant. Inter-rater agreement of image quality was quantified with bias corrected, quadratic weighted kappa statistics, with confidence intervals estimated using 1,000 bootstrap iterations, and classified according to Landis and Koch.¹⁹

RESULTS

Seventy patients were identified as having TRO CTA scans. Thirty-five patients, prior to the scanner upgrade, were imaged using the helical-only strategy. Thirty-five patients were

imaged using the sequential-if-appropriate strategy, 30 of whom underwent sequential scanning (Figure 1). There were no significant between-group differences in patient characteristics and indication, as elicited in self-reported questionnaires, or in coronary calcium scores (Table 1). A small number of items in the questionnaires were not answered and the number of responders is indicated in Table 1. There was a non-significant trend towards lower HR among patients undergoing sequential scanning. Table 2 contains details on β -blocker administration and its impact on patients' HRs. Mean noise levels of the descending aorta were greater for the sequential-if-appropriate strategy compared to the helical-only strategy and for the sequential protocol compared to the helical protocol. There were no significant differences among the groups for anterior air noise, tube current, voltage, or scan length (Table 3).

DLP was decreased by 61.6% using sequential-if-appropriate strategy compared to the helical-only strategy (439 ± 358 mGy $\times$ cm and 1144 ± 321 mGy $\times$ cm, respectively, $p < 0.0001$). Effective doses for these two strategies were 7.5 mSv and 19.4 mSv, respectively. There was a 71.5% dose decrease when using the sequential protocol compared to the helical protocol (326 ± 169 mGy $\times$ cm and 1141 ± 333 mGy $\times$ cm or 5.5 mSv and 19.4 mSv, respectively, $p < 0.0001$). Radiation dosimetry details are contained in Table 4.

Image quality scores, across all 4 dimensions examined, were comparable both between the sequential-if-appropriate and helical-only strategies and between the sequential and helical protocols (Table 5). There were no differences in scores, among any of the 4 categories of quality, when comparing the TRO CTAs to CCTAs.¹² There was fair agreement between readers for noise (quadratic weighted kappa (κ)=0.40, 95% CI 0.27 to 0.56), substantial agreement for step (κ =0.67, 95% CI 0.35 to 0.81), substantial agreement for blur (κ =0.75, 95% CI 0.70 to 0.81), and substantial agreement overall (κ =0.78, 95% CI 0.76 to 0.80). The lower weighted kappa for noise was attributable to 1 reader most commonly characterizing noise as "none", and the other reader most commonly characterizing it as "mild." Disagreement of ≥ 2 points was seen in 2.9% of patients for noise, 4.3% for step, 5.7% for blur, and 2.9% for overall quality.

DISCUSSION

Dedicated CCTA has been proven to be an accurate diagnostic modality in evaluating coronary artery disease in low-to-intermediate risk patients.^{20,21} The coronary arteries can be similarly evaluated using a TRO protocol, but with the added advantage of evaluating for other potentially life-threatening conditions by assessing the thoracic aorta for dissection and pulmonary arteries for pulmonary thromboembolism. Moreover, the wider reconstruction field of view typically used in TRO CTA may enable identification of additional non-cardiovascular findings.²² Nonetheless, TRO CTA is not a common diagnostic tool, largely due to hesitations regarding radiation dose, image quality, technically challenging protocols, and contrast load.^{1,5,7} The technical challenge largely lies in achieving optimal and consistent contrast intensity in both the right and left sided circulations.^{1,5} However, at least 2 studies have demonstrated opacification to be of diagnostic quality.^{23,24} Reimbursement concerns are additionally cited by practitioners as a barrier to its use. Not surprisingly, the literature on TRO CTAs is therefore sparse compared to that on CCTAs.

Radiation dose in TRO CTAs is substantial and is greater than in standard coronary CTAs on account of the greater scan length.1 TRO CTA with ESTCM was associated with a dose range of 14.7 mSv to 21.9 mSv in a phantom model.²⁵ Shuman et al examined radiation dose and image quality of TRO CTAs performed to evaluate nonspecific chest pain in emergency department patients. 42 patients scanned with a helical protocol were compared to 32 patients scanned with a sequential protocol after a scanner upgrade that permitted

prospective ECG triggering. There was a 71% dose reduction (31.8 mSv vs 9.2 mSv, respectively) and the latter group was more likely to have a higher quality score.¹⁷ However, readers were not completely blinded to the protocol type and aspects of the exclusion criteria bias the results towards lower radiation dose and better quality, as well as limit the applicability of the findings to a generalized population. The study excluded patients who were markedly obese (BMI >40) or who had heart rates ≥ 75 bpm, both of which have been shown to be predictors of poor image quality.²⁶

