Role of Computed Tomography in Planning the Appropriate X-Ray Gantry for Quantitative Aortography of Post-transcatheter Aortic Valve Implantation Regurgitation

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Background: The clinical robustness of contrast-videodensitometric (VD) assessment of aortic regurgitation (AR) after transcatheter aortic valve implantation (TAVI) has been demonstrated. Correct acquisition of aortic root angiography for VD assessment, however, is hampered by the opacified descending aorta and by individual anatomic peculiarities. The aim of this study was to use preprocedural multi-slice computed tomography (MSCT) to optimize the angiographic projection in order to improve the feasibility of VD assessment.

Methods and Results: In 92 consecutive patients, post-TAVI AR (i.e., left ventricular outflow tract [LVOT] AR) was assessed on aortic root angiograms using VD software. The patients were divided into 2 groups: The first group of 54 patients was investigated prior to the introduction of the standardized acquisition protocol; the second group of 38 consecutive patients after implementation of the standardized acquisition protocol, involving MSCT planning of the optimal angiographic projection. Optimal projection planning has dramatically improved the feasibility of VD assessment from 57.4% prior to the standardized acquisition protocol, to 100% after the protocol was implemented. In 69 analyzable aortograms (69/92; 75%), LVOT-AR ranged from 3% to 28% with a median of 12%. Inter-observer agreement was high (mean difference±SD, 1±2%), and the 2 observers’ measurements were highly correlated (r=0.94, P<0.0001).

Conclusions: Introduction of computed tomography-guided angiographic image acquisition has significantly improved the analyzability of the angiographic VD assessment of post-TAVI AR.

Key Words: Aortic regurgitation; Left ventricular outflow tract aortic regurgitation; Multi-slice computed tomography; Transcatheter aortic valve replacement/implantation; Videodensitometry
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tion and planning of angiographic image acquisition (including identification of the optimal angiographic view before TAVI) are needed. Recently Teng et al reported a method to identify overlap-free projection on fluoroscopy. In the present study, another method of selection of the optimal angiographic view for VD analysis based on pre-procedural multi-slice computed tomography (MSCT) has limitations of visual angiographic assessment of the Sellers et al method and echocardiographic assessment. These retrospective clinical studies, however, have noted only a moderate feasibility of VD assessment due to the non-anticipated overlap of the ROI with other opacified structures.

To improve the feasibility of VD analysis, standardization and planning of angiographic image acquisition (including identification of the optimal angiographic view before TAVI) are needed. Recently Teng et al reported a method to identify overlap-free projection on fluoroscopy. In the present study, another method of selection of the optimal angiographic view for VD analysis based on pre-procedural multi-slice computed tomography (MSCT) has

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**Table. Angiographic Acquisition Protocol for VD**

<table>
<thead>
<tr>
<th>Category / Guideline</th>
<th>Image acquisition environment</th>
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<tbody>
<tr>
<td></td>
<td>With ECG recording†</td>
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<tr>
<td></td>
<td>Image acquisition should take ≥2 beats before contrast injection‡</td>
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<td></td>
<td>Image acquisition should take ≥3–5 heart beats after contrast injection§</td>
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<td></td>
<td>The contrast enhancement-dynamic mode is inactivated</td>
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<tr>
<td>Cooperation with patients and other staff</td>
<td>No table or patient motion during image acquisition††</td>
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<td>Stop breathing during image acquisition†††</td>
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<tr>
<td>Angiographic projection</td>
<td>Avoid contrast-filled descending aorta overlap with the LVOT (ROI)‡‡</td>
</tr>
<tr>
<td></td>
<td>Avoid contrast-filled descending aorta overlap with the aortic root (reference)‡‡</td>
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<td></td>
<td>Any radio-dense objects do not over-project on ROI‡‡‡</td>
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<td></td>
<td>Avoid the diaphragmatic over-projection (it is not important)</td>
</tr>
<tr>
<td>Contrast and catheter</td>
<td>5-Fr pigtail catheter located ±20mm from the inflection point of CoreValve and top of SXT or S3 but not interfering with the prosthesis leaflets¶¶</td>
</tr>
<tr>
<td></td>
<td>Contrast injection speed 10mL/s, volume 20mL†††</td>
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†Although accurate identification of the cardiac phase is not so important for the calculation of the area under the curve for entire image acquisition, it is very important for validation of LVOT-AR against echocardiographic data. ‡Stabilization of the image by subtracting the static background was mainly performed during 2 beats before contrast injection. ‡‡LVOT-AR requires ≥3 cardiac cycles. †The co-operator should ensure that there is no table motion, and the operator should remind the patient to stay still. ††In the case of general anesthesia, the operator will require the anesthetist’s assistance. For awake patients, the operator may encourage the patients to stop breathing or avoid strong breathing. ‡‡Optimal projection for LVOT-AR is LAO 20–30 with shallow caudal angle. To identify the optimal projection for VD, utilization of the cine-angio view on MSCT is recommended. ‡‡‡Especially for transapical TAVI, any radio-dense object should localize around only the apex. ¶¶For CoreValve the pigtail catheter should be located just above the level of the inflection point of the stent frame, while for the Sapien, the pigtail catheter should be located just above the prosthetic valve. †††20 mL contrast volume is sufficient. Contrast filling mainly depends on the catheter position. AR, aortic regurgitation; ECG, electrocardiogram; LAO, left anterior oblique; LVOT, left ventricular outflow tract; MSCT, multi-slice computed tomography; ROI, region of interest; TAVI, transcatheter aortic valve implantation; VD, videodensitometry.

