HeartFlow®

Acquisition and Reconstruction Techniques for Coronary CT Angiography

Siemens Healthineers Scanner Platforms

SIEMENS Healthineers

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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. Siemens SOMATOM Definition Flash, SOMATOM Drive and SOMATOM Force

SOMATOM Definition Flash, SOMATOM Drive and Siemens SOMATOM Force are Dual Source systems allowing for a heart rate independent temporal resolution of 75 ms for both the SOMATOM Definition Flash and SOMATOM Drive and 66 ms for the SOMATOM Force.

1. Topogram

General	Data Acquisition (default)	Patient Preparation
AP topogram covering the chest.	• Ref. kVp: 120 kVp • Qual. ref. mAs: 35 mAs • Slice/Collimation: 6 x 0.6 mm • Length: 512 mm	• Patient positioning: The following technique provides patient comfort and optimal image quality for the study: – Head or feet first, supine with head, knees, and lower legs supported by appropriate accessories. – Arms raised above the head, resting comfortably on the head-arm support. – The torso of the patient must be straight, not rotated. – Torso in the middle of the scan field, centered with the help of the laser light markers. • Place ECG-electrodes, as anatomically depicted on the labeled electrodes and IV access in accordance with institutional policies. Recommendation: 18-gauge or larger intravenous needle in the right antecubital vein. Automated contrast injection using a dual-cylinder injector. • Provide enough time for the patient to practice breath hold prior to acquisition. To avoid breathing motion artifacts, the patient is instructed not to breathe and swallow during the acquisition. It is necessary to observe the ECG behavior during the breath hold procedure. The heart rate may decrease during the initial seconds of breath-holding or increase if the patient is straining to hold his breath at the end of the scan.

2. CaSc (optional) – Non-contrast Examination

General	Data Acquisition	Data Reconstruction
Scan range of 12-15 cm from the carina to the apex of the heart. Can be used for subsequent contrast-enhanced data acquisition. Can be used to rule out the presence of excessive calcification, which may reduce the diagnostic accuracy of the CTA study.	• Prospective ECG-triggering • Ref. kVp: 120 kVp • Qual. ref. mAs: 80 mAs • CARE kV: Off • CARE Dose4D™: on • Rotation time: 0.28 s (SOMATOM Definition Flash, SOMATOM Drive) 0.25 s (SOMATOM Force) • Temporal resolution: 75 ms (SOMATOM Definition Flash, SOMATOM Drive) 66 ms (SOMATOM Force) • Slice/Collimation: 2 x 128 x 0.6 mm (SOMATOM Definition Flash, SOMATOM Drive) 2 x 192 x 0.6 mm (SOMATOM Force) • Scan direction cranio-caudal	• Axial reconstruction within the ECG trigger window, commonly BestDiast • Field of view limited to the heart • Slice thickness: 3 mm • Increment: 1.5 mm • WFBP Reconstruction (filtered back projection) Convolution kernel: B35f (SOMATOM Definition Flash, SOMATOM Drive) Qr36 (SOMATOM Force)

3. Test Bolus

General	Data Acquisition
A series of sequential scans to monitor the arrival of the bolus to generate a time density curve. The peak of the curve is then used to determine the scanning delay for the CTA acquisition. Scans are set up at the level of ascending aorta at the level of the carina. The region of interest (ROI) is placed within the ascending aorta. A small bolus of contrast plus saline chaser is injected at the same flow rate that will be used for CTA acquisition.	• Delay: 10 s • Ref. kVp: 100 kVp • Qual. ref. mAs: 24 mAs • Slice/Collimation: 1 x 10 mm • No. of scans: 15 But can be suspended when the bolus has passed through the region