Several approaches may decrease radiation dose of TRO CTA. The use of ESTCM reduced radiation doses by more than 50% (18.0 mSv vs 8.75 mSv) without a loss in image quality among a cohort of 267 patients.¹⁶ Uehara et al concluded that a limited range scan from the top of the aortic arch to the undersurface of the heart would decrease doses approximately 22% compared to a scan of the entire chest without missing the diagnosis of an acute pulmonary thromboembolus.²⁷ Excluding the lung apices may reduce the scan length by up to 5 cm with an estimated dose reduction of 15% to 20%.⁵ The use of lower voltage CCTAs in normal weight patients was shown to decrease dose.¹¹ The possibility of further dose reduction by scanning the coronary arteries with the thinnest possible collimator and the remainder of the chest with a wider collimator has been proposed.¹

More recent technological advances are likely to further decrease radiation exposures due to the ability to scan the whole chest extremely rapidly, in some cases under 1 second. A recent study by Sommer et al examined a high-pitch dual source TRO protocol in a series of 31 patients and reported a dose similar to that of a standard non-gated chest scan (4.1 mSv vs 4.4 mSv, respectively) and 80% less than the traditional helical protocol (20.4 mSv).²⁸

We found an average effective dose of 7.5 mSv for all patients scanned using the sequential-if-appropriate strategy. There was a 71.5% decrease in effective radiation dose using the sequential protocol (5.5 mSv) compared to the helical protocol using ESTCM (19.4 mSv). The dose for our sequential protocol is among the lowest found in the literature and approaches that observed using the high-pitch dual source scanner. The dose of the helical protocol with ESTCM is similar to that published in other studies. As anticipated, the dose was significantly greater than that for the CCTA scans. The dose in our TRO CTA protocol could be reduced further by using a limited range scan,^{1,27} an approach which requires further investigation.

Image quality for the TRO CTA scans was not sacrificed by using the dose-reducing sequential protocol. Furthermore, coronary artery image quality of TRO CTA was similar to that previously reported for CCTA.¹² This may help to allay the concern that quality is sacrificed with a TRO protocol. Differences in HR are unlikely to be confounding the finding of comparable image quality between the strategies and protocols, overall, as the difference in HRs between these groups is negligible and not significant.

Image noise in the descending aorta was significantly greater with the sequential-if-appropriate strategy than with the helical-only strategy and in sequential protocol scans compared to helical protocol scans. There is not a clear explanation for this difference. Tube current and voltage were similar and thus unlikely to explain the noise findings. Unidentified differences in the reconstruction algorithm may be a contributing factor. Nonetheless, despite an increase in measured image noise with sequential scanning, blinded reads by experienced physicians did not reveal any differences in image quality, including artifacts from noise.

A limitation of this study is the small size of patients in the sequential-if-appropriate strategy scanned with the helical protocol (n=5). The comparison of protocols used within the sequential-if-appropriate strategy is limited on account of the less than ideal statistical

power. Another limitation is the lack of a “gold standard.” Since no patient was scanned with both protocols, we cannot compare sensitivity or specificity of the techniques for coronary artery disease, aortic dissection, or for pulmonary embolism. We thus cannot be sure that the readers’ subjective assessment of similar image quality led to equivalent performance overall.

Our study is unique in 3 main regards. Firstly, there has been only 1 study,¹⁷ to the best of our knowledge, which examines the application of sequential scanning to TRO CTAs. Our criteria for inclusion were relatively broad, increasing the applicability of our findings to general outpatient practices. Secondly, we employed a unique method to assess quality. Our grading scale focuses on individual common artifacts and their effects on interpretability. Two experienced readers, blinded to the protocol used, assessed each study and assigned a score to each category. The studies discussed above assessed quality based on vessel opacification in addition to either motion artifact or diagnostic quality^{23,24} or by diagnostic interpretability of the coronary artery segments as defined by the American Heart Association.¹⁷ Although initial studies have suggested that sequential scanning has comparable diagnostic performance to helical scanning,^{29,30} there is still some concern that it may be associated with slightly reduced accuracy,³⁰ and randomized multicenter trials are needed to further elucidate its utility. Thirdly, our study is unique in that we examine diagnostic strategies. From the perspective of a cardiovascular imaging laboratory, this may be more useful than simply comparing sequential to helical protocols as the former is not suitable for all patients. Modern scanners are capable of both methods of scanning and clinicians must use an algorithm to decide on one protocol. The sequential protocol was appropriate in 86% of 35 consecutive patients in the sequential-if-appropriate strategy, and demonstrated an effective radiation dose reduction of 61.6%.

