Calcium Scoring with Prospective ECG-Triggered coronary CT Angiography: A Path to Reduce Radiation Dose

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Research Article

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Abstract

Objectives:

To examine if calcium scoring CT (CAS-CT) reduces the whole-examination radiation dose of prospectively ECG-triggered coronary CT-angiography (CCTA).

Methods

In this retrospective study, patients underwent CAS-CT and prospectively ECG-triggered CCTA on a 2nd generation Dual-Source CT scanner. CCTA was planned on CAS-CT images. We further simulated CCTA-planning on scout-view. Therefore, the scan length of the scout-view-derived CCTA was set equal to the CAS-CT scan length. Effective doses were compared for the following scenarios: (1) CAS-CT-derived CCTA + CAS-CT and (2) scout-view-derived CCTA without CAS-CT. Dose differences between the scenarios were additionally examined with respect to scan mode and body-mass-index.

Results

Among 182 patients (58±12 years, 47% females), planning cCTA on CAS-CT resulted in a shorter scan length than planning on scout-view (114.3 ± 9.7 mm vs 133.7 ± 13.2 mm, p<0.001). The whole-examination effective dose was slightly lower for scenario (1) (3.2 [1.8 – 5.3] mSv vs 3.4 [1.5 – 5.9] mSv; p<0.001, n=182). Scenario (1) resulted in a substantially lower radiation dose in sequential scans (3.6 [2.3 – 6.1] mSv vs 3.9 [2.4 – 6.50] mSv, n=150), or in obese patients (6.8 mSv [4.5 – 9.1]) vs 7.3 mSv [4.7 – 9.9], n=45), p<0.001 respectively. Only in high-pitch spiral CCTA, scenario (2) resulted in a dose salvage (0.8 mSv [0.6 – 1.4] vs 1.0 mSv [0.8 – 1.5], n=32; p<0.001).

Conclusions

Planning prospectively ECG-triggered CCTA on CAS-CT reduces the overall radiation dose of the examination compared to a scout-view planning approach where no CAS-CT is acquired. Only for high-pitch spiral CCTA a slightly opposite effect was observed.

Key Points

- Calcium scoring CT improves planning of prospectively ECG-triggered coronary CT angiography and reduces overall radiation dose.
- In prospectively ECG-triggered coronary CT angiography omitting calcium scoring CT to reduce the whole-examination radiation dose should only be considered if clinically justifiable and if a high-pitch spiral CT scan is performed.

1. Introduction

Cardiovascular disease is the leading cause of mortality in adults worldwide [1]. Early diagnosis, risk adjustment, and treatment have improved patient outcomes [2]. CT coronary angiography (CCTA) represents a reliable and accurate non-invasive imaging technique for detecting coronary artery disease (CAD) with a sensitivity of 96% and a specificity of 82% [3–6]. In the updated guidelines of the European Society of Cardiology, cCTA received a class-I recommendation for patients with chronic chest pain [7].

Although there have been improvements in recent years, concerns regarding the associated radiation exposure of a CCTA exist. With the emergence of 2nd generation Dual Source CT scanners (DSCT), two novel low-dose, prospectively ECG-triggered scan modes are available: sequential (“step and shoot”) and high-pitch spiral (“flash”) scan mode [8].

Furthermore, the Society of Cardiovascular CT published guideline recommendations for optimized cCTA acquisitions which include many measures to keep radiation exposure as low and reasonable as achievable while maintaining diagnostic accuracy [9]. Among the multiple measures is tube voltage reduction in underweight and normal-weight patients [10, 11], iterative reconstruction techniques [12], and adaption of z-axis [13]. Another proposed strategy to reduce the overall radiation dose of CCTA is to omit non-contrast calcium scoring (CAS)-CT before contrast-enhanced CCTA in patients with low pretest probability for obstructive CAD [14].

However, scan length adjustment of CCTA on CAS-CT images has shown to reduce the whole-examination radiation dose in retrospectively ECG-gated spiral CCTA [15]. Retrospective spiral CT, however, is now increasingly being replaced by modern prospective ECG-triggered protocols due to the associated radiation exposure [16]. It has never been investigated whether scan length adjustment of CCTA on CAS-CT images influences the whole-examination radiation dose for modern, prospectively ECG-triggered low-dose CCTA protocols. Our study aimed to close this gap and to examine if CAS-CT reduces the whole-examination radiation dose of prospectively ECG-triggered CCTA.

