Conventional and Partially ECG-Gated Triple Rule-Out Computed Tomography Angiography with Extension to Abdominal Aorta: Comparative Radiation Dose and Imaging Quality

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Abstract

Background: Triple rule-out (TRO) computed tomography angiography (CTA) is an ECG-gated protocol that enables the simultaneous evaluation of the coronary arteries, thoracic aorta, and pulmonary arteries in a single scan. It is especially useful for patients in the emergency department with low to moderate risk of acute coronary syndrome, particularly when aortic dissection and pulmonary embolism are also considered in the differential diagnosis.

Objective: This study aimed to compare two TRO protocols, fully electrocardiogram (ECG)-gated (protocol A) and partially ECG-gated (protocol B), both including coverage of the abdominal aorta, in terms of radiation dose and image quality. Such a comparison of protocols can be useful when iterative reconstruction algorithms are not available and a manual transition between partially ECG-synchronized protocols is required.

Methods: Radiation dose was evaluated using dose-length product (DLP), effective dose (ED), and virtual dose. Attenuation values were measured in the coronary and pulmonary arteries, as well as in the descending and abdominal aorta. Image quality and vessel conspicuity were assessed using a 5-point Likert scale.

Results: A total of 56 patients were included. Protocol B demonstrated significantly lower radiation exposure compared to protocol A across all metrics: median DLP (1.1 mSv [interquartile range: 0.9 to 1.1] versus 2.2 mSv [interquartile range: 1.6 to 2.8]), ED (17.0 mSv [interquartile range: 14.3 to 18.1] versus 32.6 mSv [interquartile range: 24.4 to 42.7]), and virtual dose (16.2 [interquartile range: 9.3 to 20.4] versus 34.7 [interquartile range: 19.9 to 43.5]); all differences were statistically significant ($p < 0.001$). There were no significant differences in attenuation measurements or qualitative image assessment between the two protocols.

Conclusion: Partially ECG-gated TRO CTA provides comparable image quality to the fully ECG-gated technique while significantly reducing radiation exposure, becoming a more radiation dose-efficient alternative when iterative reconstruction algorithms are not available and manual transition is necessary.

Keywords: Electrocardiography; Drug Tapering; Radiation Dose-Response Relationship.

Introduction

Chest pain is one of the most frequent reasons for emergency rooms visits worldwide. Its differential diagnosis is broad, encompassing both cardiac causes (particularly coronary artery disease) and non-cardiac conditions such as aortic dissection and pulmonary embolism. Cardiovascular disorders may be present in up to 20% of patients,[1] with acute coronary syndrome as the most feared condition. A prompt and accurate diagnosis is critical to reducing morbidity and mortality in patients presenting with chest pain. However, distinguishing those who require urgent hospitalization from those with benign conditions who can be safely discharged remains a common challenge in clinical practice.

In this context, computed tomography angiography (CTA) can expedite the evaluation of patients with chest pain by effectively ruling out acute coronary syndrome, offering a high negative predictive value.[2,3] Advances in CT technology and contrast injection protocols have further enabled the implementation of triple rule-out (TRO) CTA.[4] TRO CTA is an electrocardiogram (ECG)-gated protocol that enables the simultaneous evaluation of the coronary arteries, thoracic aorta, and pulmonary arteries in a single scan. It is currently regarded as a cost-effective diagnostic tool for patients in the emergency department with low to moderate risk of acute coronary syndrome,[2] particularly when aortic dissection and pulmonary embolism are also considered in the differential diagnosis.[5,6] However, before

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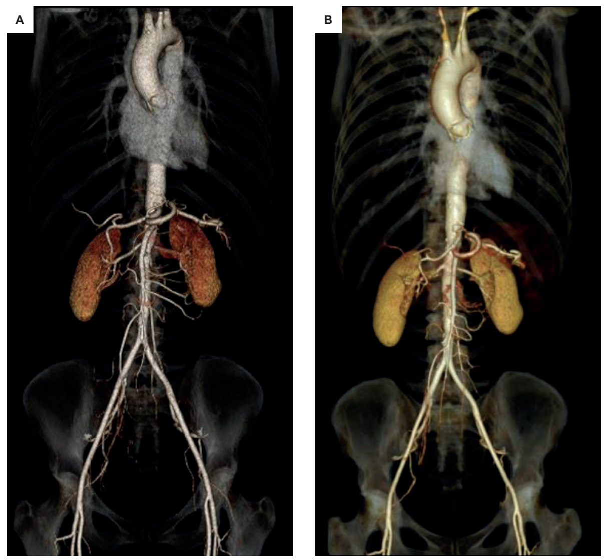
Central Illustration: Conventional and Partially ECG-Gated Triple Rule-Out Computed Tomography Angiography with Extension to Abdominal Aorta: Comparative Radiation Dose and Imaging Quality



