HeartFlow®

Acquisition and Reconstruction Techniques for Coronary CT Angiography

GE Healthcare Scanner Platforms

Education Collaborator
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1. Overview

Coronary computed tomography angiography (CCTA) is a non-invasive diagnostic for detecting coronary artery disease (CAD). CCTA is increasingly utilized in clinical practice for evaluating coronary anatomy for obstructive disease and plaque.

It is, however, imperative that artifact free CCTA image data is obtained in order for it to be successfully analysed for anatomic assessment and/or to act as adequate input for adjunct analyses such as physiologic simulations. Data acquisition strategies and scanning protocols may vary depending on scanner manufacturer, system, and institutional preferences. This document provides references for reliable image acquisition for CCTA.

2. Introduction

Image acquisition in computed tomography is governed ultimately by the principle of As Low As Reasonably Achievable (ALARA). In the first 10 years of CCTA, the focus was almost exclusively on the detection of anatomical stenosis in low to intermediate risk patients. With the evolution of technology, the clinical utility of CCTA has extended beyond stenosis assessment to atherosclerosis characterization, the evaluation of structural heart disease, and the functional and physiological assessment of coronary stenoses. Recently the SCCT acquisition guidelines were updated and provide an excellent reference for Cardiac CT imaging specialists to help optimize their scan protocols. That being said, given the growing information that is provided from cardiac CT, the imaging requirements have evolved and require tailoring to meet the clinical indication. The purpose of this white paper is to highlight the parameters and image acquisition protocols that are important to help optimize image quality, provide accurate representation of anatomy and thus enable quantitative CT.

Importance of Heart Rate Control

With the advancements in scanner technology, the necessary requirement for heart rate reduction has decreased over time. The demands for a low and steady heart rate to ensure diagnostic image quality may not be what they once were but best practice remains to optimize image quality through heart rate control. SCCT guidelines recommend performing CCTA with heart rates below 60 bpm.

In addition, CCTA no longer simply provides stenosis evaluation but needs to enable the interpreting physician to identify and characterize plaque and, following the identification of a stenosis, to perform functional or physiologic evaluation. As a result, while latest generation CT scanners may enable diagnostic image quality at higher heart rates, there remains meaningful image quality benefits from heart rate reduction. In addition, lower heart rates allow the use of lower dose scan acquisitions that are not possible at higher heart rates. Heart rate control strategies are well established and the appropriate strategy is dependent on a number of variables including available medications, setting of practice and site preference. For recommendations please refer to the recently updated SCCT acquisition guidelines.

Importance of Nitrates

Nitrates as smooth muscle dilators have direct effect on coronary vasodilation and result in tangible enlargement of coronary size. As such, similar to invasive coronary catheterization, nitroglycerine (glyceryl trinitrate) should be administered prior to CCTA to optimize image quality and enable the most accurate stenosis evaluation. A commonly used regimen is 400-800 μg of sublingual nitroglycerin administered as either sublingual tablets or a metered lingual spray (commonly 1-2 tablets or 1-2 sprays) prior to the CCTA. While the evidence is modest and there is no randomized data, both a higher dose and administration via spray are becoming increasingly preferred in clinical practice and have been shown to help optimize coronary evaluation.

Selection of Tube Current and Potential

The scan parameters used for any cardiac CT should be tailored to the individual patient but also the intended application. The image quality issues with the greatest impact on the interpretability of CT are misalignment and image noise. As such, care must be given to ensure that image noise properties are appropriate and adequate for accurate lumen segmentation. To do so, tube current and potential should be selected carefully, guided by chest wall circumference, the iodine concentration of the intravenous contrast medium, and whether iterative reconstruction is available or not.

Iterative reconstruction (IR) has the ability to reduce image noise in CT without compromising the diagnostic quality of the CT image dataset, which permits a significant reduction in effective radiation dose. In current clinical practice, IR has enabled a significant reduction in radiation dose by allowing for a reduction in tube current and is now increasingly available across all cardiac capable CT scanners. IR commonly takes the form of a blended reconstruction of IR and filtered back projection (FBP). While a very helpful tool, care should be given when using a very high percentage of IR for quantitative CT analysis due to the potential impact on vessel segmentation.

