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CT angiography for planning transcatheter aortic valve replacement using automated tube voltage selection: Image quality and radiation exposure

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ABSTRACT

Purpose: To assess image quality and accuracy of CT angiography (CTA) for transcatheter aortic valve replacement (TAVR) planning performed with 3rd generation dual-source CT (DSCT).
Material and methods: We evaluated 125 patients who underwent TAVR-planning CTA on 3rd generation DSCT. A two-part protocol was performed including retrospectively ECG-gated coronary CTA (CCTA) and prospectively ECG-triggered aortoiliac CTA using 60 mL of contrast medium. Automated tube voltage selection and advanced iterative reconstruction were applied. Effective dose (ED), signal-to-noise (SNR) and contrast-to-noise ratios (CNR) were calculated. Five-point scales were used for subjective image quality analysis. In patients who underwent TAVR, sizing parameters were obtained.
Results: Image quality was rated good to excellent in 97.6% of CCTA and 100% of aortoiliac CTAs. CTA studies at >100 kV showed decreased objective image quality compared to 70–100 kV (SNR, all $p \leq 0.0459$; CNR, all $p \leq 0.0462$). Mean ED increased continuously from 70 to >100 kV (CCTA: 4.5 ± 1.7 mSv–13.6 ± 2.9 mSv, all $p \leq 0.0233$; aortoiliac CTA: 2.4 ± 0.9 mSv–6.8 ± 2.7 mSv, all $p \leq 0.0414$). In 39 patients TAVR was performed and annulus diameter was within the recommended range in all patients. No severe cardiac or vascular complications were noted.
Conclusion: 3rd generation DSCT provides diagnostic image quality in TAVR-planning CTA and facilitates reliable assessment of TAVR device and delivery option while reducing radiation dose.

1. Introduction

Transcatheter aortic valve replacement (TAVR) has gained acceptance as a minimally invasive therapeutic option for patients with severe aortic stenosis ineligible for surgical valve replacement [1,2]. In order to reduce TAVR-related complications, patients increasingly undergo pre-procedural CT angiography (CTA), currently routinely performed at tube voltages ≥100 kV [3–6]. With current indications radiation concerns are of limited relevance in the TAVR population. However, as the target population for TAVR potentially broadens to increasingly younger patients [7] and impaired renal function is common in TAVR candidates [3], efforts have been made to individually tailor CTA protocols to patient-specific characteristics, in order to optimize image quality, limit radiation exposure, and reduce contrast medium volume [8,9]. With tube voltage reduction proving to be an effective technique to accomplish these goals [9–11], a fully-automated tube voltage selection (ATVS) algorithm has been shown to improve image quality and lower radiation dose [12–14]. ATVS is a fully-automated

Abbreviations: TAVR, transcatheter aortic valve replacement; ATVS, automated tube voltage selection; BMI, body mass index; CCTA, coronary CT angiography; ROI, region of interest; LM, left main coronary artery; LAD, left anterior descending coronary artery; CX, circumflex coronary artery; RCA, right coronary artery; SNR, signal-to-noise ratio; CNR, contrast-to-noise ratio; $CTDI_{vol}$, volume CT dose index 32 cm phantom; DLP, dose-length-product; ED, effective dose.

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algorithm that adjusts tube voltage according to a combination of an individual patient's attenuation profile determined by the scout image, information on the patient habitus, and the examination type [15]. The tube voltage settings range from 70 to 120 kV in 10 kV increments. This radiation dose saving technique is combined with automated tube current modulation which calculates the tube current at each z-axis location based on attenuation information obtained from the scout image. Based on the difference in diameter compared to a reference phantom, the tube current is calculated by the algorithm [16].

However, it has not yet been investigated if image quality parameters remain constant at the different tube voltages.

The purpose of our study was to assess the efficiency of the ATVS algorithm at each tube voltage in patients evaluated for TAVR performed with 3rd generation dual-source CT (DSCT) and to investigate if this imaging algorithm enables reliable planning of the TAVR procedure.

2. Materials and methods

2.1. Patient population

This study was approved by the Institutional Review Board (Medical Ethics Committee) with a waiver of informed consent. We retrospectively analyzed 127 consecutive patients who underwent dedicated TAVR-planning CTA between May 2014 and June 2015.

Patients were excluded if any deviations from the standard scan protocol occurred (n = 2). Due to a limited number of high-kV studies (CCTA: 110 kV, n = 5; 120 kV, n = 17; aortoiliac CTA: 110 kV, n = 7; 120 kV, n = 16) the 110 kV and 120 kV examinations were grouped together for further analysis.

2.2. CT acquisition protocol

All examinations were performed with a 3rd generation DSCT system (SOMATOM Force, Siemens Healthcare, Forchheim, Germany) equipped with a fully-integrated circuit detector system (Stellar Infinity, Siemens) and two x-ray tubes (Vectron, Siemens) with substantially increased power (120 kW each) which allow for low-kV imaging within a broader patient collective [17].