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Three-dimensional volume-rendering CTA reconstructions of the same patient showing no significant difference in the overall image quality between fully (A) and partially (B) ECG-gated TRO scans.

implementing TRO CTA, it is essential to consider radiation exposure and technical scanning parameters, as these factors can present challenges depending on the operational capabilities of the available CT system.

Various CT systems can be used to perform the TRO CTA protocol, including 64-slice and 128-slice multidetector scanners, as well as dual-source systems. These typically employ retrospective ECG-gating to enhance coronary arteries visualization. However, the use of expanded anatomic coverage and small pitch values is associated with a significant increase in mean radiation dose.[7,8] Additionally, contrast injection protocols and scan techniques for TRO CTA vary widely across institutions, often leading to inconsistent image quality.[9] Given these challenges, it is essential to maintain high image quality while minimizing radiation exposure.

In recent years, several strategies have been proposed to address this issue.[4,10-14] Ketelsen et al.,[15] for instance, demonstrated a significant reduction in radiation dose using prospective ECG-gated acquisition compared to the traditional retrospective approach. Other studies have explored dose reduction through technical optimizations, such as tube current modulation.[14] To date, existing studies on radiation dose reduction in TRO CTA have not included full coverage of the abdominal aorta, potentially limiting the evaluation of descending aortic dissections. In this context, the aim of our study was to compare radiation dose and diagnostic image quality between two TRO CTA protocols, one using full (protocol A) and the other partial (protocol B) ECG-gating, with both extending to the abdominal aorta.

Materials and methods

Study population

This prospective study was approved by the institutional review board, and informed consent was obtained from all participants. Consecutive patients presenting with chest pain between January and June 2018 and referred for TRO CTA with abdominal aorta extension were enrolled to undergo the partially ECG-gated protocol (protocol B). Inclusion criteria consisted of having previously undergone a fully ECG-gated protocol (protocol A) at our institution within the past 5 years. Patients with contraindications to contrast-enhanced CT, as defined by institutional guidelines, were excluded.

TRO computed tomography

All TRO CTA exams were performed on a single-source 128-slice scanner (SOMATOM Definition AS+, Siemens, Erlangen, Germany) equipped with SAFIRE (sinogram-affirmed iterative reconstruction) technology, using retrospective ECG-gating. Scans were acquired with patients in the supine position (feet first), arms raised, and during breath-hold (apnea) lasting 8 to 20 seconds, depending on body habitus.

Scan parameters included a detector collimation of 128 × 0.6 mm, slice thickness of 0.6 mm, and a gantry rotation time of 0.3 seconds. For both protocols, automatic exposure control systems (CAREDose 4D for tube current modulation and CAREkV for tube voltage optimization) were activated.

- Protocol A (fully ECG-gated): tube voltage of 120 kV and reference tube current (mAs reference) of 210 mAs.
- Protocol B (partially ECG-gated): two sequential acquisitions:
  - Thoracic aorta phase (ECG-gated): 120 kV, 160 mAs reference, with CAREDose 4D.
  - Abdominal aorta phase (non-ECG-gated): same voltage and mAs settings.
- Table 1 summarizes the main differences between protocols A and B.
- Reconstruction parameters were as follows:
- Chest: 1.0 mm thickness, 0.7 mm increment, D30f medium smooth filter, mediastinal window.
- Aorta (full extent): 1.0 mm thickness, 0.7 mm increment, I26f smooth filter, angiographic window.
- Coronary arteries: 0.6 mm thickness, 0.3 mm increment, D30f filter, angiographic window.