Acknowledgments

Funding: Dr. Einstein was supported by an NIH K12 institutional career development award (KL2 RR024157) and by the Louis V. Gerstner, Jr. Scholars Program.

References

1. Gallagher MJ, Raff GL. Use of multislice CT for the evaluation of emergency room patients with chest pain: the so-called “triple rule-out”. *Catheter Cardio Interv.* 2008; 71:92–99.
2. Lee HY, Yoo SM, White CS. Coronary CT angiography in emergency department patients with acute chest pain: triple rule-out protocol versus dedicated coronary CT angiography. *Int J Cardiovasc Imaging.* 2009; 25:319–326. [PubMed: 18853277]
3. Schussler JM, Smith ER. Sixty-four-slice computed tomographic coronary angiography: will the “triple rule out” change chest pain evaluation in the ED? *Am J Emerg Med.* 2007; 25:367–375. [PubMed: 17349915]
4. van der Wall EE, Schuijf JD, Bax JJ. Triple rule-out CT coronary angiography: three of a kind? *Int J Cardiovasc Imaging.* 2009; 25:327–330. [PubMed: 19002601]
5. Halpern EJ. Triple-rule-out CT angiography for evaluation of acute chest pain and possible acute coronary syndrome. *Radiology.* 2009; 252(2):332–345. [PubMed: 19703877]
6. Frauenfelder T, Appenzeller P, Karlo C, Scheffel H, Desbiolles L, Stolzmann P, Marincek B, Alkadhi H, Schertler T. Triple rule-out CT in the emergency department: protocols and spectrum of imaging findings. *Eur Radiol.* 2009; 19:789–799. [PubMed: 19015860]
7. Thomas J, Rideau AM, Paulson EK, Bisset GS. Emergency department imaging: current practice. *J Am Coll Radiol.* 2008; 5(7):811–816e2. [PubMed: 18585658]
8. Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. *JAMA.* 2007; 298:317–323. [PubMed: 17635892]