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**Figure 1.** Catheter tip position during contrast injection. The tip of the pigtail catheter was located just above the leaflet coaptation level to avoid interference with the prosthetic valve leaflets. (A) For CoreValve, the pigtail catheter was located just above the level of the inflection point of the transcatheter heart valve frame, while (B) for Sapien XT and Sapien 3, the pigtail catheter was located just above the prosthetic valve.
CT for Post-TAVI Aortographic Projection Planning

Angiography Protocol

All aortic root angiograms were performed by the anesthesiologist with temporary breath arrest and were performed using a pigtail catheter (5 Fr) with a fixed amount of contrast volume (20 mL) at a predetermined contrast-injection speed of 10 mL/s under 450 pound-force per square inch and acquired with the Artis Zee Ceiling-Mounted Systems (OR; Siemens AG, Forchheim, Germany). Final angiographic image acquisition was done ≥10 min after transcatheter heart valve (THV) implantation or final post-dilatation.

The planned angiographic image acquisition protocol to improve the feasibility for VD analysis requires that (1) image acquisition of fluoroscopy is recorded ≥2 heart beats prior to the contrast injection and for 3–5 beats during the contrast injection and a minimum of 30 cine-fluoroscopic frames were evaluated.

The aim of this study was therefore to identify on MSCT the optimal angiographic view for VD assessment. The analyzability before and after the implementation of a comprehensive standardized acquisition protocol was evaluated and compared.

Methods

TAVI

Ninety-two consecutive patients undergoing TAVI at Yamaguchi University Hospital constitute the study population. All patients received general anesthesia with endotracheal intubation, mechanical ventilator support and hemodynamic monitoring with Swan-Ganz catheter via right internal jugular vein. The indication and strategy for TAVI were determined by the institutional heart team. This study was approved by the institutional review board of Yamaguchi University Hospital.