2. Patients And Methods

2.1 Ethics Statement

Approval was obtained on 11/03/2021 (No. **BLINDED**) by the institutional review board of **BLINDED**, and the need for informed consent was waived.

2.2 Patients

Between 01-2020 and 09-2020, consecutive patients referred for CCTA were retrospectively included in the study group. The following data of patient characteristics were recorded: gender, age, height, weight, clinical symptoms, pretest probability for CAD, blood pressure, and heart rate. Exclusion criteria included a deviating or incomplete examination protocol, scan abortion, and an already known CAD.

2.3 CT Protocol

All CT examinations were performed on a 2nd generation DSCT scanner (Somatom Definition Flash, Siemens Healthineers, Forchheim). At first, an anterior-posterior scout view of the chest was obtained. Next, the craniocaudal extension of CAS-CT was set, with an upper limit at 1 cm below the carina and a lower limit of the apex cordis (Fig. 2). If there were no contraindications, patients received a single dose of 5.0 mg isosorbide-dinitrate before CAS-CT. Non-contrast CAS-CT was performed using the low-dose, high-pitch scan mode with the following parameters: tube voltage 120kV, automated tube current modulation (CARE Dose mAs), detector collimation of 2 x 128 x 0.6 mm, gantry rotation time of 280 ms, a pitch of 3.2 and a matrix size of 512 x 512. Images were acquired at 60% of the R-R interval during inspiratory breath-hold. A sharp reconstruction kernel (b36f) was applied. Images were transferred with a default mediastinal window setting, a slice thickness of 3.0 mm, and a field of view restricted to the heart. After CAS-CT, a beta-blocker (metoprolol, 1mg/mL) was administered intravenously if necessary. A test-bolus preceded cCTA to determine the time delay till maximal aortic contrast enhancement. Therefore, we placed a region of interest in the aortic root and started consecutive image acquisition 10 seconds after intravenous injection of 10 mL of iodinated contrast material (Iomeprol, 400 mg/dL) followed by 60 mL using a dual-syringe power injector. The time to HU-peak was appreciated and 4 seconds were added to the time to peak in sequential scan mode and 5 seconds in high-pitch spiral scan mode to determine the CCTA scan delay. 60–72 mL of contrast material were injected (Imeron 400, Bracco imaging, 400 mg iodine/mL, injection rate: 6 mL/s) followed by 60 mL saline flush (injection rate: 6 mL/s). A prospective ECG-triggered high-pitch spiral scan was applied in non-obese patients with a regular heart rate of ≤ 65 beats per minute (bpm). A sequential diastolic scan was acquired in obese patients or patients with a heart rate > 65 bpm. Additionally, systolic ECG-padding was performed in case of increased heart rate or increased heart rate variability [17].

2.4 CT-Data analysis

Two radiologists with 4 (*BLINDED*) and 9 years (*BLINDED*) of experience in cardiovascular CT analyzed CT images in consensus on a dedicated workstation (Syngo.via, software Version VA50, Siemens Healthineers). They were blinded to clinical history and prior imaging examinations.

2.4.1 Subjective image quality

Image quality was assessed regarding the coronary tree's vessel sharpness, movement artifacts, and contrast attenuation. Any disagreement was resolved by consensus. A five-point Likert scale was applied for the image quality assessment as follows: 1 = non-diagnostic (extensive artifacts, vessel deformation), 2 = fair (many artifacts; yet diagnostic in consensus), 3 = moderate (blurred vessel contour, numerous artifacts), 4 = good (slight radiating artifacts), and 5 = excellent (crisp and smooth vessel wall contours, no artifacts).

2.4.2 Scan length

The scan length of CAS-CT and the scan length of CCTA were determined in consensus. For that, the table position of the first image above the most cranial part of the coronary tree (mainly coronary

segment 6) and the first image below the cardiac apex were noted. CCTA was planned by adding 1 cm to the upper and 1 cm to the lower cardiac border on CAS. The scan length of the simulated scout-view-based CCTA was assumed to be equal to the CAS-CT. Thus, the table position of the uppermost and lowest axial images of the calcium scoring was noted and used to calculate the scout-view-derived scan length of CCTA, as previously described [15].