An electromechanical injector pump was used to administer 150 mL of non-ionic iodinated contrast (Omnipaque® 300, Iohexol 300 mg/mL; GE Healthcare, USA) at a flow rate of 4 mL/s. Scan initiation was controlled via bolus tracking software, with a region of interest (ROI) placed in the abdominal aorta.

Radiation dose

Radiation dose was assessed using the dose-length product (DLP) and effective dose (ED), expressed in millisieverts (mSv), calculated according to the European Commission's conversion factors. In addition, organ-specific doses were estimated using VirtualDose™ (Virtual Phantoms Inc., Albany, USA), a tool based on anatomically realistic computational phantoms representing pediatric, pregnant, and adult patients with varying body sizes and morphologies.[16]

Image evaluation

The image sets were anonymized and randomly ordered for review. A board-certified abdominal radiologist with 10 years of experience, blinded to the scan protocol, independently evaluated all examinations for both quantitative and qualitative image analysis.

Attenuation measurements were performed on a post-processing PACS workstation (Carestream Health, Rochester, USA) at four predefined anatomical locations: pulmonary trunk, descending aorta, anterior descending coronary artery, and abdominal aorta. Circular ROIs were manually placed at the center of each vessel with the following dimensions: 0.6 × 0.5 cm (pulmonary trunk), 0.6 × 0.5 cm (descending aorta), 0.1 × 0.1 cm (anterior descending coronary artery), and 0.6 × 0.5 cm (abdominal aorta), as illustrated in Figure 1.

Subjective assessment of image quality was performed using a five-point Likert scale,[17] where 1 = excellent, 2 = good, 3 = sufficient, 4 = suboptimal, and 5 = unsatisfactory.

Table 1 – TRO CTA parameters at our institution

Parameter	Protocol A	Protocol B
Collimation detector (mm)	128 × 0.6	128 × 0.6
Rotation time (s)	0.3	0.3
Tube voltage (kVp)	120	120
mAs reference	210	160

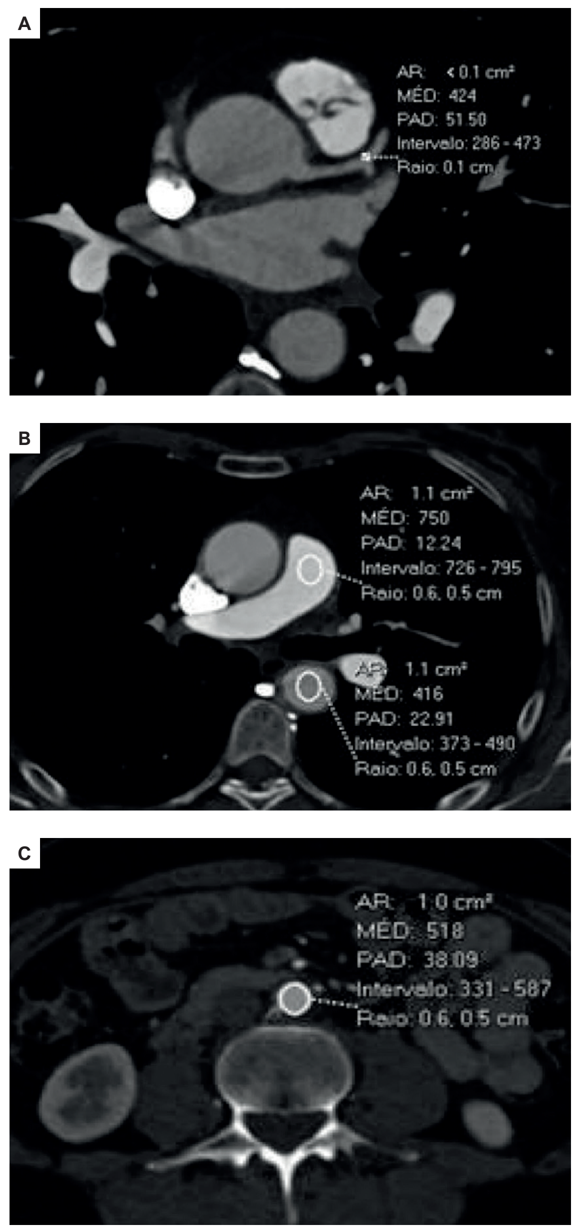

Figure 1 – *CTA in axial plane demonstrating the 4 predefined circle regions of interest to assess the attenuation measurements in the anterior descending coronary artery (A), pulmonary trunk and descending aorta (B), and abdominal aorta (C).*

