CT Acquisition and Reconstruction Techniques for Transcatheter Aortic Valve Procedure Planning Utilizing Siemens Healthineers Hardware

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WARNING: *Any reference to X–ray exposure, intravenous contrast dosage, and other medication is intended as a reference guideline only. The guidelines in this document do not substitute for the judgment of a health care provider. Each scan requires medical judgment by the health care 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.*

NOTE: *Algorithms/protocols included in this paper are for educational reference only. The authors do not endorse or support any one specific algorithm/protocol. It is up to each individual clinician and institution to select the treatment that is most appropriate.*

Philipp Blanke, MD is a paid consultant for Edwards Lifesciences

Introduction

Transcatheter aortic valve procedures have proven to be an effective alternative in the treatment of severe symptomatic aortic stenosis. Contrast-enhanced computed tomography (CT) has become an integral part of transcatheter aortic valve procedure planning by allowing for anatomical assessment of the aortic root and the aorto-iliofemoral vasculature within a single examination. It is critical that artifact-free image data is obtained to allow for reliable anatomical measurements. Data acquisition strategies and scanning protocols may vary depending on scanner manufacturer, system, and institutional preferences. This document provides recommendations for reliable CT image acquisition for transcatheter aortic valve procedures.

Work–Flow Rationale

The key component of all approaches is an ECG-assisted data acquisition that covers at least the aortic root, while the remainder of the data acquisition may be performed without ECG-assistance. If employed properly, ECG assistance allows for artifact-free depiction of the aortic root. The sequence of patient preparation and the relevant principles of CT data acquisition will be explained in brief below.

Patient Preparation

- Position the patient, typically supine, on the scanner table to closely resemble cath lab table positioning. This is important for the prediction of C-arm angulation from the CT dataset.
- Place ECG-electrodes and IV access in accordance with institutional policies.
- Provide time for the patient to practice the breath hold prior to scan acquisition to improve patient compliance and thereby scan quality.
- Allow additional scanning and instruction time as needed due to the advanced age and frailty of this patient population.

CT Scan – Scan Length and Scan Strategy

In general, two different approaches are used to combine the ECG-assisted data acquisition of the aortic root structures and the non-ECG-assisted computed tomography angiography (CTA) of the aorto/ilio/femoral vasculature for evaluation of the transfemoral access route:

1) Cardiac ECG-assisted data acquisition of the heart and aortic root (usually beginning 2cm below the carina) followed by a non-ECG-assisted CTA of the thorax, abdomen, and pelvis. Although this approach results in repeat data acquisition of the aortic root and cardiac structures, the time-intensive ECG-assisted data acquisition is kept to a minimum that aids in limiting the contrast dose. Furthermore, by limiting the ECG-assisted data acquisition this decreased the radiation dose-intensive portion of the examination, although the cardiac scan range is covered twice. The proposed protocols for all Siemens scanner families use this approach.

2) ECG-assisted data acquisition of the thorax followed by a non-ECG-assisted CTA of the abdomen and pelvis. The disadvantage of this approach is the relatively long acquisition time required for the entire thorax (may exceed 15 seconds), which increases the risk of breathing artifacts at the level of the cardiac structures.

SIEMENS SOMATOM DEFINITION FLASH / DRIVE AND SOMATOM FORCE

Siemens SOMATOM Flash / Drive and Siemens SOMATOM Force systems are Dual-Source CT systems allowing for a heart rate independent temporal resolution of 75 msec and 66 msec, respectively.

1. Topogram

General

- AP topogram covering the thorax, abdomen, and pelvis including the proximal femoral to the lesser trochanter

Data acquisition

- Manufacturers' default setting

2. CaSc (optional)

General

- Can be used for visualization of annular calcification
- Can be used for planning of subsequent contrast-enhanced data acquisition

Data acquisition

- Prospective ECG-triggered sequential acquisition
- Default trigger in end-systole with a +300ms start- and end phase.
- Scan direction cranio-caudal
- *SW version syngo CT VB10 / VB20:*
- CARE KV: ON, (Dose saving optimized for "bone/calcium"), Ref. kVp: 120 kVp, Ref. mAs: 80 mAs/rot,
  all other SW versions
- CARE KV: Off, Ref. kVp: 120 kVp, CARE dose 4D: On, Ref. mAs: 80 mAs/rot