3. Reference Protocol: Revolution CT ES and/or EX

1. Scout

General	Data Acquisition	Comment
Lateral and AP scout covering the heart and coronaries	• Start: Superior 60 mm • End: Inferior 350 mm • Tube Current 10 mA • Tube Voltage: 120 kV • ECG Trace: On • Scout Plane: 90 and 0 degrees • Auto Voice: (Breath hold command)	Take note of the iso-center indicator line on the first scout to ensure that the patient is positioned within 2 cm of isocenter to allow for best image quality. Adjust table height to indicated iso-center location if more than 2 cm off before acquiring the second scout.

2. ECG-gated Axial Data Acquisition of the Coronaries/Heart

Smart Prep

General	Data Acquisition	Comment
• Bolus tracking to automatically trigger the diagnostic scan acquisition based on the HU reading in the ROI reaching the prescribed enhancement threshold • Slice Location: approx 2 cm below the carina • ROI Location: Ascending aorta	• Monitoring Delay: 12 sec • Monitoring Inter Scan Delay: 1 sec • Tube Voltage: 120 kV • Tube Current: 100 mA • Diagnostic Delay: Auto minimum • Threshold: 200 HU Enhancement	The effective 'diagnostic' delay between reaching the threshold and the start of the subsequent data acquisition is the combined time comprising the autovoice, the time needed for table movement.

Scan Parameters

General	Settings	Comment
• ECG-gated axial data acquisition of the heart • Scan range beginning 2 cm below the carina to the base of the heart for routine CCTA without previous CABG procedure • Smart mA automatically sets the tube current to achieve the targeted Noise Index within the range defined by the min and max values • Noise index reference of 31 is specific to the standard recon type with ASiR-V of 50%	**Anatomy Selection:** • Start Location: ~2 cm below the carina • End Location: Base of heart • SFOV: Cardiac large • DFOV: 25 cm **ECG & Gating:** • Auto Gating: On, GE CCTA • Gating Based On: Latest recording • Acquisition Window: Determined by HR • HR Variation Allowance: 1 BPM	The Auto Gating profile should be set according to the goals of the study. For example, the GE CCTA is intended for a routine CCTA study without having full phases for functional analysis. The auto gating profile will set phase acquisition window and HR variation allowance. "Latest recording" uses the ECG trace information within the last test breath hold to determine target phases for reconstruction. For example, if the

Scan Parameters (contd.)

General	Settings	Comment
• For systems with Cardiac Hi-Res scan modes, HD Standard, HD Standard Plus and HD Detail reconstruction kernels are recommended for patients with known high calcium scores, stents or in general where body habitus is appropriate	• Repeat Acquisition: On • Adaptive Gating: On • Smart Arrythmia Management: On • Scan window: – Low HR (30-60 BPM): 75% – Moderate HR (71-70 BPM): 70-80% – Intermediate HR (71-85 BPM): 40-55% and 70-80% – High HR (>85 BPM): 40-55% **kV and mA:** • kV Mode: kV Assist • kV: Will be set by kV Assist • mA Mode: Smart mA to achieve targeted Noise Index • Noise Index: 31 **Timing:** • Auto Voice (Breath hold command): On • Pre-set Delay Time: 2 seconds (Together with the auto voice command and table movement, this results in a diagnostic delay of 4-5 sec) **Scan Type:** • Scan Type: Cardiac • Hi Res Mode: Off • Rotation Speed: 0.28 seconds **Coverage Speed:** • Table Positions: One • Detector Coverage: SC:160 mm (Smart Collimation will automatically select the appropriate collimation for the planned scan range) **Primary Recon:** • Thickness: 0.625 mm • Recon Type: Stnd • ASiR-V™: 50% **Secondary Recon:** • SmartPhase: On	HR was steady at 65 BPM the acquisition window will be set to acquire a phase range of 70-80% of the R to R. Use ECG editing if necessary. kV Assist - recommend adjusting the minimum value to 100 kVp. SnapShot Freeze is a optional feature that should be turned on if the HR is >60 BPM.