The radiologist also rated the conspicuity of key thoracic and abdominal vascular structures, including pulmonary trunk, lobar and segmental pulmonary arteries, aortic arch, descending aorta, aortic valve, left coronary trunk, right coronary artery, circumflex artery, celiac trunk, superior and inferior mesenteric arteries, right and left renal arteries, and right and left iliac arteries. Additionally, image quality of relevant findings such as coronary stents and aortic endoprostheses was assessed.

Table 2 – Patient characteristics

Characteristics	Total (N = 56) Median (IQR or %)
Sex (male/female)	38/18 (68%/32%)
Age (years)	66 (59-70)
BMI (kg/m^2)	23.5 (21.0-25.9)
Interval between protocol A and B (months)	24 (14.2-33.3)

BMI: body mass index; IQR: interquartile range.

Table 3 – Radiation doses of protocol A and B

	Protocol A	Protocol B	p
Dose length product, median (IQR)	2.2 (1.6-2.8)	1.1 (0.9-1.1)	< 0.001
ED, median (IQR)	32.6 (24.4-42.7)	17.0 (14.3-18.1)	< 0.001

IQR: interquartile range; ED: effective dose.

Table 4 – Arterial attenuation in Hounsfield unit measurements in protocols A and B

	Protocol A	Protocol B	p
Ascending aorta, median (IQR)	432 (377-390)	439 (387-500)	0.601
Descending aorta, median (IQR)	399 (346-458)	405 (363-451)	0.890
Abdominal aorta, median (IQR)	406 (364-475)	393 (335-456)	0.486
Pulmonary trunk, median (IQR)	460 (387-551)	477 (416-531)	0.835

IQR: interquartile range.

Statistical analysis

Continuous variables were presented as medians with interquartile ranges (IQR), while categorical variables were expressed as counts and proportions. Comparisons between protocols A and B were performed using either Student's t-test or the Wilcoxon rank-sum test, depending on data distribution. A p value < 0.05 was considered statistically significant. All statistical analyses were conducted using SPSS software (version 22.0, IBM Corp.). The statistical methodology was reviewed by an independent statistician.

Results

The final study population included 56 patients, of whom 38 (68%) were men, with a median age of 66 years (IQR: 59 to 70). The median time interval between protocol A and protocol B was 24 months (IQR: 14.2 to 33.3). Patient characteristics are summarized in Table 2.

In terms of radiation dose, the median DLP for Protocol B was 1.1 mSv (IQR: 0.9 to 1.1), while for Protocol A it was 2.2 mSv (IQR: 1.6 to 2.8). The median ED for Protocol B was 17.0 mSv (IQR: 14.3 to 18.1), compared to 32.6 mSv (IQR: 24.4 to 42.7) for Protocol A. Both the DLP and ED values were significantly lower for protocol B compared to protocol A ($p < 0.001$). Additionally, the virtual dose

Table 5 – Comparison of subjective evaluation of overall imaging quality and conspicuity of the main thoracic and abdominal vessels

	p
Overall image quality	0.610
Pulmonary trunk	0.564
Lobular arteries	0.705
Segmental arteries	1.000
Aortic arch	0.317
Descending aorta	0.157
Aortic valve	0.107
Left coronary trunk	1.000
Right coronary artery	0.750
Circumflex artery	0.301
Celiac trunk	0.317
Superior mesenteric artery	1.000
Inferior mesenteric artery	1.000
Right renal artery	1.000
Left renal artery	1.000
Right iliac arteries	0.317
Left iliac arteries	0.317

for protocol B was significantly lower than for protocol A, 16.2 (IQR: 9.3 to 20.4) versus 34.7 (IQR: 19.9 to 43.5), respectively ($p < 0.001$), as shown in Table 3.