3.1. Alternatively, CARE Bolus

General	Data Acquisition
CARE Bolus (automatic bolus tracking) monitors the attenuation within the vessel of interest (ascending aorta). Scans are set up at the level of ascending aorta at the level of the carina. The full dose of contrast media is injected at the decided flow rate. The CTA acquisition is automatically triggered when the vessel enhancement reaches the pre-defined HU level (100- 150HU) above the baseline. See "Contrast Protocols" for customers' best practice.	• Delay: 10 s • Ref. kVp: 100 kVp • Qual. Ref. mAs: 24 mAs • Slice/Collimation: 1 x 10 mm

4. Prospective Adaptive Triggered Sequential Coronary CT Angiography (Heart Rates: up to 80 bpm)

General	Data Acquisition	Data Reconstruction
General ECG triggered Dual Source data acquisition of the heart. Scan range of 12-15 cm from the carina to the apex of the heart. Use unenhanced CaSc CT data for planning if available. kV will be automatically selected by CARE kV. Use TrueStack reconstructions.	**If Test Bolus was used:** • Delay: time-to-peak value in s • Ref. kVp: 100 kVp * • Qual. Ref. mAs: 380 mAs (Flash) 300 mAs (Drive) 300 mAs (Force) • Slice/Collimation: 2 x 128 x 0.6 mm (Flash, Drive) 2 x 192 x 0.6 mm (Force) • CARE kV: on • CARE Dose4D™: on • ECG Pulsing: auto • Scan direction craniocaudal • Rotation time: 0.28 s (Flash, Drive) 0.25 s (Force) • Temporal resolution: 75 ms (Flash, Drive) 66 ms (Force • Scan window: **Stable HR** HR < 65 bpm: 70% HR < 70 bpm: 65%-75% HR > 70 bpm: 35%-75% HR > 80 bpm: 30%-40% **Arrhythmic HR** (e.g. atrial fibrillation) HR < 70 bpm: 250ms-450ms HR > 70 bpm: 200ms-400ms * If the patient has high calcium or stents consider the Care kV setting to 'Semi' or adjust the kV to 120	• Axial reconstruction within the ECG trigger window, commonly BestDiast. Choose BestSyst and Millisecond unit for arrhythmic heart rates. • Field of view limited to the heart • Slice thickness: 0.6 mm • Increment: 0.4 mm • TrueStack: on • Medium smooth convolution kernel with either filltered back projection: B26f Or iterative reconstruction (e.g. SAFIRE/ADMIRE, strength ≤ 2) • If the patient has high calcium consider a sharper convolution kernel: B46f (Flash, Drive) and Bv49 (Force)

4.1. Alternatively, Flash/ Turbo Flash Cardio (Heart Rates: Below 62 bpm (Flash/Drive), below 66 bpm (Force), stable HR)

General	Data Acquisition	Data Reconstruction
High pitch ("Flash" "Turbo Flash") single heart beat acquisition. Scan range of 12-15 cm from the carina to the apex of the heart. Use unenhanced CaSc CT data for planning if available. kV will be automatically selected by CARE kV.	**If Test Bolus was used:** • Delay: time-to-peak value in s • Ref. kVp: 100 kVp * • Qual. ref. mAs: 380 mAs (Flash) 300 mAs (Drive) 300 mAs (Force) • Slice/Collimation: 2 x 128 x 0.6 mm (Flash, Drive) 2 x 192 x 0.6 mm (Force) • CARE kV: on * • CARE Dose4D™: on • ECG Pulsing: auto • Scan direction cranio-caudal • Rotation time: 0.28 s (Flash, Drive) 0.25 s (Force) • Temporal resolution: 75 ms (Flash, Drive) 66 ms (Force) • Pitch: 3.4 (Flash, Drive) 3.2 (Force) * If the patient has high calcium or stents consider the Care kV setting to 'Semi' or adjust the kV to 120.	• Axial reconstruction Field of view limited to the heart • Slice thickness: 0.6 mm • Increment: 0.4 mm • Medium smooth convolution kernel with either filtered back projection: B26f (Flash, Drive) Bv40 (Force) Or iterative reconstruction (e.g. SAFIRE ADMIRE, strength ≤ 2) • If the patient has high calcium consider a sharper convolution kernel: B46f (Flash, Drive) and Bv49 (Force)

