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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

1. Scout

<table>
<thead>
<tr>
<th>General</th>
<th>Data Acquisition</th>
<th>Comment</th>
</tr>
</thead>
</table>
| 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**

<table>
<thead>
<tr>
<th>General</th>
<th>Data Acquisition</th>
<th>Comment</th>
</tr>
</thead>
</table>
| • 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**

<table>
<thead>
<tr>
<th>General</th>
<th>Settings</th>
<th>Comment</th>
</tr>
</thead>
</table>
| • 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 | **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.)

<table>
<thead>
<tr>
<th>General</th>
<th>Settings</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Repeat Acquisition: Off</td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td>• Adaptive Gating: On</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>kV and mA:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• kV Mode: kV Assist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• kV: Will be set by kV Assist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• mA Mode: Smart mA 50-620</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Noise Index: 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Timing:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Auto Voice (Breath hold command): On</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 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)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Scan Type:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Scan Type: Cardiac</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Hi Res Mode: Off</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Rotation Speed: 0.28 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coverage Speed:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Table Positions: One</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Detector Coverage: SC:160 mm (Smart Collimation will automatically select the appropriate collimation for the planned scan range)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary Recon:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Thickness: 0.625 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Recon Type: Stnd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• ASiR-V™: 50%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Contrast Protocol

<table>
<thead>
<tr>
<th>General</th>
<th>Specific</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Single contrast application for both the ECG-gated axial CTA of the aortic root/heart and the CTA of the thorax/abdomen/pelvis</td>
<td>• 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)</td>
</tr>
<tr>
<td>• Triphasic administration protocol with pure contrast, followed by a contrast/saline mixture, followed by a saline chaser</td>
<td>• 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)</td>
</tr>
<tr>
<td>• Placement of IV access per hospital protocol (an 18-guage IV typically provides the highest safety)</td>
<td>• Automated contrast injection using a dual-cylinder injector</td>
</tr>
</tbody>
</table>

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

1. Scout

<table>
<thead>
<tr>
<th>General</th>
<th>Data Acquisition</th>
<th>Comment</th>
</tr>
</thead>
</table>
| 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

<table>
<thead>
<tr>
<th>General</th>
<th>Data Acquisition</th>
<th>Comment</th>
</tr>
</thead>
</table>
| • 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

<table>
<thead>
<tr>
<th>General</th>
<th>Data Acquisition Prospective Gating</th>
<th>Data Acquisition Differences With Retrospective Gating</th>
</tr>
</thead>
<tbody>
<tr>
<td>• ECG-gated acquisition of the aortic root and heart. Scan range beginning 2 cm below the carina to the base of the heart typically.</td>
<td>• Scan Type: Cardiac</td>
<td>• Cardiac Mode: SnapShot Segment (Helical)</td>
</tr>
<tr>
<td></td>
<td>• Snapshot™ Pulse is a prospective gating approach that is best suited for coronary imaging when the HR is &lt;64 bpm and stable. It is typically the lowest dose imaging option for CCTA.</td>
<td>• Cardiac Mode: SnapShot Pulse (Cine)</td>
</tr>
<tr>
<td></td>
<td>• SnapShot Segment &amp; Burst are retrospective gating options which provide more flexibility in phases for reconstruction which is helpful in higher HR or unstable HRs</td>
<td>• Rotation Speed: 0.35 sec</td>
</tr>
<tr>
<td></td>
<td>• mA ranges will vary based on individual scanner configurations</td>
<td>• Slice/Collimation: 0.625 mm</td>
</tr>
<tr>
<td></td>
<td>• 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</td>
<td>• SFOV: Cardiac large</td>
</tr>
<tr>
<td></td>
<td>• mA (manual): 450/600/700 mA for small, average and large patients at 120 kVp</td>
<td>• DFOV: 25 cm</td>
</tr>
<tr>
<td></td>
<td>• ECG Dose Modulation</td>
<td>• Tube Voltage</td>
</tr>
<tr>
<td></td>
<td>• Target Phase reconstruction:</td>
<td>– 120 kVp for BMI &gt; 25 kg/m2</td>
</tr>
<tr>
<td></td>
<td>– 75% for HR &lt;64 typically</td>
<td>– 100 kVp for BMI &lt; 25 kg/m2</td>
</tr>
<tr>
<td></td>
<td>• Recon Type: Snd</td>
<td>• Recon Option: ASiR, Slice 50%</td>
</tr>
<tr>
<td></td>
<td>• Recon Option: SnapShot Segment Plus recon</td>
<td>• Auto Voice (Breath hold command)</td>
</tr>
<tr>
<td></td>
<td>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 heart rate scenarios.</td>
<td></td>
</tr>
</tbody>
</table>
Contrast Protocol

