

Effect of body mass index on the image quality of rotational angiography without rapid pacing for planning of transcatheter aortic valve implantation: a comparison with multislice computed tomography

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Aims

To evaluate the feasibility of procedural planning for transcatheter aortic valve implantation (TAVI) using rotational angiography (R-angio) by comparison with multislice computed tomography (MSCT) and to investigate determinants of the image quality of R-angio.

Methods and results

Patients who underwent R-angio of the left ventricle and cardiac MSCT were eligible. R-angio acquisition was performed during contrast injection through a 6F pigtail catheter positioned in the left ventricle. On 3D R-angio and MSCT data sets, diameter measurements were made on short-axis images at the level of the aortic annulus ($D_{\text{perimeter}}$, D_{area}), ascending aorta, sino-tubular junction (ST-junction), and the sinus of Valsalva. At the level of the aortic annulus, diagnostic image quality was obtained in 49 of 56 patients. In all patients with a body mass index (BMI) $< 29 \text{ kg/m}^2$, image quality was acceptable whether or not rapid pacing was used. In patients with BMI $\geq 29 \text{ kg/m}^2$, the image quality was poor in 1 of 9 (11%) who were rapidly paced compared with 6 of 12 (50%) who were not. The correlation between R-angio and MSCT measurements was high for aortic annulus $D_{\text{perimeter}}$, D_{area} , ST-junction, Valsalva sinus, and ascending aorta (respectively, $R = 0.90, 0.90, 0.91, 0.92$, and 0.89). The correlations improved further when the analysis was limited to patients with a BMI $< 29 \text{ kg/m}^2$ (respectively, $0.92, 0.92, 0.92, 0.92$, and 0.93).

Conclusion

R-angio of the left ventricle allows precise measurement of the aortic root and annulus and was feasible for sizing at the time of TAVI. Diagnostic image quality was obtained without rapid pacing in all patients with a BMI $< 29 \text{ kg/m}^2$.

Keywords

Rotational angiography • Multislice computed tomography • Transcatheter aortic valve implantation • Multimodality • Annulus • Left ventricle

Introduction

Transcatheter aortic valve implantation (TAVI) for severe aortic stenosis reduces mortality when compared with medical therapy

in patients who are considered to have high surgical risk.¹ Evaluation of the permissiveness of patient anatomy for TAVI based on set criteria relies on imaging.² Minimally, a combination of coronary angiography and echocardiography is needed. Yet, 3D

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imaging modalities such as multislice computed tomography (MSCT) are increasingly being used for the evaluation of the complex 3D anatomy of the aortic root and the non-circular aortic annulus for sizing.³ The 3D data sets have the advantage of allowing measurements on short-axis images of the aortic root without the restrictions imposed by the 3D orientation of the heart on fixed echocardiographic windows, but add a logistic burden.^{4,5} In the catheter laboratory, rotational angiography (R-angio) has the capability to create 3D images of contrast-filled vascular structures with isovolumetric voxels similar to MSCT.⁶ The images are available for analysis within a minute after acquisition and when used for evaluation after endovascular procedures may reduce the need for MSCT.^{7–9} The role of R-angio for TAVI planning is not yet defined.

The aims of this study were (i) to evaluate the feasibility of patient selection and procedural planning for TAVI using R-angio by comparison of the measurements with those obtained from MSCT and (ii) to investigate determinants of the image quality of R-angio.

Methods

Patient selection

The study was approved by the institutional review board. Patient privacy was ensured by data anonymization. Eligible patients who underwent rotational ventriculography for the evaluation of left ventricular function during the investigation for coronary disease or prior to TAVI and who had a cardiac MSCT in the year prior to the invasive procedure were retrospectively identified. Body mass index (BMI) was measured in kilogram per square metre and obesity was defined as a BMI ≥ 30 kg/m².