2.4.3 Radiation dose

The dose-length product (DLP) and volume CT dose index (CTDIvol) were noted from the scan protocol recorded with each CT examination. According to the European Working Group for Guidelines on Quality Criteria for Computed Tomography method, the effective dose was calculated via multiplying the DLP with an averaged conversion coefficient (k = 0.017 mSv x mGy-1 x cm-1) among both sexes on Monte Carlo Simulations [18]. The radiation dose estimates for the CAS-CT, as well as CCTA with a scout-view-derived scan length and a CAS-CT-derived scan length were calculated.

2.5 Statistical analysis

IBM SPSS Statistics 27 (Armonk; NY, USA) was used for statistical analysis. The Shapiro-Wilk test was used to determine whether variables followed a normal distribution. Continuous variables were expressed as number (frequency), mean ± standard deviation (SD), or median [interquartile range] [IQR]. Spearman's correlation analysis was used to determine the correlation between subjective image quality (Likert value) and heart rate, body-mass-index and increased heart rate variability. CCTA scan length of CAS-CT-derived and of scout-view-derived planning was compared using the Wilcoxon signed-rank test. The following radiation dose scenarios were calculated and compared using the Wilcoxon signed-rank test: *scenario (1)* CAS-CT derived CCTA + CAS-CT, *scenario (2)* scout-view-derived CCTA without CAS-CT. Radiation dose differences between *scenarios (1)* and *scenario (2)* were compared with respect to scan mode, tube voltage and body-mass-index using the Wilcoxon signed-rank test. A p-value of < 0.05 was considered statistically significant for all tests.

3. Results

3.1 Patients’ characteristics

182 patients (mean age 58 ± 12 (SD) years, 47% females) were included. High-pitch spiral CT was performed in 18% (32/182) of cases, and sequential scan in 82% (150/182). In 34% (51/150) of patients scanned with the sequential scan mode, a diastolic ECG-padding window of ≤ 20% of the R-R interval was applied. Patients' characteristics are summarized in Table 1, and a flowchart for patient inclusion and exclusion is provided in Fig. 1.

Table 1
Demographic data and baseline characteristics

Characteristics	Total (*n* = 182)
Age (years)	58 ± 12
Gender	
Male	97 (53.3%)
Female	85 (46.7%)
Age (years)	58 ± 12
Body-mass-index (kg/m2)	27.0 ± 5.3
Non-obese (BMI < 30)	132 (74.9%)
Obese (BMI ≥ 30)	45 (25.1%)
Heart rate during CCTA (bpm)	62 ± 10
Symptoms	
Angina pectoris	18 (9.9%)
Atypical angina pectoris	19 (10.4%)
Non-anginal chest pain	47 (25.8%)
Dyspnea	21 (11.5%)
Unknown	77 (42.3%)
Tube voltage (kV)	
80 kV	22 (12.1%)
100 kV	89 (48.9%)
120 kV	71 (39.0%)
Agatston-Score*	0.2 [0–36]
CCTA results	
No CAD	130 (71.4%)

Data are presented as number and frequencies in parenthesis, mean ± standard deviation; BMI, body-mass-index; CCTA, coronary CT angiography; CAD, coronary artery disease; ECG, electrocardiography; kV, kilovolt; bpm, beats per minute; RR interval, elapsed time-percentage between two R waves of the QRS signal on the electrocardiogram.

*Data are presented as the median and interquartile range in square brackets.

Characteristics	Total (*n* = 182)
1-vessel-CAD	40 (22%)
2-vessel-CAD	9 (4.9%)
3-vessel-CAD	3 (1.6%)
CCTA scan mode	
High-pitch spiral CCTA	32 (17.6%)
Sequential CCTA	150 (82.4%)
ECG-Padding > 20% of the R–R interval	99/150 (66%)
Data are presented as number and frequencies in parenthesis, mean ± standard deviation; BMI, body-mass-index; CCTA, coronary CT angiography; CAD, coronary artery disease; ECG, electrocardiography; kV, kilovolt; bpm, beats per minute; RR interval, elapsed time-percentage between two R waves of the QRS signal on the electrocardiogram.	
*Data are presented as the median and interquartile range in square brackets.	