5. Contrast Protocol

General	Parameter	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.	**Test Bolus** • CM Bolus: 10-15mL • Saline chaser: 40-50mL • Flow rate: 4-5mL/s (same as during CTA Acquisition) **cCTA** (Generally:) • Iodine Concentration: • 300-370mg Iodine/mL • Contrast Volume: 50-80mL • Saline Volume: 50mL • Flow rate: 4-5mL/s	

4. Siemens SOMATOM Definition AS+ & Edge

Siemens SOMATOM Definition AS+ and Edge are single source systems allowing for a temporal resolution of 166 ms and optionally 150 ms and 142 ms, respectively, when rotation times of 300 ms and 285 ms are employed.

1. Topogram

General	Data Acquisition (default)	Patient Preparation
AP topogram covering the chest.	• Ref. kVp: 120 kVp • Qual. ref. mAs: 35 mAs • Slice/Collimation: 6 x 0.6 mm • Length: 512 mm	• Patient positioning: The following technique provides patient comfort and optimal image quality for the study: – Head or feet first, supine with head, knees, and lower legs supported by appropriate accessories. – Arms raised above the head, resting comfortably on the head-arm support. – The torso of the patient must be straight, not rotated. – Torso in the middle of the scan field, centered with the help of the laser light markers. • Place ECG-electrodes, as anatomically depicted on the labeled electrodes and IV access in accordance with institutional policies. Recommendation: 18-gauge or larger intravenous needle in the right antecubital vein. Automated contrast injection using a dual-cylinder injector. • Provide enough time for the patient to practice breath hold prior to acquisition. To avoid breathing motion artifacts, the patient is instructed not to breathe and swallow during the acquisition. It is necessary to observe the ECG behavior during the breath hold procedure. The heart rate may decrease during the initial seconds of breath-holding or increase if the patient is straining to hold his breath at the end of the scan.

2. CaSc (optional) – Non-contrast Examination

General	Data Acquisition	Data Reconstruction
Scan range of 12-15 cm from the carina to the apex of the heart. Can be used for subsequent contrast-enhanced data acquisition. Can be used to rule out the presence of excessive calcification, which may reduce the diagnostic accuracy of the CTA study.	• Prospective ECG-triggering • Ref. kVp: 120 kVp • Qual. ref. mAs: 40 mAs • CARE kV: semi • CARE Dose4D™: on • Rotation time: 0.30 s (SOMATOM Definition AS+) 0.28 s (SOMATOM Definition Edge) • Temporal resolution: 150 ms (SOMATOM Definition AS+) 142 ms (SOMATOM Definition Edge) • Slice/Collimation: 128 x 0.6 mm • Scan direction cranio-caudal	• Axial reconstruction within the ECG trigger window, commonly BestDiast • Field of view limited to the heart • Slice thickness: 3 mm • Increment: 1.5 mm • WFBP Reconstruction (Filtered Backprojection) Convolution kernel: B35f

3. Test Bolus

General	Data Acquisition
A series of sequential scans to monitor the arrival of the bolus to generate a time density curve. The peak of the curve is then used to determine the scanning delay for the CTA acquisition. Scans are set up at the level of ascending aorta at the level of the carina. The region of interest (ROI) is placed within the ascending aorta. A small bolus of contrast plus saline chaser is injected at the same flow rate that will be used for CTA acquisition.	• Delay: 10 s • Ref. kVp: 100 kVp • Qual. ref. mAs: 30 mAs • Slice/Collimation: 1 x 10 mm • No. of scans: 15 But can be suspended when the bolus has passed through the region

3.1. Alternatively, CARE Bolus

General	Data Acquisition
CARE Bolus (automatic bolus tracking) monitors the attenuation within the vessel of interest (ascending aorta). Scans are set up at the level of ascending aorta at the level of the carina. The full dose of contrast media is injected at the decided flow rate. The CTA acquisition is automatically triggered when the vessel enhancement reaches the pre-defined HU level (100- 150HU) above the baseline.	• Delay: 10 s • Ref. kVp: 100 kVp • Qual. Ref. mAs: 30 mAs • Slice/Collimation: 1 x 10 mm