Figure 2. Method to predict the optimal angiographic view for videodensitometric analysis on multi-slice computed tomography (MSCT). (A, D) Volume rendering images reconstructed by the dedicated software (3mensio Valve version 8.0, 3mensio Medical Imaging BV, Bilthoven, Netherlands). (B, E) 2-D cine-angio view reconstructed using the dedicated software. (C, F) Post-procedural aortic root angiograms. (A, B, D, E) Light-blue bar, “perpendicular plane” in which the nadirs of the 3 coronary cusps are aligned; red shaded region, contrast-filled descending aorta. (A, B) When the descending aorta is seen between the spine and the aligned cusps plane on reconstructed MSCT images, (C) the contrast-filled descending aorta overlaps either the region of interest (ROI) or the reference area on the final aortic root angiograms. (A’, B’) To avoid the overlap of the contrast-filled descending aorta on ROI/reference, we rotated the 2-D reconstructed images to the right with minimum angulation so that the descending aorta did not overlap the ROI on 2-D reconstructed MSCT. (C’) Subsequently, when the planned fluoroscopic view is used to perform the aortic root angiogram, the absence of overlap of the contrast-filled descending aorta on the ROI or reference area is confirmed. (D, E) When the aligned cusps plane is seen between the spine and the descending aorta on 2-D reconstructed MSCT, (F) the contrast-filled descending aorta overlaps the ROI on post-procedural aortic root angiogram. (D’, E’) To avoid the overlap of the contrast-filled descending aorta with the ROI, we rotated the 2-D reconstructed images to the left with minimum angulation so that the descending aorta did not overlap the ROI on reconstructed MSCT images. (F’) When the planned angiographic view was used to perform the post-procedural aortic root angiogram, the absence of overlap of contrast-filled descending aorta with the ROI is confirmed.
frames are recorded – software required; (2) the contrast enhancement-dynamic mode is inactivated; (3) during image acquisition, the patient and the table of the cath-lab are kept immobile; (4) the tip of the pigtail catheter is located just above the leaflet coaptation level to avoid the interference of the catheter with the valve leaflets (Table; Figure 1); and (5) after identification of the optimal implanter view, in which the nadirs of 3 coronary cusps are aligned, using a dedicated software (3mensio Valve version 8.0, 3mensio Medical Imaging BV, Bilthoven, Netherlands), the optimal angiographic view for VD analysis is identified, in order to avoid the overlap of background structures with the ROI (sub-aortic segment designed by the basal third of the LV on fluoroscopy) and to minimize LVOT foreshortening on MSCT. Figure 2 shows examples of volume rendering images reconstructed using the dedicated software (3mensio Valve version 8.0; 3mensio Medical Imaging BV, Bilthoven, Netherlands; Figure 2A,A’,D,D’), 2-D virtual “fluoroscopic” view derived from MSCT (Figure 2B,B’,E,E’) and aortograms (Figure 2C,C’,F,F’). In Figure 2A,B,D,E, the contrast-filled descending aorta overlapped either the ROI or the reference area. To avoid the overlap of background structures, the X-ray gantry is rotated toward either the right anterior oblique (RAO) or left anterior oblique (LAO) using the dedicated software. In Figure 2A–C, the 2-D virtual fluoroscopic views are rotated to the right with minimum angulation so that the descending aorta did not overlap the ROI on the reconstructed MSCT images (Figure 2A’). In Figure 2D–F, the 2-D reconstructed images are rotated to the left with minimum angulation so that the descending aorta did not overlap the ROI on reconstructed MSCT. When the planned fluoroscopic views were used to perform the aortic root angiogram, the absence of overlapping of the contrast-filled descending aorta with the ROI or reference area was confirmed on aortography (Figure 2C’,F’).  

**AR Assessment**

Post-TAVI AR was quantified using a contrast VD software (CAAS A-Valve 2.0.2 research version, Pie Medical Imaging, The Netherlands) that calculates the ratio of the contrast time-density between the ROI (basal LV) and the reference area (aortic root), resulting in the assessment (LVOT-AR). After contouring the aortic root and basal LV (i.e., one-third of the LV), the software automatically provided the area under the curve (AUC) of the time-density curves for both ROI and reference area, and LVOT-AR was calculated as the ratio AUC_ROI to AUC_Reference. Theoretically, LVOT-AR ranges from 0 to 1 (Figure 3). Furthermore, the reproducibility of this VD method was evaluated by 2 local trained observers at Yamaguchi University Hospital and by core laboratory staff at an independent core...
laboratory (Cardialysis Clinical Trials Management and Core Laboratories, Rotterdam, the Netherlands).

The distance between the bioprosthesis and the bottom of the pigtail catheter was measured using the Coronary Angiography Analysis System-QCA (Pie Medical BV, Maastricht, The Netherlands). In the case of Sapien XT and Sapien 3, the distance between the top of the valve and the bottom of the pigtail catheter was measured. In the case of CoreValve and CoreValve evolut, the distance between the inflection point of the THV frame and the bottom of the pigtail catheter was measured.

