HeartFlow®

Acquisition and Reconstruction Techniques for Coronary CT Angiography

Canon Medical Systems Scanner Platforms

Edited and Approved by

Jonathon Leipsic MD FSCCT
Past-President Society of Cardiovascular CT

1400 Seaport Blvd, Building B | Redwood City, CA 94063
ph: +1.650.241.1221 | info@heartflow.com | heartflow.com

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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: Aquilion

1. Scanogram

General	Data Acquisition	Comments
Lateral and AP scout covering the heart and coronaries	• AP Scanogram: 120kVp/50mA • Lat Scanogram: 120kVp/100mA • Auto Voice (Breath hold command):	Position the patient for AP scanogram to acquire AP and lateral scanograms. Offset the patient to the right so the heart is at the center of the scan field. Place the patient's arms above their head with the ECG leads outside the scan range. Have the patient practice breath-holding before starting the examination. This should be a single "breathe in and hold" command. The patient should be instructed to hold their breath at about 75% of maximum lung capacity (“take a comfortable breath in”) and to take the same size breath each time they are told. This important step has two purposes: To ensure that the patient can hold their breath for the required scan time. To monitor the patient's heart rate during breath-holding. Make sure that a steady heart rate is displayed with a clean ECG signal.

2. Non-enhanced Scan (optional) – Calcium Score

General	Data Acquisition	Data Reconstruction
• Can be used for quantification of annular calcification • Can be used for planning of subsequent contrast-enhanced data acquisition • Volume data can be acquired as a single-beat/one rotation scan	**Helical CCTA Acquisition** • Acquisition mode: Ca Score Volume Mode • Tube Voltage: 120kVp • Tube Current: $^{\text{SURE}}$Exposure • R-R Scanning Window: HR<71BPM (75%) HR>71BPM (40%) Determined by scanner • Slice/Collimation: 0.5/240 (120mm) • Rotation time: Aquilion One 640 – 350msec Aquilion One Vision: 275msec	**Coronary CTA (Acquisition)** • Field of View limited to the heart (200-220 mm) • Slice thickness 0.5mm • Increment 0.25mm • $^{\text{SURE}}$IQ: Ca Score FC -12 OSR – Cardiac Dose Reduction - OFF Filter - OFF

3. ECG Gated CTA

a. kV and mA

General	Data Acquisition	Data Reconstruction
From the calcium scoring examination, select the start and end positions, the same scanogram can be used as the Calcium scan. It is advisable to plan 1 cm above the superior image selected and 1 cm below the inferior image selected in case the patient's breath-holding is inconsistent. Note: that the proximal LAD is often located superior to the origin of the left main coronary artery Can be used for quantification of annular calcification	• Tube Voltage: 120kVp (the kV can be adjusted by selecting the lowest kV where the graph does not reach the maximum) • Tube Current: SUREExposure Cardiac recommendations **SD – 33** **SUREIQ – Cardiac CTA** **Max mA – 580** **Min mA – 40** • Open the SURECardio menu and click the 'Breath Ex', this monitors the patient's heart rate during breath-hold training	• Low Dose CTA mode is a low-dose scanning technique in which exposure is performed for only a portion of the R-R interval (general diastole). The desired exposure phase is set as a percentage of the R-R interval, so the actual exposure time varies depending on the patient's heart rate. The exposure phase setting can be expanded to include systole if the heart rate is high, and a function is provided to perform such setting based on the results of breathing exercise. Multisegments reconstruction is also available for patients with high heart rates. Functional analysis is not possible in this scan mode because exposure does not cover the entire R-R interval.

b. Timing: Acquiring the SUREStart S and V

General	Data Acquisition	Data Reconstruction
	• Confirm that the descending aorta can be clearly identified on the SUREstart slice. • Place the SUREStart ROI over the descending aorta as shown above • Set the SUREStart trigger at 180 HU	• OPTION You may prefer to trigger SUREStart using manual mode. Triggering SUREStart in manual mode is easy, but you need to be confident of your anatomy. Remember that you will still get a graphical readout of the ROI density. In manual mode, you can easily compensate for low cardiac output by delaying the start of scanning. Place the SUREStart ROI over the descending aorta as shown above • Reassure the patient that it is normal to experience a sensation of warmth following contrast administration. Inform the patient that the next breath-hold is the last one for the examination. Confirm that the patient's heart rate is steady. It is a good idea to have someone monitor the first few seconds of contrast administration to avoid extravasation. GO Contrast injection and scanning are started simultaneously