4. Prospective Adaptive Triggered Sequential Coronary CT Angiography (Heart Rates: up to 70 bpm)

General	Data Acquisition	Data Reconstruction
General ECG triggered data acquisition of the heart. Scan range of 12-15 cm from the carina to the apex of the heart. Use unenhanced CaSc CT data for planning if available. kV will be automatically selected by CARE kV. Use TrueStack reconstructions.	**If Test Bolus was used:** • Delay: time-to-peak value in s • Ref. kVp: 100 kVp • Qual. Ref. mAs:190 mAs (AS+) 150 mAs (Edge) • Slice/Collimation: 128 x 0.6 mm • CARE kV: on * • CARE Dose4D™: on • ECG Pulsing: auto • Scan direction craniocaudal • Rotation time: 0.30 s (AS+) 0.28 s (Edge) • Temporal resolution: 150 ms (AS+) 142 ms (Edge) • Scan window: **Stable HR** HR < 70 bpm: 60%-80% **Arrhythmic HR** (e.g. atrial fibrillation) HR < 70 bpm: 200-400 ms For HRs > 70 bpm switch to retrospective gated cCTA with same parameter settings * If the patient has high calcium or stents consider the Care kV setting to 'Semi' or adjust the kV to 120	• Axial reconstruction within the ECG trigger window, commonly BestDiast. Choose BestSyst and Millisecond unit for arrhythmic heart rates • Field of view limited to the heart • Slice thickness: 0.6 mm • Increment: 0.4 mm • TrueStack: on • Medium smooth convolution kernel with either filltered back projection: B26f Or iterative reconstruction (e.g. SAFIRE/ADMIRE, strength ≤ 2) • If the patient has high calcium consider a sharper convolution kernel

5. Contrast Protocol

General	Parameter	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.	**Test Bolus** • CM Bolus: 10-15mL • Saline chaser: 40-50mL • Flow rate: 4-5mL/s (same as during CTA Acquisition) **cCTA** (Generally:) • Iodine Concentration: • 300-370mg Iodine/mL • Contrast Volume: 50-80mL • Saline Volume: 50mL • Flow rate: 4-5mL/s	

5. Siemens SOMATOM go.Top

Siemens SOMATOM go.Top is a single source system allowing for a temporal resolution of 165 ms, when rotation times of 330 ms are employed.

1. Topogram

General	Data Acquisition (default)	Patient Preparation
AP topogram covering the chest.	• Sn100 kV; 60 mA • Scan mode: ScanplanningTopoAdultSn • Length: 512 mm	• Patient positioning: The following technique provides patient comfort and optimal image quality for the study: – Head or feet first, supine with head, knees, and lower legs supported by appropriate accessories. – Arms raised above the head, resting comfortably on the headarm support. – The torso of the patient must be straight, not rotated. – Torso in the middle of the scan field, centered with the help of the laser light markers. • Place ECG-electrodes, as anatomically depicted on the labeled electrodes and IV access in accordance with institutional policies. Recommendation: 18-gauge or larger intravenous needle in the right antecubital vein. Automated contrast injection using a dual-cylinder injector. • Provide enough time for the patient to practice breath hold prior to acquisition. To avoid breathing motion artifacts, the patient is instructed not to breathe and swallow during the acquisition. It is necessary to observe the ECG behavior during the breath hold procedure. The heart rate may decrease during the initial seconds of breath-holding or increase if the patient is straining to hold his breath at the end of the scan.