3.2 Subjective Image quality

The overall diagnostic image quality was good (median Likert score 4 [IQR, 3–5], n = 182). Excellent image quality was achieved most frequently (n = 66/182 (36%)). In 5 out of 182 examinations (3%), diagnostic image quality could not be achieved (Likert score 5). In 4 of these 5 patients (80%), the midpart of the right coronary artery was not assessable due to severe motion artifacts.

3.3 Scan length

Out of 182 exams, 166 (91%) CAS-CT-derived cCTA scans were found to have a shorter scan length than cCTA scans planned using scout-view images. On average, planning cCTA on scout-view was 18% longer than planning on axial CAS-CT (133.7 ± 17.8 mm vs. 114 + 9.7 mm; $p < 0.001$). Both planning approaches fully displayed the coronary tree in all cCTA examinations (Table 2, Fig. 3).

Table 2
scan length and radiation dose

	CAS-CT planned CCTA + CAS CT	Scout-view planned CCTA, no CAS-CT	p-value
Total (n = 182)			
Scan length (mm)	114.6 ± 9.7	133.0 ± 13.2	p < 0.001
CTDIvol (mGy)	15.3 [7.3–28.5]	15.3 [7.3–28.5]	NS
DLP (mGy*cm)	191 [103–314]	198 [94–345]	p < 0.001
Effective dose (mSv)	3.2 [1.8–5.3]	3.4 [1.5–5.9]	p < 0.001
Sequential scan mode (n = 150)			
Scan length (mm)	113.1 ± 9.3	132.5 ± 13.0	p < 0.001
CTDIvol (mGy)	18.4 [10.9–31]	18.4 [10.9–31]	NS
DLP (mGy*cm)	214 [138–359]	227 [141–385]	p < 0.001
Effective dose (mSv)	3.6 [2.3–6.1]	3.9 [2.4–6.5]	p < 0.001
High-pitch spiral scan mode (n = 32)			
Scan length (cm)	121.7 ± 8.2	135.2 ± 14.0	p < 0.001
CTDIvol (mGy)	3.3 [3.0–5.8]	3.3 [3.0–5.8]	NS
DLP (mGy*cm)	57 [48–88]	48 [40–80]	p < 0.001
Effective dose (mSv)	1.0 [0.8–1.5]	0.8 [0.6–1.4]	p < 0.001

Data are presented as mean ± standard deviation or median [interquartile range].

Abbreviations: CAS-CT, calcium scoring computed tomography; cCTA, coronary computed tomography angiography; DLP, dose length product; CTDIvol, computed tomography dose index; NS, non-significant.

3.4 Radiation dose

CCTA planned on scout-view showed a 13% higher DLP than cCTA planned on axial CAS-CT images (198 [94–345] mGy*cm vs 174 [84–293] mGy*cm; p < 0.001). The radiation dose of CAS-CT was 20 [16–22] mGy*cm.

Thus, the overall DLP of *scenario (1)* (= CAS-CT derived CCTA + CAS-CT) was 191 [103–314] mGy*cm and consequently only slightly lower than that of *scenario (2)* (= scout-view derived CCTA) (198 [94–345] mGy*cm, p < 0.001).

When stratified by the ECG-triggering scan mode, the differences were more substantial: *scenario (1)* resulted in a substantially lower radiation dose, when a sequential scan mode (n = 150) was applied (214 [138–359] mGy*cm vs 227 [141–385] mGy*cm; p < 0.001), or when the ECG-padding of sequential CCTA exceeded 20% of the RR-interval (n = 99): 241 [164–431] mGy*cm vs 269 [188–464] mGy*cm; p < 0.001. *Scenario (1)* showed a significant radiation dose reduction in obese patients (n = 45) (398 [264–530] mGy*cm vs 427 [274–584] mGy*cm; p < 0.001), or when a tube voltage of 120 kV was applied: 359 [229–490] mGy*cm vs 373 [222–527] mGy*cm, p < 0.001. In the case of low-dose, high-pitch spiral cCTA (n = 32), *scenario (2)* resulted in a lower radiation dose than *scenario (1)*: (48 [40–80] mGy*cm vs. 57 [48–88]; p < 0.001).