### Statistical Analysis

Continuous data are presented as mean ± SD if normally distributed or as median (IQR) if non-normally distributed. Continuous variables were tested for normal distribution using the Shapiro-Wilk test and verified with histograms. Categorical variables are given as frequency and percentage. For continuous variables, Student’s t-test or Wilcoxon signed-rank test was performed for comparison between 2 groups. For categorical variables, the chi-squared test was used. For the evaluation of inter-observer differences, the Student’s t-test for paired samples was used for comparison. For the evaluation of inter-observer agreement, the Student’s t-test was performed using JMP Pro 12.2.0 (SAS institute, Cary, NC, US) and MedCalc version 17.2 (MedCalc Software, Ostend, Belgium). Two-tailed P<0.05 was defined as statistically significant.

### Results

The severity of AR was assessed in 92 consecutive TAVI on VD analysis after implantation of THV. TAVI was performed in 73.9% using the balloon-expandable valve and in 26.1% with self-expandable valve. Of the 92 aortic root angiograms after TAVI, 69 aortograms were analyzable for VD analysis (75%). The 92 aortic root angiograms were then divided into 2 groups: 54 patients prior to introduction of the standardized acquisition protocol; and 38 patients after implementation of the standardized acquisition protocol. The feasibility of analysis after implementation of the standardized acquisition protocol was significantly higher (38/38, 100%) than the feasibility prior to introduction of the standardized acquisition protocol (31/54, 57.4%, before vs. after, P<0.0001; Figure 4).

The median X-ray gantry position (expressed as angulation or rotation degree) of the analyzable angiographic views using the standardized acquisition protocol were as follows: LAO/cranial (CRA) or caudal (CAU), 35º (IQR, 30–40°)/1º (IQR, 1–4º) or 9º (IQR, 6–10º); and RAO/CRA or CAU, 21º (IQR, 20–27º)/1º or 10º (IQR, 9–10º). The distribution of the analyzable angiographic views prior to introduction of the standardized acquisition protocol was as follows: LAO/CRA or CAU, median, 10º (IQR, 6–15º)/8º (IQR, 7–11º) or median, 10º (IQR, 7–17º); and RAO/CAU, median, 3º/14°, while the distribution of the non-analyzable views prior to introduction of the standardized acquisition protocol was as follows: LAO/CRA or CAU, median, 10º (IQR, 10–15º)/8º (IQR, 7–11º) or median, 10º (IQR, 7–17º); and RAO/CAU, median, 3º/14°, while the distribution of the non-analyzable views prior to introduction of the standardized acquisition protocol was as follows: LAO/CRA or CAU, median, 10º (IQR, 10–15º)/8º (IQR, 7–11º) or median, 10º (IQR, 7–17º); and RAO/CAU, median, 5º (IQR, 4–6º)/10º (IQR, 8–15º; Figure 5).

As shown in Figure 5, the angiographic views with the standardized acquisition protocol tended to be more rotated than those prior to the introduction of the standardized acquisition protocol. Following the implementation of the standardized acquisition protocol it became apparent that the angulation in the CRA-CAU direction was not a prerequisite for optimal fluoroscopy acquisition of the aortogram, but noticeably 36 of the 38 assessed aortograms were obtained with either LAO rotation >25º (n=31) or RAO rotation >15º (n=5). In the 5 cases necessitating a rotation to the right, the descending aorta was elongated and angled toward the left hemi-side of the patient.

In the 40 randomly selected analyzable angiograms analyzed twice, the inter-observer difference was minor (mean±SD, 13±6% vs. 13±6%; mean difference±SD, 1±1%) and the inter-observer correlation was substantial (r=0.96, P<0.0001; ICCa=0.95). The scatter diagram with regression line and Bland-Altman plots are shown in Figure 6. The inter-observer agreement at the core laboratory
The present study has demonstrated the high feasibility of VD analysis with excellent reproducibility when a planned fluoroscopic image acquisition protocol was applied. The position of the pigtail catheter was located at a median of 3.50 mm (IQR, 1.34–6.21 mm) above the bioprosthesis on quantitative coronary angiography.