2. CaSc (optional) – Non-contrast Examination

General	Data Acquisition	Data Reconstruction
Scan range of 12-15 cm from the carina to the apex of the heart . Can be used for subsequent contrastenhanced data acquisition. Can be used to rule out the presence of excessive calcification, which may reduce the diagnostic accuracy of the CTA study.	• Prospective ECG-triggering • CARE Dose4D™ & CARE kV: Manual kV • Qual. ref. mAs @ 120 kV: 20 mAs • Scan mode: CardiacSequenceAdult • Scan direction cranio-caudal	• Axial reconstruction within the ECG trigger window, commonly BestDiast • Field of view limited to the heart • Slice thickness: 3 mm • Increment: 1.5 mm • WFBP Reconstruction (Filtered Backprojection) Convolution kernel: Qr36

3. Test Bolus

General	Data Acquisition
A series of sequential scans to monitor the arrival of the bolus to generate a time density curve. The peak of the curve is then used to determine the scanning delay for the CTA acquisition. Scans are set up at the level of ascending aorta at the level of the carina. The region of interest (ROI) is placed within the ascending aorta. A small bolus of contrast plus saline chaser is injected at the same flow rate that will be used for CTA acquisition.	• Delay: 8 s • CARE Dose4D™ & CARE kV: Manual kV • Qual. ref. mAs @ 120 kV: 20 mAs • Slice/Collimation: 1 x 10 mm • Scan mode: BolusSequenceAdult2d • No. of scans: 15 • Cycle time: 1.5 s But can be suspended when the bolus has passed through the region

3.1. Alternatively, CARE Bolus

General	Data Acquisition
CARE Bolus (automatic bolus tracking) monitors the attenuation within the vessel of interest (ascending aorta). Scans are set up at the level of ascending aorta at the level of the carina. The full dose of contrast media is injected at the decided flow rate. The CTA acquisition is automatically triggered when the vessel enhancement reaches the pre-defined HU level (100- 150HU) above the baseline.	• Delay: 10 s • CARE Dose4D™ & CARE kV: Manual kV • Qual. ref. mAs @ 120 kV: 20 mAs • Slice/Collimation: 1 x 10 mm • Scan mode: BolusSequenceAdult2d

4. Coronary CT Angiography (Heart Rates: up to 70 bpm)

General	Data Acquisition	Data Reconstruction
General ECG triggered data acquisition of the heart. Scan range of 12-15 cm from the carina to the apex of the heart. Use unenhanced CaSc CT data for planning if available. kV will be automatically selected by CARE kV.	**If Test Bolus was used:** • Delay: time-to-peak value in s + 3 s • CARE Dose4D™ & CARE kV*: Full • Qual. Ref. mAs @ 120 kV: 70 mAs + different geometry of systems • Scan mode: CardiacSpiralAdultAngio • ECG Pulsing: Standard • Pulsing window: Stable HR HR < 70 bpm: 65%-85% HR > 70 bpm: 30%-80% Arrhythmic HR (e.g. atrial fibrillation) 250-450 ms * If the patient has high calcium or stents consider the CARE kV setting to 'Manual kV' or adjust the kV to values equal to 120 kV. Additionally define the minimum voltage for CARE kV in the scan protocol assistant to be 80 kV for adults.	Axial reconstruction within the ECG trigger window, commonly BestDiast. Choose BestSyst and Millisecond unit for arrhythmic heart rates • Field of view limited to the heart • Slice thickness: 0.8 mm • Increment: 0.5 mm • Medium smooth convolution kernel with either filtered back projection: Bv40 or iterative reconstruction (e.g. SAFIRE/ADMIRE, strength ≤ 2) • If the patient has high calcium consider a sharper convolution kernel (Bv49) • Enable TrueStack option to be switched on

5. Contrast Protocol

General	Data Acquisition
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.	**Test Bolus** • CM Bolus: 10-15mL • Saline chaser: 40-50mL • Flow rate: 4-5mL/s (same as during CTA Acquisition) **cCTA** (Generally:) • Iodine Concentration: • 300-370mg Iodine/mL • Contrast Volume: 50-80mL • Saline Volume: 50mL • Flow rate: 4-5mL/s

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