<table>
<thead>
<tr>
<th>General</th>
<th>Specific</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Single contrast application for the retrospectively ECG-gated axial CTA of the heart</td>
<td></td>
</tr>
<tr>
<td>• Triphasic administration protocol with pure contrast, followed by a contrast/saline mixture, followed by a saline chaser</td>
<td></td>
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<tr>
<td>• Placement of IV access per hospital protocol (an 18-guage IV typically provides the highest safety)</td>
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<td>• Automated contrast injection using a dual-cylinder injector</td>
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<tr>
<td>• 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)</td>
<td></td>
</tr>
<tr>
<td>• 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)</td>
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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
5. ECG Editing on Revolution CT

It may be helpful to insert, remove, or move a trigger to normalize a heart cycle when a trigger occurs at an incorrect location. This may occur when abnormal ECG waveform patterns or excessive background noise are present during scan acquisition.

- Open the ECG-gated scan series in the Reconstruction and Image Processing area on the image monitor
- To [insert] a trigger, place the cursor at the intended position on the ECG trace (right-click to “Insert R-peak Trigger”). An additional trigger will display on the ECG trace.
- To [delete] a trigger point on the ECG trace, place the cursor on the trigger and right-click “Delete R-peak Trigger”
- To [move] a trigger, place the cursor over the trigger and click and drag it to the new location
- To switch to a second heartbeat when repeat acquisition is used, place the cursor in the ECG Editor, right-click and select “Switch Scan”. The reconstruction window toggles to the other scan.
6. ECG Editing on Revolution HD, Revolution EVO, Optima CT660, Discovery CT750 HD and LightSpeed VCT Scanner Platforms

Cardiac Helical exams allow for image reconstruction at any point in the R-R interval as image data was acquired throughout the entire cardiac cycle using retrospective ECG-gating. The ECG editor provides the ability to move or reposition the reconstruction window.

In the ECG Editor click the “Rx” icon for the global phase prescription method, i.e. the entered phase values are applied to all available heart cycles.

Global phase prescription allows selecting the phases of the cardiac cycle from which images are created. The blue highlighted areas represent the recon windows for each available R-R interval. The example below displays a recon window ranging from 35 to 60% of the R-R interval. Gray areas represent x-ray exposure/available image data within the exam.

ECG-editing: If R-peaks of the ECG trace were not correctly identified by the trigger points, the trigger points need to be corrected along the ECG trace. Insert, remove, or move a trigger to normalize a heart cycle when a trigger occurs at an undesirable location.
To [insert] a trigger, place the cursor at the intended location along the ECG trace (right-click “Insert Trigger”). An additional trigger point (red line) appears on the ECG trace.

- Following insertion of a trigger point, a recon window needs to be added (right-click “Add Recon Window”)
- Confirm that the recon window is in the desired location before confirming image reconstruction
- To [delete] a trigger point on the ECG trace, place the cursor on the trigger (red line), right-click “Delete Trigger”
- To [move] a trigger, place the cursor over the trigger and click and drag it to the desired location
- Deleting a trigger affects the position of recon windows in adjacent R-R intervals, when relative reconstructions (%) are employed. In contrast, “Delete Image Recon Window” retains the trigger point while image data following the selected trigger point does not contribute to image reconstruction, thus not affecting adjacent R-R intervals. This approach may be employed to improve image quality, e.g. in cases of premature contractions or atrial fibrillation with extremely variable heart rates.
- Place the cursor in the blue image reconstruction window in the ECG editor, right click “Delete Image Recon Window”
An orange (relaxed phase) or red (ungated) area appears on the trace if recon window removal results in insufficient z-axis overlap to create gated images in order to compensate for the removed recon window. Relaxed phase reconstruction windows indicate where relaxed phase recon images will be created. The images are reconstructed as close to the requested phase as possible, with a maximum of a 20% phase offset.

In contrast to the global phase prescription across all R-R intervals, reconstruction windows can also be moved manually. Manually move or adjust recon window of one or more heart cycles, e.g. in setting of varying heart rates. Always review the images created from the edit ECG Trace process. Editing the trace changes the reconstruction using the original scan data.
7. Bibliography


This paper is presented as a service to medical personnel by HeartFlow and GE. The information in this white paper has been compiled from available literature and best practices from expert users. Although every effort has been made to faithfully convey this information, the editors and publisher are not responsible for the content of the materials cited in this paper. This paper is not intended to be, and should not be construed as, medical advice. For any use, the product information guides, inserts, and operation manuals of the various CT acquisition devices should be consulted. HeartFlow and the editors disclaim any liability arising directly or indirectly from the use of drugs, devices, techniques, or procedures described in this paper.

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.