Data reconstruction

- Axial reconstruction within the pulsing window at the same cardiac phase of +300ms
- Field of view limited to the heart, Slice thickness: 3.mm, Increment: 1.5 mm
- *SW version syngo CT VB10 / VB20:*
- Convolution kernel: Sa36 (Flash / Drive / Force)
  all other SW versions
- Convolution kernel: B35f (Flash), Qr36 (Drive / Force)

3. Premonitoring for Bolus tracking (CARE Bolus)

General

- Plan location of pre-monitoring on topogram: 2 cm below carina. Alternatively plan pre-monitoring using the CaSc CT images, Pre-monitoring should transect through ascending aorta; Place region of interest (ROI) within the ascending aorta

Data acquisition

- Manufacturers' default setting

4. Monitoring for Bolus tracking (CARE Bolus)

General

- Same location as pre-monitoring; Threshold: Change of 100HU to trigger retrospective ECG-gated spiral data acquisition

Data acquisition (manufacturers' default settings)

- Delay: 6s

SIEMENS SOMATOM DEFINITION FLASH / DRIVE AND SOMATOM FORCE (Cont)

5. Retrospective ECG-gated spiral data acquisition – Contrast enhanced

General

- ECG-gated dual source spiral data acquisition of the aortic root and heart
- Plan data acquisition on topogram: Scan range beginning 2 cm below the carina to the apex of the heart
- Use unenhanced CaSc CT data for planning if available

Data acquisition

- Delay after monitoring has reached threshold: 7 seconds
- Breath hold command: Inspiration only
- CARE KV: On (Dose saving optimized for "vascular") Ref. kVp: 100 kVp, Ref. mAs: 280 mAs/rot
- ECG spiral pulsing (dose modulation throughout cardiac cycle): Off
- Scan direction: Cranio-caudal,
- Pitch: automatic (adaption to heart rate)

Data reconstruction

- Axial multiphasic reconstruction covering the entire cardiac cycle, 5 or 10% intervals in sinus rhythm, 50 msec intervals in atrial fibrillation (Use ECG editing if necessary)
- Field of view limited to the heart
- Slice thickness: 0.75 mm, Increment: 0.5 mm
- *SW version syngo CT VB10 / VB20:*
- Convolution kernel with either filtered back projection Bv38 (Flash/Drive), Bv40 (Force) or iterative reconstruction (e.g. ADMIRE, strength 3)
  all other SW versions
- Convolution kernel with either filtered back projection B26f (Flash), Bv38 (Drive), Bv40 (Force) or iterative reconstruction (e.g. ADMIRE, strength 3)

6. High-pitch CTA of the thorax, abdomen, pelvis – Contrast enhanced

General

- High-pitch ("Flash") dual source data acquisition of the thorax, abdomen, and pelvis
- Scan range: Upper thoracic aperture to the proximal femoral (lesser trochanter)

Data acquisition

- Delay 5 s (minimum delay; needed for repositioning the patient table and adjusting the tube-detector system)
- No additional automated breath hold command; alternatively, manual instruction to slowly exhale.
- CARE KV: On (Dose saving optimized for "vascular") • Ref. kVp: 100 kVp Reference tube current: 200 mAs/rot
- Pitch: 3.4 (Flash/Drive) 3.2 (Force)

Data reconstruction

- Axial reconstructions, Slice thickness: 0.75 mm, Increment: 0.5 mm
- *SW version syngo CT VB10 / VB20:*
- Convolution kernel with either filtered back projection Bv38 (Flash/Drive), Bv40(Force) or iterative reconstruction (e.g. ADMIRE, strength 3)
  all other SW versions
- Convolution kernel with either filtered back projection B26f (Flash), Bv38 (Drive), Bv40 (Force) or iterative reconstruction (e.g. ADMIRE, strength 3)

Contrast application protocol

General

- Single contrast application for both the retrospectively ECG-gated CTA of the aortic root/heart and the CTA of the thorax/abdomen/pelvis
- Placement of an IV access in an antecubital vein (an 18-guage IV typically provides the highest safety)
- Automated contrast injection using a dual-cylinder injector

Specific

- Contrast bolus monitoring and timing of data acquisition by means of bolus tracking at the level of the ascending aorta with an ROI placed within the ascending aorta; threshold set at 100 HU above baseline, delay to start of data acquisition after reaching threshold 6 sec. The proposed delay can be considered a default setting and may be increased in patients with poor ejection fraction. This may help prevent the high pitch spiral acquisition from outrunning the bolus

SIEMENS SOMATOM DEFINITION AS64, AS+, Edge, Edge+

Siemens SOMATOM Definition AS64, AS+, Edge and Edge+ are single-source CT systems for a heart rate independent temporal resolution of between 142 msec and 150 msec, when rotation times of 300 msec and 285 msec are employed.