R-angio acquisition

R-angio was performed using the Artis Zee system (Siemens AG, Forchheim, Germany) with a 20×20 cm² detector size and isotropic pixel length of 100 μ m. In preparation for R-angio the table was positioned to locate the left ventricular outflow tract (LVOT) at the isocentre. A 6F pigtail catheter was positioned in the left ventricle. If the procedure allowed it, the patient's arms were positioned above the head. In patients who had TAVI (and rapid pacing) the patient's arms were not positioned above the head due to the requirement for a transradial arterial access as part of the standard procedure at our hospital. During a breath hold, the 5 s rotational acquisition with an angular range of 200° ($\pm 100^\circ$ left-to-right anterior oblique) was started simultaneously with a 5 s contrast injection, which consisted of a 70 mL mixture of Visipaque 400 diluted 50/50 with 0.9% saline and injected at a rate of 14 mL/s, requiring a total of 35 mL pure contrast. In patients who had a temporary pacemaker wire located in the right ventricle in preparation for TAVI, rapid pacing at a rate of 180 bpm was performed during the rotational acquisition. A total of 133 images were acquired during the rotational run at a detector entrance dose of 0.36 μ Gy per frame. From the images, a 3D R-angio data set was reconstructed (Inspace3D, Siemens AG, Forchheim, Germany) with a matrix of 256 and 0.5 mm³ voxel size, and interrogated on a standard 3D workstation (Syngo X workplace, Siemens AG, Forchheim, Germany).

MSCT acquisition

The MSCT acquisition method has been described before.¹⁰ In brief, the acquisition was performed using a 128-slice dual-source CT (Somatom Definition Flash, Siemens, Forchheim, Germany) in the spiral scan mode with a variable table speed which depended on the heart rate and without RR-interval-triggered tube current modulation. Further acquisition parameters were detector collimation $2 \times 64 \times 0.6$ mm³ with rapid alternation of focal spot position in the Z-axis (Z-sharp[®]), rotation time 285 ms, and tube voltage 120 kV. The scan range was set from the top of the aortic arch to the diaphragm. The volume of iodinated contrast material was adapted to the expected scan time. A 50–60 mL bolus of iodixanol (Visipaque[®] 320 mg L/mL, GE Health Care, Eindhoven, the Netherlands) was injected in an antecubital vein at a flow rate of 4.5 mL/s, followed by a second contrast bolus of 30–40 at 3.0 mL/s. Bolus tracking was used to trigger the start of the scan with the arrival of contrast in the aortic root. ECG-gated reconstructions were made in end-systole using a single-segmental reconstruction algorithm with slice thickness 1.5 mm; increment 0.4 mm; medium-to-smooth convolution kernel (B26f) resulting in a spatial resolution of 0.6–0.7 mm in-plane and 0.4–0.5 mm through-plane, and a temporal resolution of 72 ms. The radiation doses ranged from 8 to 20 mSv depending on body habitus and table speed.

MSCT and R-angio analyses

MSCT and R-angio analyses were blinded. Calcification of the aortic leaflets and aortic root was measured as Agatston score on non-contrast MSCT. The method of analysis for contrast MSCT for setting up a short-axis viewing plane of the aortic annulus was described before and the same method was used to interrogate the R-angio data set.^{4,5} In brief, a short-axis view of the aortic annulus was defined as the image that showed the virtual ring of the LVOT, where the most caudal attachments of the three aortic leaflets were simultaneously and proportionately in view (Figure 1). Thereafter, aortic root dimensions listed in the patient selection matrix for TAVI were measured¹¹ (Figure 2). At the level of the aortic annulus, the following measurements were obtained: maximum diameter (D_{\max}), minimum diameter (D_{\min}), perimeter, and area. The mean diameters were calculated as follows: $D_{\text{perimeter}} = \text{perimeter}/\pi$; $D_{\text{area}} = \text{SQRT}(\text{area}/\pi) \times 20$; $D_{\text{mean}} = (D_{\max} + D_{\min})/2$. Diameter measurements were also obtained on short-axis images at the level of the ascending aorta 4 cm above the annulus plane, the sino-tubular junction (ST-junction), and the sinus of Valsalva at the level of central coaptation of the aortic leaflets. The sinus of Valsalva diameter was calculated as a mean of three measurements obtained along the three coaptation lines and to the opposite sinus of the three leaflets (Figure 2).

Grading of image quality on R-angio

Image quality on the R-angio was graded based on a short-axis image of the aortic annulus as follows: (i) excellent (low noise, clear transition between contrast and tissue); (ii) good (moderate noise, clear transition between contrast and tissue); (iii) borderline (noisy, transition of contrast to tissue is not always clear but sufficient); (iv) uninterpretable (either due to unclear transition of contrast to tissue impairing measurement or because the level or plane of measurement cannot be defined; Figure 3).