**Discussion**

The present study has demonstrated the high feasibility of VD analysis with excellent reproducibility when a planned fluoroscopic image acquisition protocol was applied.
Previous studies have noted the limitation of the modest feasibility of VD analysis as compared with other intra-procedural imaging options (e.g., transesophageal echocardiography, or AR index). This limitation has been improved but not eliminated by the LVOT-AR method as compared with the entire LV method,\textsuperscript{1,4} given that most of the studies were retrospective in nature and lacked a standardized acquisition. The implanter’s view, in which the nadirs of 3 coronary cusps are aligned, is not necessarily compatible with VD analysis. The main cause of the modest analysis feasibility is the overlap of the contrast-filled descending aorta with the ROI and/or the reference region of VD analysis. We hypothesized that a selected adequate fluoroscopic view for LVOT-AR assessment guided by 3-D CT to predict the optimal angiographic view for VD analysis on pre-procedural MSCT would eliminate this overlap. This planning can minimize the X-ray exposure of both patients and operators because it precludes searching at random for the optimal fluoroscopic view. At Yamaguchi University Hospital, TAVI was performed under general anesthesia, and aortography is performed with a ventilator-induced breath hold. In other centers with more minimalistic TAVI practice, VD analysis might be affected by breathing motion and diaphragmatic overlap with the ROI.

When looking at alternative tools for procedural guidance, an accurate echocardiographic assessment is still challenging,\textsuperscript{13} because it is not quantitative and has not yet been well-validated using other modalities.\textsuperscript{14} Substantial inter-modality inconsistencies between echocardiography and both angiographic grading (Sellers grading) and MRI have been reported.\textsuperscript{14,15} Another option is the hemodynamic indices, which tend to be used as prognostic rather than diagnostic tools. Furthermore, these indices are likely to also incorporate other markers of adverse prognosis that are not related to the degree of PVL (e.g., impaired LV systolic or diastolic function, aortic stiffness, and/or pathological vasodilatation due to a systemic inflammatory response).\textsuperscript{16}

Recently, Miyazaki et al in an experimental setting noted an excellent agreement between VD results and AR fraction evaluated in an in vitro mock circulation with a progressively deformed Edward valve.\textsuperscript{6,7} In addition, Abdel-Wahab et al recently established the relationship between AR on MRI and LVOT-AR on VD.\textsuperscript{9} In the current study, we showed that the feasibility of VD analysis was markedly improved with the introduction of the planned angiographic acquisition protocol and the pre-procedural identification of the optimal fluoroscopic view. Therefore, VD assessment (LVOT-AR) could become the standard tool for TAVI guidance, given that the main limitation of this technology, which is the low feasibility of the assessment, has been overcome. The location/mechanism of the AR, however, is determined on echocardiography during TAVI because it cannot be evaluated on aortography. Hence the combination of these 2 assessments (quantitative AR assessment on videodensitometry [angiography] and color Doppler assessment [echocardiography]) could compensate for the weakness of each individual technology.

Acquisition of the aortogram either in an angled angiographic projection >25° in the left anterior rotation or >15° in the right anterior rotation is a simple rule of thumb that can pragmatically be applied.\textsuperscript{9} In the present study these projections were systematically different from the angiographic projection in which the 3 aortic cusps were aligned.

An optimal procedure requires the co-axiality of the catheter with respect to the alignment of the 3 cusps – an angiographic appearance that indicates that the X-ray beam is approximately perpendicular to the nadir of the 3 cusps. Another parallax effect, however, needs to be avoided, which is the foreshortening of the LVOT that could be misleading in terms of depth of valve implantation. Therefore it seems to be appropriate to distinguish the angiographic view selected for the implantation of the device from the angiographic view used for the VD assessment, given that for VD assessment the foreshortening of the LVOT does not affect the result.

In the present study, it is clear that the so-called rule of thumb – going above 25° left or 15° right – is extremely effective in planning the VD-AR assessment. This simple rule may not comply with the angiographic alignment of the cusps, which could be, nevertheless, achieved by adapting rotation and angulation of the gantry towards the S-curve (Figure 5). Geometrically speaking a single angiographic view fulfilling these 2 criteria is not impossible but requires careful geometry planning.

Study Limitations

The small subject group and the single-center nature are limitations of the present study. All procedures were performed with the use of general anesthesia and breath arrest. Therefore, generalization of the findings to analysis performed under different circumstances should be done cautiously. The optimal feasibility (100% of analyzability) found in the present study could not necessarily be reproduced in a different clinical setting, such as deep conscious sedation.

Conclusions

Introduction of a planned angiographic image acquisition protocol has significantly improved the feasibility of VD analysis.

References