4. Discussion

We examined in our study whether the inclusion of CAS-CT into a low-dose, prospectively ECG-triggered CCTA protocol results in a whole-examination radiation dose reduction compared to an alternative approach, where prospectively ECG-triggered CCTA is planned on scout-view images and no CAS-CT is acquired. The essential findings of our study can be summarized as follows: (I) consistently planning the scan length of CCTA on axial non-contrast CAS-CT images results in a shorter scan length than planning on a scout-view. (II) The whole-examination radiation dose of prospective ECG-triggered CCTA planned on CAS-CT is slightly lower than CCTA planned on scout-view, even if no CAS-CT is acquired in the latter scenario. (III) CAS-CT planning of prospective ECG-triggered CCTA results in a radiation dose salvage compared to scout-view planning when individual factors (e.g., high BMI), or technical factors (e.g., high tube voltage, sequential scan with extended ECG-padding) contributing to a higher overall radiation dose are present. (IV) Omitting CAS-CT to save radiation dose of cCTA is not a reasonable strategy because the potential to reduce CCTA scan length and, consequently, the radiation dose cannot be exploited. (V) In that regard, the acquisition of low-dose high-pitch spiral cCTA constitutes an exception.

4.1 Scan length

Our results show that planning CCTA on CAS-CT images results in a shorter scan length than planning on scout-view images (133.7 ± 17.8 mm vs. 114.3 ± 9.7 mm; p < 0.001). These results are confirmatory to a previous study conducted by Leschka et al. using the same CCTA planning approach (their reported result: 139 ± 13 mm for cCTA using scout-view planning vs. 117 ± 9 mm for CCTA using CAS-CT planning (17).

4.2 Radiation dose

We observe a minimal overall radiation dose salvage in prospective ECG-triggered CCTA when the scan-length planning is performed on CAS-CT images compared to scout-view planning of CCTA (mean effective dose reduction, 0.2 mSv, 3.1%). Leschka et al. observed a mean radiation dose reduction of 1.0 mSv, 16% [15]. The differences can be explained as, in their study, only retrospective ECG-synchronized scan protocols were investigated. Retrospective ECG-gating is associated with high radiation exposure, and adjustment of the scan length seems very effective.

In our study, the median overall dose length product of 174 mGy*cm for CCTA is comparable to current data of the PROTECTION VI registry (reported median: 195 mGy*cm) [16]. Subgroup analysis of the specific prospective ECG-triggered acquisition scan mode indicates a crucial finding regarding radiation dose safety: In all high-pitch spiral scans, scout-view planning of CCTA with the omission of CAS-CT would have resulted in a 15.4% radiation dose saving. However, when using sequential scan mode, particularly when ECG-padding exceeds 20% of the R-R interval, the overall radiation dose salvage using CCTA planning on CAS-CT was 10.4% (0.5 mSv).

4.3 Role of Calcium Scoring CT

In addition to being a planning tool, non-contrast CAS-CT itself adds to the benefit of additional diagnostic and prognostic value. In a prospective study on 13.644 individuals and a median follow-up of 9.4 years, it was demonstrated that the use of statins in patients suffering from hyperlipoproteinemia only led to a reduction in serious adverse cardiovascular events if coronary calcification was present [19]. It has also been observed that knowledge of the calcium score increases patients' compliance with statin medication [20]. Therefore, case-by-case, it must be considered whether the omission of CAS-CT seems reasonable for radiation safety reasons. Our study's effective dose of the calcium scoring scan was 0.33 mSv (IQR, 0.25–0.37 mSv), thus slightly lower than in previous comparable studies [21]. One explanation could be that we always acquired the CAS-CT using a high-pitch spiral scan, while in other studies, a sequential scan is obtained if the heart rate exceeds 80 bpm. It should be noted that with the emergence of 3rd generation DSCT and tin filtration, the acquisition of a high-pitch, low-voltage CAS-CT is feasible and results in much lower radiation exposure (0.13 mSv) than in our study [22]. It can be assumed that under such conditions, adjustment of the cCTA z-axis extension on CAS-CT images would result in an even lower whole-examination effective radiation dose.