Statistical methods

Data are presented as a mean (SD, standard deviation) when normally distributed and a median (25th to 75th quartile) if not. Pearson's or Spearman's correlation coefficient is determined as appropriate.

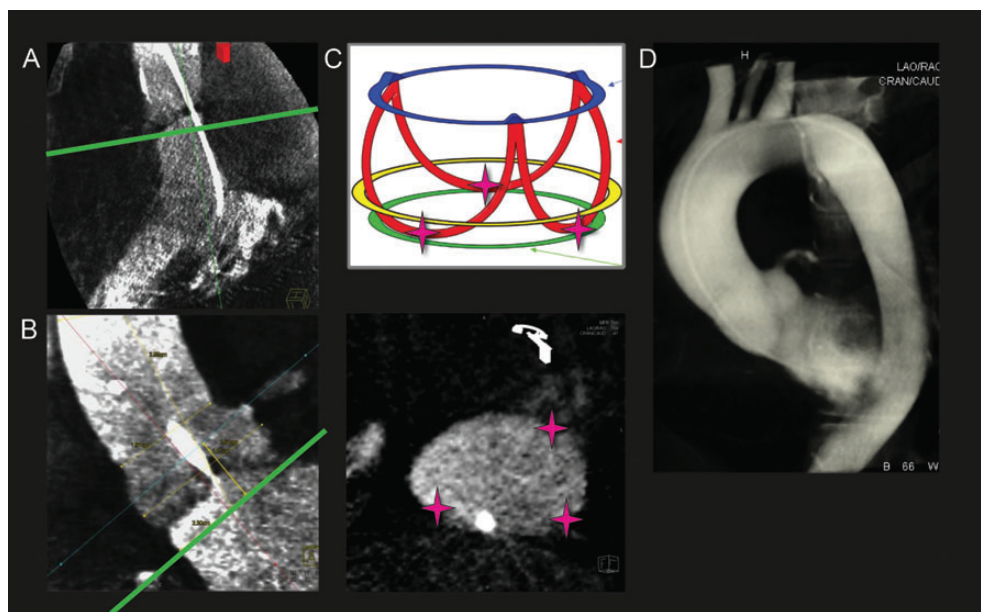


Figure 1 The definition of the aortic annulus on R-angio and MSCT. The aortic annulus was defined on the short-axis image of the LVOT that showed the virtual ring, where the most caudal attachments of the three aortic leaflets were simultaneously and proportionately in view (C). The schematic shows the virtual ring of the aortic annulus (green) with three anchor points at the nadirs of the aortic leaflets (pink stars). Orthogonal images from R-angio are shown in the oblique sagittal (A), coronal (B), and short-axis (C) views with a corresponding 3D reconstruction of the LVOT and aortic arch (D).