Regarding image evaluation, no significant differences were observed in the quantitative attenuation measurements of the ascending aorta, descending aorta, abdominal aorta, and pulmonary trunk between protocols A and B (Table 4). Similarly, no significant differences were found in the qualitative assessment of the conspicuity of the main thoracic and abdominal arteries or in the overall image quality between protocols A and B (Table 5 and Central Illustration).

Discussion

In our study population, the median DLP and ED were significantly lower in protocol B compared to protocol A, with a similarly significant reduction in virtual dose for protocol B. However, there were no significant differences between the two protocols regarding quantitative analysis of ROI measurements in the main thoracic and abdominal arteries or qualitative assessments of vessel conspicuity and overall image quality.

A previous study focusing solely on chest evaluation reported estimated ED values for retrospective ECG-gated TRO CTA ranging from 7.4 to 13.4 mSv for men and 10.1 to 17.5 mSv for women.[15] Another study also including only the chest, using a larger coverage scanner, demonstrated ED of 9.7 to 23.2 mSv, depending on the patient heart rate.[18] In comparison, our results for the partially ECG-gated TRO CTA protocol, which included the abdomen, showed an ED range of 14.3 to 18.1 mSv. This range is consistent with previous studies and has the added advantage of evaluating the abdominal aorta.

In recent years, equipment manufacturers have developed various acquisition protocols to combine thoracic and abdominal images in angiography scans. For example, some manufacturers have implemented automatic switching to non-gated scanning with a faster pitch for imaging the abdominal aorta. However, in certain CT units, automatic iterative reconstruction algorithms are unavailable, requiring manual transitions in partially ECG-gated protocols. This manual switch between gated and non-gated sequences can be time-consuming and may introduce reconstruction artifacts. The CT unit used in our study lacked the automatic iterative reconstruction algorithm, yet no significant loss in image quality was observed. Based on these findings, we strongly advocate for the incorporation of partially ECG-gated protocols when including the abdominal aorta, even in the absence of automatic switching.

Currently, TRO CTA is recognized as an important diagnostic tool for selected patients in the emergency department with acute chest pain.[19,20] However, there are no established guidelines outlining its clinical indications. Very few studies, like ours, have incorporated the abdominal aorta into the protocol to enhance the evaluation of the entire aorta when descending aortic dissections need to be ruled out. The clinical significance of our findings lies in the feasibility of including abdominal aorta scanning in a partially ECG-gated TRO CTA protocol, which provides additional diagnostic information without a substantial increase in effective radiation dose compared to previous thoracic-only studies.[7,8,15,18]

Several limitations of this study should be noted. First, imaging analysis was conducted by a single experienced radiologist, which precluded the assessment of interobserver agreement and may have introduced bias in the evaluation of image quality. Additionally, the impact of heart rate on image quality was not explored in a subgroup comparison. Lastly, we did not compare the procedural times for each protocol or the time required for image reconstruction. These aspects should be addressed in future studies. Furthermore, additional research is needed to assess the cost-benefit ratio of including abdominal scanning in TRO CTA for patients at different risk levels for aortic dissection.

In conclusion, our study demonstrates the feasibility of using a partially ECG-synchronized acquisition protocol as an effective strategy to reduce radiation dose compared to the fully ECG-synchronized technique in CCTA with TRO, when iterative reconstruction algorithms are not available. The proposed protocol maintained image quality, with scan extension to include the abdominal aorta, without loss of image quality when a manual transition between partially ECG-synchronized protocols is necessary.

Author Contributions

Conception and design of the research: Bertolazzi P, Horvat N; acquisition of data: Bertolazzi P, Silva CFG, Oliveira FF, Pereira FP, Viana PCC; analysis and interpretation of the data and critical revision of the manuscript for intellectual content: Horvat N, Araújo-Filho JAB; statistical analysis: Castro I; writing of the manuscript: Bertolazzi P, Silva CFG; Iunes L.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Sources of Funding

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of the Instituto de ensino e pesquisa sirio-libanes under the protocol number 2.445.680. All the procedures in this study were in accordance with the 1975 Helsinki Declaration, updated in 2013. Informed consent was obtained from all participants included in the study.

Use of Artificial Intelligence

The authors did not use any artificial intelligence tools in the development of this work.

Availability of Research Data

All datasets supporting the results of this study are available upon request from the corresponding author.

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