High-pitch dual-source CT angiography in patients considered for transcatheter aortic valve replacement using low volume of contrast medium

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Purpose

Transcatheter aortic valve replacement (TAVR) is an emerging minimally invasive procedure in patients with severe aortic valve stenosis who are considered at high risk for surgical treatment [1]. A comprehensive pre-procedural diagnostic workup is essential for careful patient selection and proper TAVR planning [2]. In this context, computed tomography (CT) is increasingly gaining importance as it provides both information about aortic annular sizing for prosthesis deployment and assessment of the aortoiliac access route within a single examination [3].

While designing a CT protocol for TAVR planning, two comorbidities have to be kept in mind which can be frequently found in these patients: atrial fibrillation and chronic renal dysfunction [4]. The former might lead to incorrect aortic root measurements caused by cardiac motion and can be addressed by using a retrospectively ECG-gated scan mode. The latter enhances the risk of acute renal failure and, hence, requires a reduction of contrast medium (CM) volume. Since scan duration is a key parameter of CT angiography (CTA) [5], modern dual-source CT (DSCT) systems might facilitate a substantial decrease of CM volume by scanning the aortoiliac vasculature using a high-pitch data acquisition mode.

Therefore, we sought to investigate the feasibility of a combined CT protocol consisting of a retrospective ECG-gated cardiac CTA immediately followed by a high-pitch scan of the aortoiliac access route using a single low volume CM bolus for planning of TAVR.
Methods and Materials

Patients

Between January 2012 and January 2013, 37 patients who were considered for the TAVR procedure were included in this retrospective analysis. All patients had severe aortic valve stenosis and did not qualify for surgical treatment. In the context of the pre-procedural planning, the aortic root complex, the thoraco-abdominal aorta, and the iliofemoral arteries were evaluated by CTA.

Scan Protocol

All scans were performed on a second generation DSCT system (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany). Initially, a pilot scan of the thorax, abdomen, and pelvis was obtained for planning of the two-part examination: First, the heart was scanned in a caudocranial direction using retrospective ECG-gating. Second, this was immediately followed by a high-pitch CTA of the thoraco-abdominal aorta and the iliofemoral arteries in craniocaudal direction. The second scan was prospectively ECG-triggered and targeted at the 35% interval of the R-R' cycle. No beta blocker for heart rate control was administered according to institutional policy.

The patients were divided into two groups by the volume of CM (320 mgI/mL Visipaque, GE Healthcare, Chalfont St. Giles, UK), that they had received: group A (normal renal function) with a total volume of 70-144 mL of iodinated contrast medium or group B (with serum creatinine >1.5 mg/dL) with 60 mL. All injections were followed by a saline chaser bolus using a dual-syringe injection system (Stellant D, Medrad Inc, Indianola, PA, USA). The cardiac scan was automatically started with a delay of 2 seconds after the attenuation of a region of interest (ROI) placed in the descending aorta reached 100 HU. The detailed scan parameters are summarized and illustrated in Table 1 and Figure 1, respectively.

Image Quality

Intravascular CT attenuation (Hounsfield units, HU) and image noise defined as standard deviation (SD) of CT attenuation were measured by using region of interest (ROI) analysis [6]. Intravascular CT attenuation of the cardiac scan was measured by drawing a circular ROI at 5 different anatomic locations: (C1) pulmonary artery, (C2) left ventricle, (C3) aortic root / left ventricular outflow tract, (C4) ascending aorta, (C5) descending aorta. Intravascular CT attenuation of the aortoiliac scan was measured by drawing circular ROIs at 5 different anatomic locations within the aorta and 6 different anatomic locations within the iliac vasculature: (A1) ascending aorta, (A2) aortic arch, (A3) thoracic descending aorta at the level of pulmonary trunk (descending aorta, level 1), (A4) abdominal aorta at the level of the renal arteries (descending aorta, level 2), and (A5)
above the bifurcation (descending aorta, level 3); (I1,I2) and left and right common iliac arteries, (I3,I4) left and right external iliac arteries, (I5,I6) left and right common femoral arteries (measurements were averaged per vessel segment). The ROI was placed in the center of each structure as large as possible while sparing the vessel wall and avoiding atherosclerotic plaques. Mean arterial attenuation was calculated as the average of the mean attenuation values of the ROIs. At each level, an additional ROI was placed in an adjacent muscle for noise measurement.

Based on these measurements, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) and a figure of merit were calculated on a per level basis as previously described [6-8]:

\[
\text{SNR} = \frac{HU_{\text{vessel}}}{\text{noise}}
\]

\[
\text{CNR} = \frac{(HU_{\text{vessel}} - HU_{\text{muscle}})}{\text{noise}}
\]

\[
\text{FOM} = \frac{\text{CNR}^2}{\text{ED}} \quad \text{[with ED = effective radiation dose]}
\]

In addition, summary scores for attenuation, SNR, and CNR were calculated by averaging the measurements per section: "cardiac" based on C1 - C5, "access route" based on A1 - A5 ("aorta") and I1 - I6 ("iliac arteries").

**Radiation dose**

Dose reports recording volume CT dose index (CTDI\text{VOL}) and dose length product (DLP) were generated automatically after each CT study. The mean effective radiation doses (ED) for both the cardiac scan and thoraco-abdominal scan were calculated by multiplying the DLP by region-specific conversion coefficients based on the recommendations of the European Working Group for Guidelines on Quality Criteria for CT [9, 10]: cardiac, k=0.014 mSv/mGy x cm; thoracoabdominal, k=0.017 mSv/mGy x cm (mean value of the region-specific conversion factors for chest, abdominal, and pelvic acquisitions as previously described [11]).