1. Topogram

General

- AP topogram view covering the thorax, abdomen, and pelvis including the proximal femoral to the lesser trochanter

Data acquisition

- Manufacturers' default setting

2. CaSc (optional)

General

- Can be used for visualization of annular calcification
- Can be used for planning of subsequent contrast-enhanced data acquisition

Data acquisition

- Prospective ECG-triggered sequential acquisition.
- Default trigger in end-systole with a +300 ms start- and end phase.
- Scan direction cranio-caudal
- *SW version syngo CT VB10 / VB20:*
- CARE KV: ON, (Dose saving optimized for "bone/calcium"), Ref. kVp: 120 kVp, Ref. mAs: 40 mAs/rot,
  all other SW versions
- CARE KV: Off, Ref. kVp: 120 kVp, CARE dose 4D: On, Ref. mAs: 40 mAs/rot

Data reconstruction

- Axial reconstruction within the pulsing window at the same cardiac phase of +300ms
- Field of view limited to the heart, Slice thickness: 3.mm, Increment: 1.5 mm
- *SW version syngo CT VB10 / VB20:*
- Convolution kernel: Sa36
  all other SW versions
- Convolution kernel: B35f

3. Pre-monitoring for Bolus tracking (CARE Bolus)

General

- Plan location of pre-monitoring on topogram: 2 cm below carina
- Alternatively plan premonitoring using the CaSc CT data.
- Pre-monitoring should transect through ascending aorta. Place ROI within the ascending aorta

Data acquisition

- Manufacturers' default setting

4. Monitoring for Bolus tracking (CARE Bolus)

General

- Same location as pre-monitoring , threshold: Change of 130HU to trigger retrospective ECG-gated spiral data acquisition

Data acquisition (manufacturers' default settings)

- Delay: 6 s

5. Retrospective ECG-gated spiral data acquisition – Contrast enhanced

General

- ECG-gated data acquisition of the aortic root and heart Plan data acquisition on topogram: Scan range beginning 2 cm below the carina to the apex of the heart
- Use unenhanced CaSc CT data for planning if available

Data acquisition

- Delay after monitoring has reached threshold: 7 seconds
- Breath hold command: Inspiration only
- CARE KV: ON (Dose saving optimized for "vascular") Ref. kVp: 100 kVp, Ref. mAs: 140 mAs/rot
- ECG spiral pulsing (dose modulation throughout cardiac cycle): Off
- Scan direction: Cranio-caudal,
- Pitch: automatic (adaption to heart rate)

Data reconstruction

- Axial multiphasic reconstruction covering the entire cardiac cycle, 5 or 10% intervals in sinus rhythm, 50 msec intervals in atrial fibrillation (Use ECG editing if necessary)
- Field of view limited to the heart,
- Slice thickness: 0.75 mm, Increment: 0.5 mm
- *SW version syngo CT VB10 / VB20:*
- Convolution kernel with either filtered back projection Bv38 or iterative reconstruction (e.g. ADMIRE, strength 3)
  all other SW versions
- Convolution kernel with either filtered back projection B26f or iterative reconstruction (e.g. ADMIRE, strength 3)

6. CTA of the thorax/abdomen/pelvis – Contrast enhanced

General

- Scan range: Upper thoracic aperture to the proximal femoral (lesser trochanter)

Data acquisition

- Non-gated single source spiral data acquisition with a pitch > 1.2
- Delay 5s (minimum delay; needed for repositioning of the patient table and adjusting the tube-detector system)
- No additional automated breath hold command; alternatively, manual instruction to slowly exhale.
- CARE KV: On (Dose saving optimized for "vascular") Ref. kVp: 100 kVp, Ref. mAs: 140 eff mAs
- Scan direction: Cranio-caudal