9. Jakobs TF, Becker CR, Ohnesorge B, Flohr T, Suess C, Schoepf UJ, Reiser MF. Multislice helical CT of the heart with retrospective ECG gating: reduction of radiation exposure by ECG-controlled tube current modulation. *Eur Radiol.* 2002; 12:1081–1086. [PubMed: 11976849]
10. Abada HT, Larchez C, Daoud B, Sigal-Cinqualbre A, Paul JF. MDCT of the coronary arteries: feasibility of low-dose CT with ECG-pulsed tube current modulation to reduce radiation dose. *Am J Roentgenol.* 2006; 186:S387–S390. [PubMed: 16714613]
11. Leschka S, Stolzmann P, Schmid FT, Scheffel H, Stinn B, Marincek B, Alkadhi H, Wildermuth S. Low kilovoltage cardiac dual-source CT: attenuation, noise, and radiation dose. *Eur Radiol.* 2008; 18:1809–1817. [PubMed: 18392829]
12. Einstein AJ, Wolff SD, Manheimer ED, Thompson J, Terry S, Uretsky S, Pilip A, Peters MR. Comparison of image quality and radiation dose of coronary computed tomographic angiography between conventional helical scanning and a strategy incorporating sequential scanning. *Am J Cardiol.* 2009; 104:1343–1350. [PubMed: 19892048]
13. Bischoff B, Hein F, Meyer T, Krebs M, Hadamitzky M, Martinoff S, Schömig A, Hausleiter J. Comparison of sequential and helical scanning for radiation dose and image quality: results of the prospective multicenter study on radiation dose estimates of cardiac CT angiography (PROTECTION) I study. *Am J Roentgenol.* 2010; 194:1495–1499. [PubMed: 20489088]
14. Earls JP, Berman EL, Urban BA, Curry CA, Lane JL, Jennings RS, McCulloch CC, Hsieh J, Londt JH. Prospectively gated transverse coronary CT angiography versus retrospectively gated helical technique: improved image quality and reduced radiation dose. *Radiology.* 2008; 246(3):742–753. [PubMed: 18195386]
15. Earls JP, Schrack EC. Prospectively gated low-dose CCTA: 24 months experience in more than 2,000 clinical cases. *Int J Cardiovasc Imaging.* 2009; 25:177–187.
16. Takakuwa KM, Halpern EJ, Gingold EL, Levin DC, Shofer FS. Radiation dose in a “triple rule-out” coronary CT angiography protocol of emergency department patients using 64-MDCT: the impact of ECG-based tube current modulation on age, sex, and body mass index. *Am J Roentgenol.* 2009; 192:866–872. [PubMed: 19304688]
17. Shuman WP, Branch KR, May JM, Mitsumori LM, Strote JN, Warren BH, Dubinsky TJ, Lockhart DW, Caldwell JH. Whole-chest 64-MDCT of emergency department patients with nonspecific chest pain: radiation dose and coronary artery image quality with prospective ECG triggering versus retrospective ECG gating. *Am J Roentgenol.* 2009; 192:1662–1667. [PubMed: 19457832]
18. European guidelines on quality criteria for computed tomography. [Accessed October 1, 2009]. Available at: <http://www.drs.dk/guidelines/ct/quality/index.htm>
19. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977; 33(1):159–174. [PubMed: 843571]
20. Meijboom WB, Meijjs MFL, Schuijf JD, Cramer MJ, Mollet NR, van Mieghem CAG, Nieman K, van Werkhoven JM, Pundziute G, Weustink AN, de Vos AM, Pugliese F, Rensing B, Jukema JW, Bax JJ, Prokop M, Doevendans PA, Hunink MGM, Krestin GP, de Feyter PJ. Diagnostic accuracy of 64-slice computed tomography coronary angiography. *J Am Coll Cardiol.* 2008; 52:2135–2144. [PubMed: 19095130]
21. Budoff MJ, Dowe D, Jollis JG, Gitter M, Sutherland J, Halamert E, Scherer M, Bellinger R, Martin A, Benton R, Delago A, Min JK. Diagnostic performance of 64-multidetector row coronary computed tomographic angiography for evaluation of coronary artery stenosis in individuals without known coronary artery disease. *J Am Coll Cardiol.* 2008; 52:1724–1732. [PubMed: 19007693]
22. Takakuwa KM, Halpern EJ. Evaluation of a “triple rule-out” coronary CT angiography protocol: use of 64-section CT in low-to-moderate risk emergency department patients suspected of having acute coronary syndrome. *Radiology.* 2008; 248:438–446. [PubMed: 18641247]
23. Rahmani N, Jeudy J, White CS. Triple rule-out and dedicated coronary artery CTA: comparison of coronary artery image quality. *Acad Radiol.* 2009; 16:604–609. [PubMed: 19282205]
24. Halpern EJ, Levin DC, Zhang S, Takakuwa KM. Comparison of image quality and arterial enhancement with a dedicated coronary CTA protocol versus a triple rule-out coronary CTA protocol. *Acad Radiol.* 2009; 16:1039–1048. [PubMed: 19523852]

25. Ketelsen D, Luetkhoff MH, Thomas C, Werner M, Buchgeister M, Tsiflikas I, Reimann A, Burgstahler C, Kopp AF, Claussen CD, Heuschmid M. Estimation of the radiation exposure of a chest pain protocol with ECG-gating in dual-source computed tomography. *Eur Radiol.* 2009; 19:37–41. [PubMed: 18648818]
26. Gutstein A, Wolak A, Lee C, Dey D, Ohba M, Suzuki Y, Cheng V, Gransar H, Suzuki S, Friedman J, Thomson LE, Hayes S, Pimentel R, Paz W, Slomka P, Berman DS. Predicting success of prospective and retrospective gating with dual-source coronary computed tomography angiography: development of selection criteria and initial experience. *J Cardiovasc Comput Tomogr.* 2008; 2:81–90. [PubMed: 19083926]
27. Uehara M, Tanabe N, Funabashi N, Takaoka H, Ikari J, Toyama S, Shimizu H, Hoshino S, Sugiura T, Saito M, Kawata N, Matsuura Y, Kuriyama T, Tatsumi K, Komuro I. Detailed distribution of acute pulmonary thromboemboli: direct evidence for reduction of acquisition length and radiation dose for triple rule-out CT angiography. *Int J Cardiol.* 2009 doi:10.1016/j.ijcard.2009.08.040.
28. Sommer WH, Schenzle JC, Becker CR, Nikolaou K, Graser A, Michalski G, Neumaier K, Reiser MF, Johnson TR. Saving dose in triple-rule-out computed tomography examination using a high-pitch dual spiral technique. *Invest Radiol.* 2010; 45(2):64–71. [PubMed: 20027121]
29. Herzog BA, Husmann L, Burkhard N, Gaemperli O, Valenta I, Tatsugami F, Wyss CA, Landmesser U, Kaufmann PA. Accuracy of low-dose computed tomography coronary angiography using prospective electrocardiogram-triggering: first clinical experience. *Eur Heart J.* 2008; 29:3037–3042. [PubMed: 18996954]
30. Pontone G, Andreini D, Bartorelli AL, Cortinovis S, Mushtaq S, Bertella E, Annoni A, Formenti A, Nobili E, Trabattoni D, Montorsi P, Ballerini G, Agostoni P, Pepi M. Diagnostic accuracy of coronary computed tomography angiography: a comparison between prospective and retrospective electrocardiogram triggering. *J Am Coll Cardiol.* 2009; 54:346–355. [PubMed: 19608033]