Limitations

Our study has several limitations. First, this was a retrospective, single-center, and single-scanner trial. Therefore, the generalizability of the results is, by default, limited. Second, the analyzed prospective ECG-triggered scan protocols are vendor-specific. Third, all participants were included consecutively, and CCTA was clinically indicated; however, selection bias cannot be entirely excluded. Fourth, all scout-view CCTA plannings were simulated, and a simulated scan length and radiation dose were calculated. Here a prospective study design would have been more accurate.

However, our study is the first to investigate the role of CAS-CT as a planning tool for optimizing whole-examination radiation dose in low-dose, prospectively ECG-triggered cCTA. Prospective ECG-triggered CCTA acquisitions have replaced retrospective spiral scans in most clinical settings [16]. Therefore, it is important to critically reevaluate already established methods for reducing radiation dose to ensure their effectiveness in modern, prospective, and low-dose scan protocols.

Conclusion

Planning prospectively ECG-triggered CCTA on CAS-CT reduces the overall radiation dose of the examination compared to a scout-view planning approach where no CAS-CT is acquired. Only for high-pitch spiral CCTA a slightly opposite effect was observed.

Abbreviations

CAD, *coronary artery disease*

CAS-CT, *calcium scoring CT*

CCTA, *coronary CT-angiography*

CTDIvol, volume CT dose index

DLP, *dose-length product*

DSCT, *Dual Source CT*

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Figures

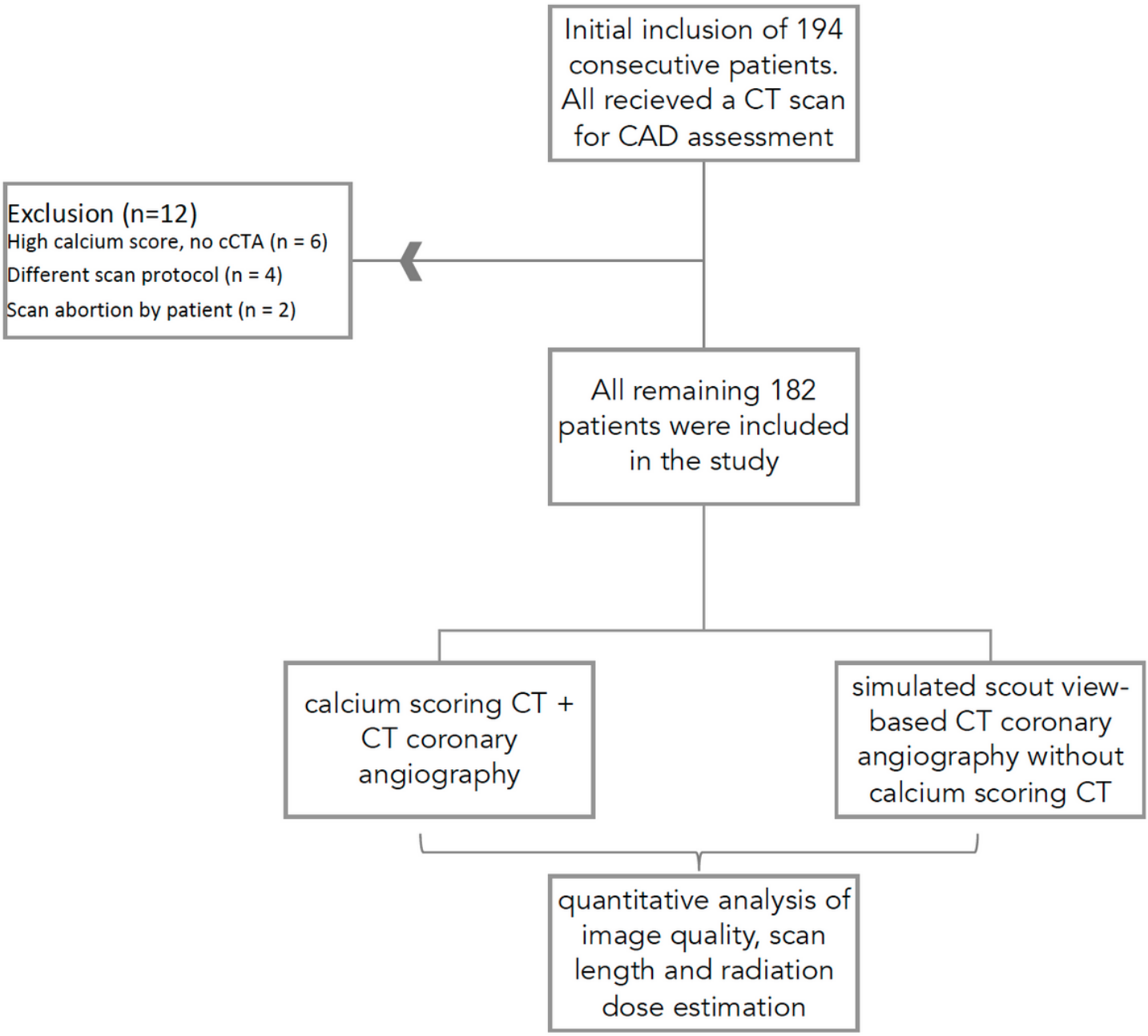

Figure 1

Flow chart of patient inclusion and exclusion.