Contrast Protocol

General	Specific	
• Single contrast application for both the ECG-gated axial CTA of the aortic root/heart and the CTA of the thorax/abdomen/pelvis • Triphasic administration protocol with pure contrast, followed by a contrast/saline mixture, followed by a saline chaser • Placement of IV access per hospital protocol (an 18-guage IV typically provides the highest safety) • Automated contrast injection using a dual-cylinder injector	• For normal weighted patients and an iodinated contrast agent with 300 mg/ml apply 30 ml contrast at 3.5 ml/sec, followed by 60 ml of 70% contrast/30% saline at 3.5 ml/sec, followed by 30 ml saline at 3.5 ml/sec. This results in a total amount of 72 ml total contrast agent (adjust for contrast agents with differing iodine concentrations) • For large patients and an iodinated contrast agent with 300 mg/ml apply 40 ml contrast at 4.0 ml/sec, followed by 80 ml of 70% contrast/30% saline at 4.0 ml/sec, followed by 30 ml saline at 4.0 ml/sec. This results in a total amount of 96 ml total contrast agent (adjust for contrast agents with differing iodine concentrations)	**Small Patients** **Test Bolus:** • 4.5 cc/sec – 20 cc – contrast • 4.5 cc/sec – 20 cc – saline **CCTA:** • 4.5 cc/sec – 20 cc – contrast • 4.5 cc/sec – 42 cc – 60% contrast/40% saline • 4.5 cc/sec – 35 cc – saline **Medium Patients** **Test Bolus:** • 5.5 cc/sec – 20 cc – contrast • 5.5 cc/sec – 20 cc – saline **CCTA:** • 5.5 cc/sec – 20 cc – contrast • 5.5 cc/sec – 50 cc – 60% contrast/40% saline • 5.5 cc/sec – 40 cc – saline **Large Patients** **Test Bolus:** • 6.5 cc/sec – 20 cc – contrast • 6.5 cc/sec – 20 cc – saline **CCTA:** • 6.5 cc/sec – 60 cc – contrast • 6.5 cc/sec – 60cc – 60% contrast/40% saline • 6.5 cc/sec – 50 cc – saline

4. Reference Protocol: CardioGraphe

1. Scout

General	Data Acquisition	Comment
Lateral and AP scout covering the heart and coronaries	• Start: Superior 60 • End: Inferior 300 • Tube Current 20 mA • Tube Voltage: 120 kV • ECG Trace: On • Scout Plane: 90 and 0 degrees • Auto Voice: (Breath hold command)	Take note on the scouts to ensure that the patient is positioned within 2 cm of isocenter to allow for best image quality. Adjust table height and lateral table location to adjust iso-center location if more than 2 cm off.

2. ECG-gated Axial Data Acquisition of the Coronaries/Heart

Smart Prep

General	Data Acquisition	Comment
• Bolus tracking to automatically trigger the diagnostic scan acquisition based on the HU reading in the ROI reaching the prescribed enhancement threshold • Slice location: approx 2 cm below the carina • ROI location: Ascending aorta	• Monitoring Delay: 12 sec • Monitoring Inter Scan Delay: 2 sec • Tube voltage: 100 kV • Tube current: 60 mA • Diagnostic Delay: 5 sec • Threshold: 200 HU Enhancement • Auto Voice (Breath hold command): "Breathe in and hold your breath"	The effective ('diagnostic') delay between reaching the threshold and the start of the subsequent data acquisition is the combined time comprising (breath hold commands) and the time needed for table movement NOTE: the kV and Rotation Time parameters in the SmartPrep and diagnostic scan tasks have to be the same.

Scan Parameters

General	Settings	Comment
• ECG-gated axial data acquisition of the heart • Scan range beginning 2 cm below the carina to the base of the heart for routine CCTA without previous CABG procedure • mA set achieve the targeted Noise Index	**Anatomy Selection:** • Start location: ~2cm below the carina • End location: base of heart • SFOV: 25 cm • DFOV: 25 cm **ECG & Gating** • Acquisition Window: determined by HR • HR Variation Allowance: 1 BPM • Arrythmia Retriggering: On **kV and mA** • kV: 100-120 (see table on page 11) • mA: 400-600 (see table on page 11) • (Breath hold command): • Pre-set Delay Time: 5 seconds (Together with Breath hold command and table movement, this results in a diagnostic delay 5 sec) **Scan Type:** • Scan Type: Cardiac • Hi Res Mode: Off • Rotation Speed: 0.24 seconds (slower for very large patients with a low heart rate) **Coverage Speed:** • Table Positions: One • Detector Coverage: • Number of Passes: 1 **Primary Recon:** • Thickness: 0.5mm • Recon Type: Stnd • ASiR-CV™: 70% **Secondary Recon:** • Off line	Use the ECG trace information within the last test breath hold to determine target phases for reconstruction. For example, if the HR was steady at 65 beats per minute the acquisition window will be set to acquire a phase range of 70-80% of the R to R. Recommendation: SnapShot Freeze is an optional feature that should be turned on if HR is >60 BPM. Reconstruct off line.