Figure 1.
Comparisons between patient groups (pairs of black boxes at the same horizontal level) evaluated in the study.

Table 1
Comparisons of patient characteristics between scan strategies and between scan protocols.

Category	Number of Patients with Available Data	Helical-Only Strategy (n=35)	Sequential-if-Appropriate Strategy (n=35)	p Value	Helical Protocol (n=40)	Sequential Protocol (n=30)	p Value
Age (years)	70	52.7	54.4	0.58	54.0	53.0	0.75
Male gender	70	24 (69%)	26 (74%)	0.60	27 (68%)	23 (77%)	0.40
Diabetes mellitus	70	2 (5.7%)	2 (5.7%)	1.00	3 (7.5%)	1 (3.3%)	0.46
Smoker	60	11 (38%)	14 (45%)	0.57	12 (35%)	13 (50%)	0.25
Dyspnea	70	11 (31%)	13 (37%)	0.62	12 (30%)	12 (40%)	0.38
Abnormal ECG	67	5 (15%)	6 (18%)	0.70	6 (16%)	5 (17%)	0.96
Abnormal stress test	69	1 (2.9%)	3 (8.8%)	0.29	2 (5.1%)	2 (6.7%)	0.79
Coronary angioplasty	69	2 (5.7%)	2 (5.9%)	0.98	2 (5.1%)	2 (6.7%)	0.79
Coronary stent	69	3 (8.6%)	2 (5.9%)	0.67	3 (7.7%)	2 (6.7%)	0.87
Prior cardiac surgery	68	0 (0%)	2 (5.9%)	0.15	1 (2.6%)	1 (3.3%)	0.87
Indication for CCTA	70						
screening		6 (17%)	4 (11%)		6 (15%)	4 (13%)	
chest pain		13 (37%)	11 (31%)		15 (38%)	9 (30%)	
dyspnea		6 (17%)	7 (20%)		6 (15%)	7 (23%)	
abnormal ECG		0	0	0.59	0 (0%)	0 (0%)	0.62
abnormal stress test		0	0		0 (0%)	0 (0%)	
aortic aneurysm		0	0		0 (0%)	0 (0%)	
blank		5 (14%)	10 (29%)		7 (18%)	8 (27%)	
others		5 (14%)	3 (8.6%)		6 (15%)	2 (6.7%)	
Coronary calcium score	66	118.9	98.8	0.63	111.6	105.5	0.87

Entries represent number (percentage) for categorical variables and mean for continuous variables.

Table 2

Heart rate (HR) and beta blocker use: comparisons between scan strategies and between scan protocols.

Category	Helical-Only Strategy (n=35)	Sequential-if-Appropriate Strategy (n=35)	p Value	Helical Protocol (n=40)	Sequential Protocol (n=30)	p Value
Minimum HR (beats/min)	55.2	55.3	0.97	56.4	53.7	0.18
Maximum HR (beats/min)	65.7	62.6	0.50	67.2	60.2	0.097
β -blocker use	19 (54%)	23 (66%)	0.33	22 (55%)	20 (67%)	0.32
β -blocker dose (mg)	4.2	7.2	0.087	5.0	6.6	0.26

Table 3

Scan parameters and image noise: comparisons between scan strategies and between scan protocols.