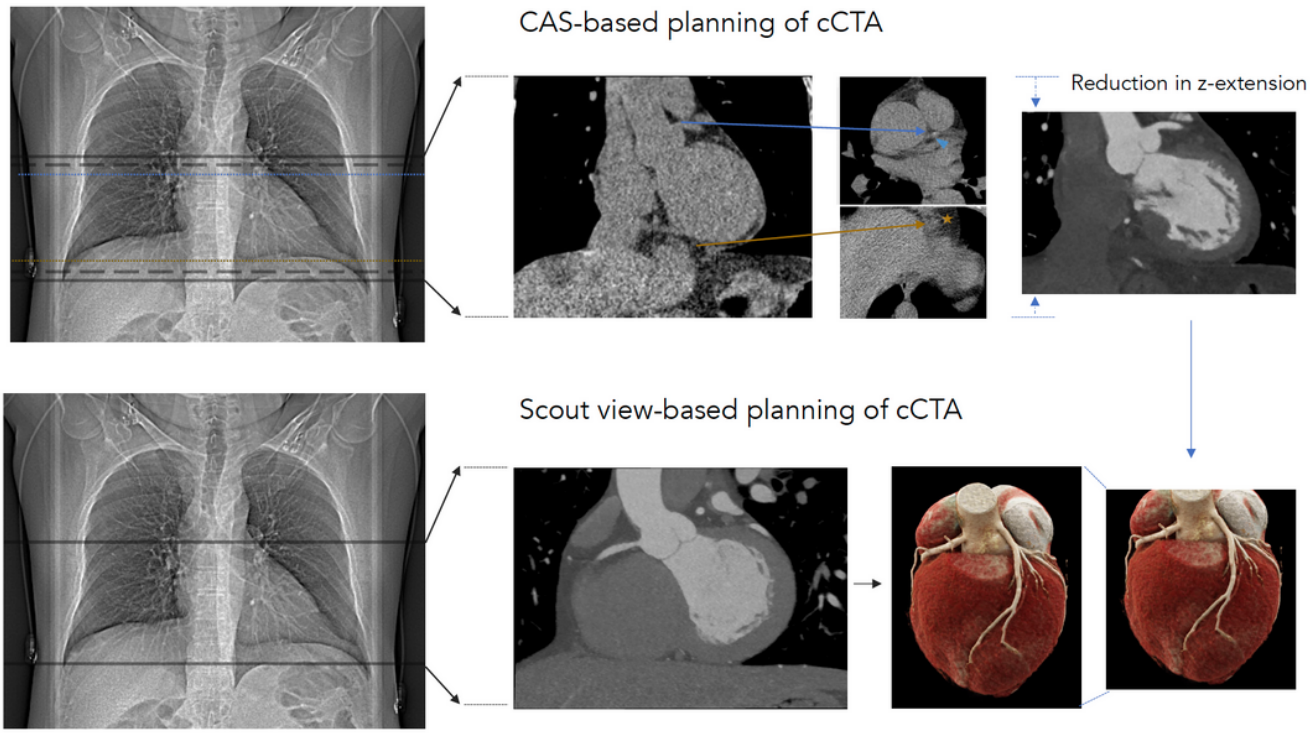

Figure 2

To obtain a complete depiction of the coronary tree, either calcium-scoring CT-based or scout view-based planning is feasible. For the calcium scoring CT-based planning (upper row), a calcium scoring scan is planned on an anterioposterior (AP) scout view with 1 cm below the carina and 1 cm below the cardiac apex (solid lines on AP-scout view). On calcium scoring images, the most cranial part of the coronary tree (coronary segment 6: blue triangle) and the cardiac apex (orange star) are appreciated (dotted lines on AP-scout view). CT coronary angiography scan length is set at 1 cm cranial and caudal to those landmarks (dashed lines on AP-scout view). In