Contrast Protocol

General	Specific	
• Single contrast application for both the ECG-gated axial CTA of the aortic root/heart and the CTA of the thorax/abdomen/pelvis • Triphasic administration protocol with pure contrast, followed by a contrast/saline mixture, followed by a saline chaser • Placement of IV access per hospital protocol (an 18-guage IV typically provides the highest safety) • Automated contrast injection using a dual-cylinder injector	• For normal weighted patients and an iodinated contrast agent with 350-370 mg/ml apply 30 ml contrast at 6 ml/sec, followed by 60 ml of 70% contrast/30% saline at 6 ml/sec, followed by 30 ml saline at 6 ml/sec; this results in a total amount of 72 ml total contrast agent (adjust for contrast agents with differing iodine concentrations) 350-370 mg/ml 6 ml/ sec of 70ml contrast 6 ml/ sec of 50 ml saline	• For large patients and an iodinated contrast agent with 350-370 mg/ ml apply 40 ml contrast at 7 ml/ sec, followed by 70 ml of 70% contrast/30% saline at 7 ml/sec, followed by 30 ml saline at 7ml/sec; this results in a total amount of 86 ml total contrast agent (adjust for contrast agents with differing iodine concentrations) 350-370 mg/ml 7 ml/sec of 70 ml contrast 7 ml/sec of 50 ml saline

Recommended mA and kV based on the patient's BMI:

BMI	kV	mA	Gantry Rotation	ASiR-CV
< 21	100	350	0.24	70%
21-23	100	400	0.24	70%
23-25	100	500	0.24	70%
25-28	100	600	0.24	70%
29-34	120	480	0.24	90%
>35*	120	600	0.33	90%

*Heart rate > 60 BPM for patients with high BMI may result in images with high degree of coronary motion

5. Reference Protocol: Revolution HD, Revolution EVO, Optima CT660, Discovery CT750 HD and LightSpeed VCT Scanner Platforms

1. Scout

General	Data Acquisition	Comment
Lateral and AP scout covering the heart and coronaries	• Start: Superior 60 • End: Inferior 300 • Tube Current 20 mA • Tube Voltage: 120 kV • ECG Trace: On • Scout Plane: 90 and 0 degrees • Auto Voice: (Breath hold command)	

2. ECG-gated Axial Data Acquisition of the Coronaries/Heart (Group 1)

Smart Prep

General	Data Acquisition	Comment
• Bolus tracking to automatically trigger the diagnostic scan acquisition based on the HU reading in the ROI reaching the prescribed enhancement threshold • Slice Location: approx 2 cm below the carina • ROI Location: ascending aorta	• Monitoring Delay: 7 sec • Tube Current: 60 mA • Diagnostic Delay: Auto minimum • Pre-set Delay Time: 3 seconds (this results in a 'diagnostic delay' of approximately 5-6 sec, if rotation time is kept identical between both groups, i.e. 0.4 sec) • Enhancement Threshold: 150 HU	