Data reconstruction

- Axial reconstructions Slice thickness: 0.75 mm Increment: 0.5 mm
- SW version syngo CT VB10 / VB20:
- Convolution kernel with either filtered back projection Bv38 or iterative reconstruction (e.g. ADMIRE, strength 3)
  all other SW versions
- Convolution kernel with either filtered back projection B26f or iterative reconstruction (e.g. ADMIRE, strength 3)

SIEMENS SOMATOM go.Top and X.Cite

Siemens SOMATOM X.Cite and go.Top are single-source CT systems for a heart rate independent temporal resolution between 150 msec and 165 msec, when rotation times of 300 msec and 330 msec are employed. As these systems are built on a novel software platform Somaris X, some of the technical nomenclature has changed and therefore these systems are discussed in a separate fashion.

Note: *Both systems are shipped with software version syngo CT VB30, which contain an ex-factory default protocol suitable for TAVI scanning ("TAVI [factory"]).*

1. Topogram

General

- AP topogram view covering the thorax, abdomen, and pelvis including the proximal femoral to the lesser trochanter

Data acquisition

- Manufacturers' default setting

2. CaSc (optional)

General

- Can be used for visualization of annular calcification
- Can be used for planning of subsequent contrast-enhanced data acquisition

Data acquisition

- Prospective ECG-triggered sequential acquisition.
- Default trigger in end-systole with +350 ms start- and end phase.
- Scan direction cranio-caudal
- CARE Dose4D & CARE kV: Full, (CARE kV optimized for "bone/calcium"), Ref. kVp: n.a., CARE kV Quality ref. mAs @120 kV: 20 eff mAs (go.Top), 26 eff mAs (X.Cite)

Data reconstruction

- Axial reconstruction within the pulsing window at the same cardiac phase of +300ms
- Field of view limited to the heart, Slice thickness: 3.mm, Increment: 1.5 mm
- Convolution kernel: Sa36

3. Pre-monitoring for Bolus tracking (CARE Bolus)

General

- Plan location of pre-monitoring on topogram: 2 cm below carina
- Alternatively plan pre-monitoring using the CaSc CT data. Pre-monitoring should transect through ascending aorta. Place ROI within the ascending aorta

Data acquisition

- Manufacturers' default setting

4. Monitoring for Bolus tracking (CARE Bolus)

General

- Same location as pre-monitoring, threshold: Change of 130 HU to trigger retrospective ECG-gated spiral data acquisition.

Data acquisition (manufacturers' default settings)

- Delay: 6 s

SIEMENS SOMATOM go.Top and X.Cite (Cont)

5. Retrospective ECG-gated spiral data acquisition – Contrast enhanced

General

- ECG-gated data acquisition of the aortic root and heart Plan data acquisition on topogram: Scan range beginning 2 cm below the carina to the apex of the heart
- Use unenhanced CaSc CT data for planning if available

Data acquisition

- Delay after monitoring has reached threshold: 7 seconds
- Breath hold command: Inspiration only
- CARE Dose4D & CARE kV: Full, (CARE kV optimized for "vascular"), Ref. kVp: n.a., CARE kV Quality ref. mAs @120 kV: 60 eff mAs (go.Top), 78 eff.mAs (X.Cite)
- ECG spiral pulsing (dose modulation throughout cardiac cycle): Off
- Scan direction: Cranio-caudal,
- Pitch: automatic (adaption to heart rate)

Data reconstruction

- Axial multiphasic reconstruction covering the entire cardiac cycle, 5 or 10% intervals in sinus rhythm, 50 msec intervals in atrial fibrillation (Use ECG editing if necessary)
- Field of view limited to the heart,
- Slice thickness: 0.8 mm, Increment: 0.5 mm
- Convolution kernel with either filtered back projection Bv40 or iterative reconstruction (e.g. ADMIRE, strength 3)

6. CTA of the thorax/abdomen/pelvis – Contrast enhanced

General

- Scan range: Upper thoracic aperture to the proximal femoral (lesser trochanter)