**Measurements for TAVR planning**

Anatomical parameters of the aortic root were assessed for risk stratification of peri-procedural coronary artery occlusion and accurate prosthesis sizing to avoid aortic rupture and post-interventional paravalvular leakage, as previously described [3]: dimensions of the aortic annulus (at the level of the basal attachments of all three aortic valve cusps), and distances between the aortic valve annulus and the coronary ostia. In addition, minimal diameters of common iliac arteries, external iliac arteries, and the common femoral arteries were assessed at both sides through the use of an automatic vessel tracking tool with manual correction. Window settings were individually adjusted.
Statistical Analysis

All statistical tests were performed using a dedicated software package (SPSS v20.0, SPSS Inc., Chicago, IL). Continuous, normally distributed variables are reported as mean ± SD, whereas continuous, non-normally distributed variables are reported as median and interquartile range (25% - 75% percentile). Nominal data were reported as frequencies and were tested for significant differences by using the chi-square test or Fisher's exact test. Descriptive statistics were applied to all data. Normally distributed variables were tested by student's t-test and non-normally distributed variables were tested by Mann-Whitney-U test for significant differences. The level of significance was defined as a p-value of 0.05.
Table 1: CT Protocol for Combined Assessment of the Aortic Root Complex and the Aortoiliac Access Route in patients eligible for TAVR

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**Fig. 1:** Figure 1 CT topogram for scan planning displaying both scan fields. The yellow box reflects the cardiac CTA in caudocranial direction from the bottom of the heart to the tracheal bifurcation. The black box reflects the immediately following high-pitch CTA of the aortoiliac access route in craniocaudal direction comprising the scan field from the lung apices to the groins.

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Results

Demographics

15 patients received full amounts of contrast medium, while 22 patients had been investigated with 60 mL of CM. Comparison of demographic characteristics showed no significant difference: gender distribution (53.3% female, 63.3% female, p = 0.734), age (78.9 years ± 12.1 years, 82.8 years ± 9.8 years, p = 0.295), body mass index (30.8 kg/m² ± 9.1, 26.4 ± 4.4, p = 0.100).

Image Quality

Table 2 provides an overview of the measurements. Regarding the cardiac CT scan, significantly lower CT attenuation was measured in the pulmonary artery. Evaluating the aortoiliac CTA, significantly lower CT attenuation values were measured in the thoracic segments. However, the summary scores did not result in a significantly lower CT attenuation. There were no significant differences between the two groups when comparing SNR and CNR (Table 2). In addition, the FOM analysis did not result in substantial differences: summary score "cardiac", 10.0 (3.9 - 16.1), 12.9 (4.3 - 30.3), p = 0.290; summary score "iliac arteries", 10.1 (2.4 - 35.7), 8.1 (3.7 - 22.5), p = 0.665.

Radiation Dose

The analysis of the dose reports resulted in an average effective radiation dose of 16.0 mSv ± 7.2 mSv for the cardiac scan and 5.6 mSv ± 6.0 mSv for the high-pitch CT angiography.

TAVR measurements

Aortic root and iliofemoral dimensions could be analyzed in all cases (examples are shown in Figures 2 and 3). The mean cross-sectional area at the level of the aortic annulus was 4.4 cm² ± 1.3 cm². The mean distance between the annulus and the coronary arteries was 15.7 mm ± 2.8 mm (left) and 16.4 mm ± 2.8 mm (right). The average minimal diameters of the iliofemoral arteries were as following: right common iliac artery, 8.3mm ± 2.6mm, right external iliac artery, 7.4 mm ± 1.6 mm, right common femoral artery, 7.0mm ± 1.7mm, left common iliac artery, 8.4 mm ± 2.2mm, left external iliac artery, 7.2 mm ± 1.6mm, left common femoral artery, 7.0 mm ± 1.6mm.
### Table 2: Assessment of objective image parameters

Mean attenuation was measured by using a ROI analysis. Based on these values, signal-to-noise and contrast-to-noise ratios were calculated. Values were provided as median and interquartile range. Significant differences were indicated by bold letters and asterisk.

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Fig. 2: Figure 2 Retrospectively ECG-gated cardiac CT for the assessment of the aortic root complex using a reduced CM volume of 60 mL 3D volume rendering (a). Pre-procedural measurements for prosthesis sizing (annulus plane indicated by the yellow line, b) with assessment of the annulus area (c) and the distance between the annulus and both coronary arteries (d, e).

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**Fig. 3:** Figure 3 High-pitch dual-source CT angiography of the aortoiliac access route for TAVR planning using a reduced CM volume of 60 mL 3D volume rendering of the aortoiliac vasculature (a). The yellow lines indicate the levels of ROI analysis, resulting in a mean attenuation of 262 HU in the descending aorta (b). The mean attenuation between 263 HU and 270 HU in the external iliac arteries (c) allows for the safe assessment of the minimal vessel diameters (d, e).

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Fig. 4: Figure 4 Image quality parameters CT attenuation, SNR, and CNR compared in two anatomical target regions for TAVR planning (summary scores "cardiac" and "iliac arteries"). Statistical analysis did not result in significant differences between the study group (group B) and the control group (group A).

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Conclusion

In TAVR planning, the performance of a combined CT protocol consisting of a retrospectively ECG-gated cardiac CTA immediately followed by a high-pitch scan of the aortoiliac access route is feasible. With this approach, the amount of contrast medium can be considerably reduced by using a single low volume CM bolus without substantial loss of image quality.
References


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