c. Cardiac Reconstructions

General	Data Acquisition	Data Reconstruction
phaseXact - Fully automated phase selection software The phaseXact software automatically determines the optimal cardiac phase for motion-free imaging. The concept of imageXact is to perform reconstruction at an absolute time point after the R wave (R + ms). Phase selection is performed using a single image located at the mid-heart level and reconstructed throughout the entire cardiac cycle.	• Phase selection is performed in the raw data domain and requires no operator intervention. • phaseXact is set ON in the eXamplan. • Select "Best Phase".	• After the eXam Plan is completed, phaseXact finds and reconstructs the best motion-free cardiac phase. It may be necessary to reconstruct other phases to create a temporal window to permit better assessment of the proximal and distal arteries. • imageXact - Guided image-based phase selection software • In rare cases, phaseXact may not be able to automatically determine the best motion-free cardiac phase. In such cases, imageXact can help by guiding the operator through a simple and precise manual phase selection process.

SUREIQ Settings

The following SUREIQ settings are recommended for cardiac reconstructions:

SUREIQ	FC	OSR	Dose Reduction	Filter
CTA	03	Cardiac	AIDR 3D	OFF
Stent	05	Cardiac	AIDR 3D	OFF
Low Dose	02	Cardiac	AIDR 3D	OFF

4. Contrast Protocol

General		Comments
The injection rate should be increased for shorter scan times and larger patients! CTA requires contrast medium with an iodine concentration of at least 350 mgI/mL. Place a 20- or 18-gauge IV cannula in the RIGHT arm.	**Set the SUREStart trigger at 180 HU**	Single Phase Contrast with Saline Flush This protocol ensures complete washout of the right side of the heart. Streak artifacts from undiluted contrast medium are eliminated, providing excellent visualization of the RCA. The saline solution replaces about 20 mL (5 seconds of injection) of the contrast medium.

4. Contrast Protocol (contd.)

General	Contrast Formula	Comments
The injection rate should be increased for shorter scan times and larger patients! CTA requires contrast medium with an iodine concentration of at least 350 mgI/mL. Place a 20- or 18-gauge IV cannula in the RIGHT arm.	**Biphasic Injection with Contrast/Saline Mix** (Maintains right heart contrast for CFA) **Phase 1 (Contrast)** **60 mL @ 4 mL/s* (15 s) @ 4 mL/s** **Phase 2 (Mix)** **50% Contrast + 50% Saline** **XX = (Scan Time s) x 4** (Simultaneous injection of contrast @2mL/s & saline @2mL/s) **XX = (Scan Time s) x 4** In the above formula, the duration of mixed injection = scan time	Biphasic Injection with a Contrast/Saline Mix A biphasic injection protocol with a contrast/saline mix reduces streak artifact in the SVC and right heart, but maintains adequate opacification of the right ventricle. This may improve the detection of the ventricular septal wall for CFA.

* The Injection rate should be increased for larger patients to ensure adequate iodine flux and therefore good arterial enhancement.

The following guidelines are suggested for injection rates:

Weight (kilograms)	Weight (pounds)	Injection Rate
< 59 kg	< 129 lb	3.5 mL/s
60 – 100 kg	130 – 219 lb	4 mL/s
> 100 kg	> 220 lb	5 mL/s

Review of Data Reconstruction and ECG-Editing

- Image reconstructions of the heart should be reviewed immediately after the scan when raw data is still available
- The ECG-gating should be reviewed to ensure that the automated algorithms correctly identified the R-peaks
- If R-peaks were not correctly identified, manual correction should be performed (e.g. add an R-peak if an R-peak was not identified, or delete an R-peak if an R-peak was placed on anything other than the R-peak; alternatively R-peaks can be shifted manually)
- In case of ectopic contractions, absolute ms reconstruction should be used and the R-peak of the ectopic beat should be deleted

ECG-editing screen showing correctly identifed R-peaks.

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1400 Seaport Blvd, Building B | Redwood City, CA 94063
ph: +1.650.241.1221 | info@heartflow.com | heartflow.com

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