Data acquisition

- Non-gated single source spiral data acquisition with a pitch > 1.2
- Delay 5s (minimum delay; needed for repositioning of the patient table and adjusting the tube-detector system)
- No additional automated breath hold command; alternatively, manual instruction to slowly exhale.
- CARE Dose4D & CARE kV: Full, (CARE kV optimized for "vascular"), Ref. kVp: n.a., CARE kV Quality ref. mAs @120 kV: 60 eff mAs (go.Top), 78 eff.mAs (X.Cite)
- Scan direction: Cranio-caudal

Data reconstruction

- Axial reconstructions Slice thickness: 0.75 mm Increment: 0.5 mm
- Convolution kernel with either filtered back projection Bv40 or iterative reconstruction (e.g. ADMIRE, strength 3)

MISC

LOW-CONTRAST DOSE PROTOCOL – RATIONALE FOR ALL SCANNER TYPES

- Same scanner settings as listed above, except the threshold setting for bolus tracking
- Reduce scan length of the retrospectively ECG-gated CTA to a minimum to cover only the aortic root as opposed to the entire heart, as this is the time-intensive part in regard to data acquisition
- Injection rate might be lowered
- Threshold to trigger initiation of the retrospective ECG-gated spiral data acquisition can be lowered to 80 HU
- Systems with the capability of low kV data acquisition (70kV - 90kV, Force) may allow for reduced iodine delivery rates as low kV data acquisition increases iodine attenuation; CARE KV settings need to be adjusted (Dose saving optimized for "soft tissue").

These alterations should allow for a sufficiently contrast-enhanced CT dataset of the aortic root. Contrast attenuation of the iliofemoral acquisition may be variable.

DOSE MODULATION FOR RETROSPECTIVE ECG-GATED SPIRAL

Data Acquisition

The protocols listed above do not employ dose modulation for the retrospective ECG-gated spiral data acquisition, allowing for image reconstructions throughout the entire cardiac cycle at a constant image noise level. This allows for identifying the reconstruction phase with largest annular dimensions and optimal image quality. If dose modulation is employed, peak dose should be applied during systole with a pulsing window set to 5 – 40%. MinDose should not be used, as this renders images non-interpretable outside of the pulsing window.

Contrast application protocol

General	Specific
• Single contrast application for both the retrospectively ECG-gated CTA of the aortic root/heart and the CTA of the thorax/abdomen/pelvis • Placement of IV access in an antecubital vein (an 18-guage IV typically provides the highest safety) • Automated contrast injection using a dual-cylinder injector	• Contrast bolus monitoring and timing of data acquisition by means of bolus tracking at the level of the ascending aorta with a ROI placed within the ascending aorta; threshold set at 100 HU above baseline, delay to start of data acquisition after reaching threshold 7 sec

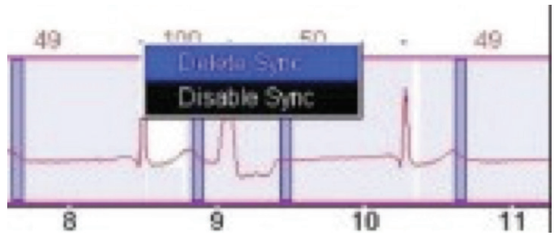
RECONSTRUCTION OF MULTIPHASIC DATA SET

Multiphasic ("dynamic", "cine") data sets can be reconstructed using a relative approach (percentage intervals [%] between two R-peaks) or an absolute approach (fixed distance of the reconstruction window from the R-peak, reported as [msec]).

The relative approach (e.g. 5 or 10% intervals) performs well in regular sinus rhythm. In case of increased heart rate variability, atrial fibrillation, or ectopic beats, absolute reconstruction should be employed (e.g. 50 msec) in combination with ECG-editing if necessary.

REVIEW OF DATA RECONSTRUCTION AND ECG-EDITING

- Image reconstructions of the aortic root and 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 (dots, also known as "Syncs" should be aligned with R-peaks)
- If R-peaks were not correctly identified, manual correction should be performed (e.g. "Insert Sync" if an R-peak was not identified, or "Delete Sync" if a Sync was placed on anything other than the R-peak; alternatively, Syncs can also be shifted manually)
- In case of ectopic contractions, absolute reconstruction should be used and the Sync of the ectopic beat should be deleted



- If misregistration or stair-step artifacts are present, ECG-editing should be employed with either modification of trigger-points (if they were initially incorrectly identified by the algorithm) or deletion of trigger-points (in premature contraction or atrial fibrillation).

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