A dedicated two-part acquisition protocol was performed including a retrospectively ECG-gated CCTA to ensure reliable measurement of the end-systolic dimensions of the aortic root [4,8,18,19]. CCTA was immediately followed by a prospectively ECG-triggered high-pitch CTA of the aortoiliac access route, initiated at 35% of the RR-interval using the same contrast medium bolus, i.e., without injecting additional contrast material for CCTA acquisition of the aortoiliac access route. Similarly, both scans were obtained under a single breath hold as the average total scan duration for both acquisitions was only 20 s.

All CTA studies were performed using automated tube current modulation (CARE Dose4D, Siemens) and ATVS (CARE kV, Siemens) with available tube voltage settings ranging from 70 to 120 kV in 10 kV increments. ECG-dependent tube-current modulation ("ECG-pulsing") was not used to enable reliable definition of the end-systolic phase in the often arrhythmic TAVR population [20].

Further scan parameters were as follows: adaptive detector collimation varying from 96 to 192 in increments of 8 × 0.6 mm; gantry rotation, 0.25 s; matrix size, 512 × 512 pixels; and pitch, 1.0 for CCTA and 1.9 for aortoiliac CTA.

As previously proposed [3,6] contrast medium volume was restricted to 60 mL (350 mgI/mL iohexol, Omnipaque, General Electric, Chalfont St. Giles, UK). We used a triphasic protocol [6,21] with an initial injection of 40 mL of undiluted contrast material at a flow rate of 5.0 mL/s, followed by 30 mL of diluted contrast material (2:1 contrast material-to-saline mixture) injected at 3 mL/s, and a 40 mL saline chaser injected at 5 mL/s. No specific per-scan medication was administered.

Scan initiation was determined using bolus-tracking software (CARE Bolus, Siemens). A region of interest (ROI) was placed within the descending aorta at the level of the carina and the scan automatically started 2 s after a threshold of 100 Hounsfield units (HU) was reached.

2.3. Image reconstruction

All studies were reconstructed with advanced modeled iterative reconstruction (ADMIRE, Siemens) at a standard strength level of 3 using a medium-sharp convolution kernel (Bv36), 0.6 mm section thickness, and 0.4 mm increment. CCTA studies were reconstructed in end-systolic and end-diastolic cardiac phase.

2.4. Objective image quality analysis

Dedicated post-processing and evaluation software (syngo.via VA30, Siemens) was used for objective and subjective analysis. All objective image quality measurements were performed by an observer (X.X.X.) with six years of experience in cardiovascular imaging.

For CCTA, attenuation was measured by manually drawing ROIs in the major coronary arteries (left main [LM], left anterior descending [LAD], circumflex [CX], and right coronary artery [RCA]. The ROI diameter was scaled as large as possible). LAD, CX, and RCA measurements were determined within the first 5 mm of the proximal and distal vessel segment. For aortoiliac CTA, attenuation measurements were obtained by drawing ROIs in the thoracic aorta (ascending aorta, aortic arch, descending aorta at the level of the pulmonary trunk and the diaphragm; size, 1.5 cm^2), abdominal aorta (at the level of the renal arteries and right above the bifurcation; size, 1.5 cm^2), and iliofemoral (right and left common and external iliac arteries, right and left common femoral arteries; size, 1.0 cm^2). In cases of severe calcifications, stent material or motion artifacts, segments were excluded from evaluation.

To assess image noise, additional measurements were performed in the left ventricular blood pool for CCTA and to assess contrast we performed further measurements in fat tissue (pericardial fat for CCTA and at the level of the attenuation measurements for aortoiliac CTA (size, 2 cm^2)). Noise was defined as the SD of the ventricular blood pool measurement for CCTA and of the arterial attenuation for aortoiliac CTA.

Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated for each measurement as follows:

$$SNR_{CCTA} = (Attenuation_{coronary\ artery}/SDventricular\ blood\ pool)$$

$$SNR_{aortoiliac\ CTA} = (Attenuation_{aortoiliac\ artery}/SD_{aortoiliac\ artery})$$

$$CNR_{CCTA} = ((Attenuation_{coronary\ artery} - Attenuation_{epicardial\ fat)})/SD_{ventricular\ blood\ pool})$$

$$CNR_{aortoiliac\ CTA} = ((Attenuation_{aortoiliac\ artery} - Attenuation_{fat)})/SD_{aortoiliac\ artery})$$

2.5. Subjective image quality analysis

Subjective image quality was assessed by two readers with six (X.X.X.) and four years (X.X.X.) of experience in cardiovascular imaging. Reviewers were blinded to patient characteristics