		Mean $\pm$ SD	95% CI	p Value
Anterior Air Noise (HU)	Sequential-if-appropriate Strategy vs	17.8 $\pm$ 3.4	16.7 - 19.0	0.19
	Helical-only Strategy	16.7 $\pm$ 3.7	15.5 - 18.0	
	Sequential Protocol vs	18.1 $\pm$ 3.6	16.8 - 19.5	0.090
	Helical Protocol	16.7 $\pm$ 3.5	15.5 - 17.8	
Descending Aorta Noise (HU)	Sequential-if-appropriate Strategy vs	44.4 $\pm$ 11.8	40.4 - 48.5	0.0011
	Helical-only Strategy	36.6 $\pm$ 6.0	34.6 - 38.7	
	Sequential Protocol vs	45.3 $\pm$ 12.4	40.7 - 50.0	0.0015
	Helical-only Protocol	36.9 $\pm$ 5.9	35.1 - 38.8	
Tube Current (mA)	Sequential-if-appropriate Strategy vs	460.5 $\pm$ 123.2	418.2 - 502.9	0.84
	Helical-only Strategy	455.4 $\pm$ 91.3	424.0 - 486.7	
	Sequential Protocol vs	455.8 $\pm$ 116.1	412.5 - 499.2	0.89
	Helical Protocol	459.6 $\pm$ 16.2	426.8 - 492.3	
Voltage (kV)	Sequential-if-appropriate Strategy vs	119.4 $\pm$ 3.4	118.3 - 120.6	0.085
	Helical-only Strategy	121.1 $\pm$ 4.7	119.5 - 122.8	
	Sequential Protocol vs	119.3 $\pm$ 3.7	118.0 - 120.7	0.098
	Helical Protocol	121.0 $\pm$ 4.4	119.6 - 122.4	
Scan Length (mm)	Sequential-if-appropriate Strategy vs	187.6 $\pm$ 26.4	178.5 - 196.7	0.52
	Helical-only Strategy	182.7 $\pm$ 36.1	170.3 - 195.1	
	Sequential Protocol vs	188.2 $\pm$ 28.2	177.7 - 198.8	0.48
	Helical Protocol	182.8 $\pm$ 39.9	172.0 - 193.7	

Table 4

Differences in radiation dose: dose-length product and effective dose. Comparisons between scan strategies and between scan protocols.

	DLP (mGy×cm)		Estimated Effective Dose (mSv)	p Value
	Mean ± SD	95% CI		
Sequential-if-appropriate Strategy vs	439.1 ± 357.7	316.3 - 562.0	7.5	< 0.0001
Helical-only Strategy	1143.5 ± 320.6	1033.4 - 1253.6	19.4	
Sequential Protocol vs	325.6 ± 168.7	262.6 - 388.6	5.5	< 0.0001
Helical Protocol	1140.6 ± 332.7	1034.2 - 1247.0	19.4	

Table 5Quality assessment scores¹²: comparisons between scan strategies and between scan protocols.

		Mean $\pm$ SD	95% CI	p Value
Noise	Sequential-if-appropriate Strategy vs	4.5 $\pm$ 0.6	4.3 - 4.7	0.92
	Helical-only Strategy	4.4 $\pm$ 0.6	4.2 - 4.6	
	Sequential Protocol vs	4.5 $\pm$ 0.5	4.3 - 4.7	0.53
	Helical Protocol	4.4 $\pm$ 0.6	4.2 - 4.6	
Step	Sequential-if-appropriate Strategy vs	4.0 $\pm$ 0.8	3.8 - 4.3	0.84
	Helical-only Strategy	4.1 $\pm$ 1.0	3.7 - 4.4	
	Sequential Protocol vs	4.2 $\pm$ 0.5	4.1 - 4.4	0.11
	Helical Protocol	3.9 $\pm$ 1.1	3.5 - 4.2	
Blur	Sequential-if-appropriate Strategy vs	3.9 $\pm$ 1.0	3.6 - 4.3	1.0
	Helical-only Strategy	3.9 $\pm$ 1.1	3.6 - 4.3	
	Sequential Protocol vs	4.1 $\pm$ 0.8	3.8 - 4.4	0.18
	Helical Protocol	3.8 $\pm$ 1.1	3.4 - 4.2	
Overall	Sequential-if-appropriate Strategy vs	3.8 $\pm$ 1.0	3.5 - 4.1	0.91
	Helical-only Strategy	3.8 $\pm$ 1.1	3.4 - 4.2	
	Sequential Protocol vs	4.0 $\pm$ 0.8	3.7 - 4.3	0.11
	Helical Protocol	3.6 $\pm$ 1.2	3.2 - 4.0	