a scout view-based coronary CT angiography (lower row) planning, the scan length is planned based on the scout view using the same landmarks for obtaining calcium-scoring images. The calcium-scoring CT scan itself can be omitted in such an approach.

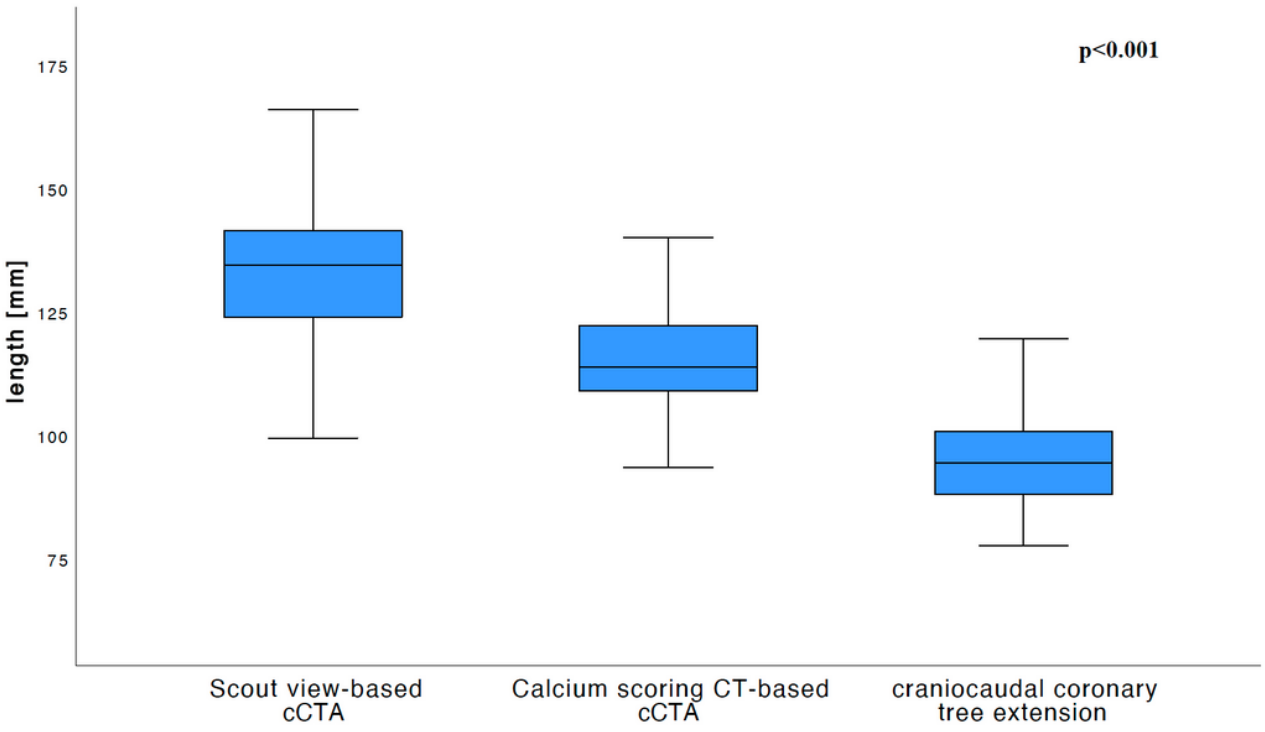

Figure 3

Boxplot showing the scan length distribution of a scout view-based coronary CT angiography (133 ± 13.2 mm), a calcium scoring CT-based coronary CT angiography (114.6 ± 9.8 mm), and the craniocaudal coronary tree extension on the acquired CT images (94.7 ± 8.7 mm). Length differences for each entity were significant (p>0.001). The entire coronary tree was depicted in all patients for each planning approach.