Scan Parameters

General	Data Acquisition Prospective Gating	Data Acquisition Differences With Retrospective Gating
• ECG-gated acquisition of the aortic root and heart. Scan range beginning 2 cm below the carina to the base of the heart typically. • Snapshot™ Pulse is a prospective gating approach that is best suited for coronary imaging when the HR is <64 bpm and stable. It is typically the lowest dose imaging option for CCTA. • SnapShot Segment & Burst are retrospective gating options which provide more flexibility in phases for reconstruction which is helpful in higher HR or unstable HRs • mA ranges will vary based on individual scanner configurations • For systems with Cardiac Hi-Res scan modes HD Standard, HD Standard Plus and HD Detail reconstruction kernels are recommended for patients with known high calcium scores, stents or in general where body habitus is appropriate • Noise Index reference of 31 is specific to the standard recon type	• Scan Type: Cardiac • Cardiac Mode: SnapShot Pulse (Cine) • Rotation Speed: 0.35 sec • Slice/Collimation: 0.625 mm • SFOV: Cardiac large • DFOV: 25 cm • Tube Voltage – 120 kVp for BMI > 25 kg/m2 – 100 kVp for BMI < 25 kg/m2 • mA (manual): 450/600/700 mA for small, average and large patients at 120 kVp • Target Phase reconstruction: – 75% for HR <64 typically • Recon Type: Stnd • Recon Option: ASiR, Slice 50% • Auto Voice (Breath hold command)	• Cardiac Mode: SnapShot Segment (Helical) – <80 bpm: SnapShot Segment – >80 bpm: SnapShot Burst • HR Override: Off (turn on to manually enter min HR present on the ECG trace when irregular HR's are seen) • Pitch: Autopitch (determined by HR) • ECG Dose modulation: On • Target phases with peak mA: – 70-80% for HR <64 typically – 40-80% for HR 65-75 typically – 40% for HR > 75 typically **Recon 2:** • Recon Option; SnapShot Segment Plus recon • Can also prescribe additional phases for reconstruction within additional recon prescriptions Using the HR override capability with manually setting the HR to a lower value, yields a lower pitch value which results in redundant CT data acquisition (and increased radiation dose). This provides the greatest flexibility in image reconstruction (e.g. utilization of SnapShot Segment, SnapShot Burst or SnapShot Burst Plus) which can be helpful in challenging heartrate scenarios.

Contrast Protocol

General	Specific	
• Single contrast application for the retrospectively ECG-gated axial CTA of the heart • Triphasic administration protocol with pure contrast, followed by a contrast/saline mixture, followed by a saline chaser • Placement of IV access per hospital protocol (an 18-guage IV typically provides the highest safety) • Automated contrast injection using a dual-cylinder injector	• For normal weighted patients and an iodinated contrast agent with 300 mg/ml apply 30 ml contrast at 3.5 ml/sec, followed by 60 ml of 70% contrast/30% saline at 3.5 ml/sec, followed by 30 ml saline at 3.5 ml/sec. This results in a total amount of 72 ml total contrast agent (adjust for contrast agents with differing iodine concentrations) • For large patients and an iodinated contrast agent with 300 mg/ml apply 40 ml contrast at 4.0 ml/ sec, followed by 80 ml of 70% contrast/30% saline at 4.0 ml/sec, followed by 30 ml saline at 4.0 ml/ sec. This results in a total amount of 96 ml total contrast agent (adjust for contrast agents with differing iodine concentrations)	**Small Patients** **Test Bolus:** • 4.5 cc/sec – 20 cc – contrast • 4.5 cc/sec – 20 cc – saline **CCTA:** • 4.5 cc/sec – 20 cc – contrast • 4.5 cc/sec – 42 cc – 60% contrast/40% saline • 4.5 cc/sec – 35 cc – saline **Medium Patients** **Test Bolus:** • 5.5 cc/sec – 20 cc – contrast • 5.5 cc/sec – 20 cc – saline **CCTA:** • 5.5 cc/sec – 20 cc – contrast • 5.5 cc/sec – 50 cc – 60% contrast/40% saline • 5.5 cc/sec – 40 cc – saline **Large Patients** **Test Bolus:** • 6.5 cc/sec – 20 cc – contrast • 6.5 cc/sec – 20 cc – saline **CCTA:** • 6.5 cc/sec – 60 cc – contrast • 6.5 cc/sec – 60 cc – 60% contrast/40% saline • 6.5 cc/sec – 50cc – saline

Review of Data Reconstruction and ECG-Editing

- Image reconstructions of the heart should be reviewed immediately after the scan when the raw data are still available
- The ECG-gating should be reviewed to ensure that the automated algorithms correctly identified the R-peaks

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WARNING: Any references to x-ray exposure, intravenous contrast dosage, and other medication are intended as reference guidelines only. The guidelines in this document do not substitute for the judgment of a trained healthcare provider. Each scan requires medical judgment by the healthcare provider about exposing the patient to ionizing radiation. Use the As Low As Reasonably Achievable (ALARA) radiation dose principle to balance factors such as the patient's condition, size and age; region to be imaged; and diagnostic task.

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