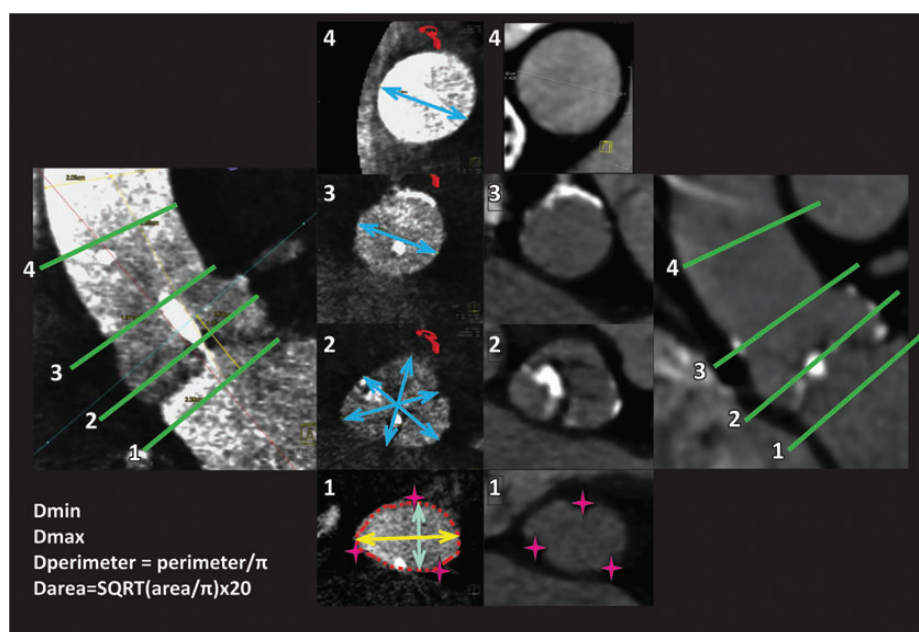


Figure 2 Measurements obtained from R-angio and MSCT. The aortic root was evaluated using the same method on R-angio (left) and MSCT (right). At the level of the aortic annulus (1), the following measurements were obtained: maximum diameter (D_{\max}), minimum diameter (D_{\min}), perimeter, and area. The mean diameters were calculated as follows: $D_{\text{perimeter}} = \text{perimeter}/\pi$; $D_{\text{area}} = \text{SQRT}(\text{area}/\pi) \times 20$. Diameter measurements were also obtained on short-axis images at the level of the ascending aorta 4 cm above the annulus plane (4), the ST-junction (3), and the sinus of Valsalva at the level of central coaptation of the aortic leaflets (2). The sinus of Valsalva diameter was calculated as a mean of three measurements obtained along the three coaptation lines and to the opposite sinus of the three leaflets (2).

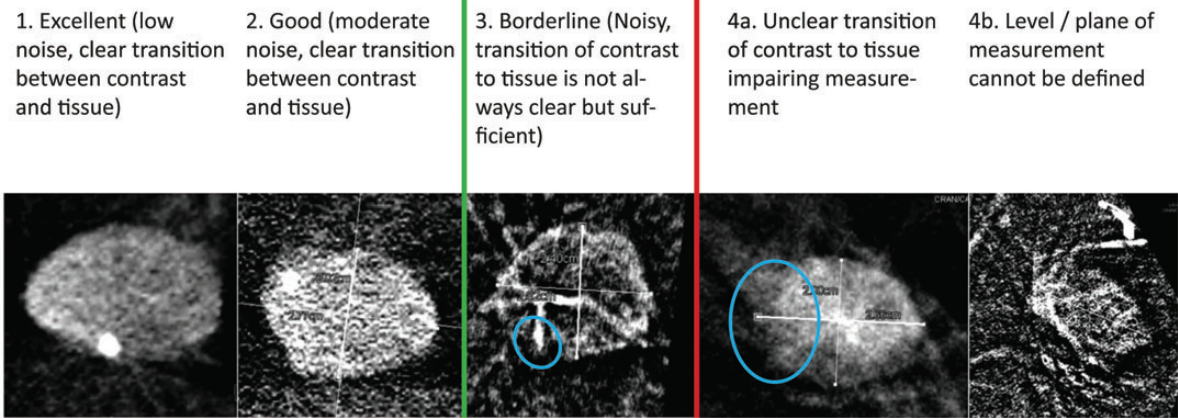


Figure 3 Evaluation of the image quality of R-angio. Image quality was evaluated at the level of the aortic annulus. Grades 4 and 5 were not interpretable. The blue ring in grades 3 and 4 indicate areas of uncertainty due to image quality.

Table 1 Demographics of the patient population

Mean (SD) or n	n = 56
Age (years)	72 (12)
Gender (M:F)	34:22
Height (cm)	170 (11)
Weight (kg)	79 (13)
BMI (kg/m ²)	27 (4)
LV ejection fraction (%)	53 (13)
Glomerular filtration rate (mL/min)	69 (14)
Heart rate before R-angio	64 (12)

Proportions in a 2 × 2 table were compared using the χ^2 test with the Bonferroni correction. To determine the value of variables to discriminate poor image quality from R-angio, receiver operating characteristic (ROC) curves were plotted (sensitivity vs. 1-specificity) and the areas under the curve were calculated. Paired comparisons between MSCT and R-angio were done using Student's *t*-test or Wilcoxon's signed-rank test as appropriate. Multiple logistic regression was used to determine independent predictors of good image quality from R-angio. Variables associated with image quality with a *P*-value < 0.1 in univariate analysis were included in the multivariate model. Tested variables included rapid pacing, BMI, gender, age, weight, height, left ventricular ejection fraction, trans-aortic gradient, heart rate, or left ventricular end-diastolic pressure. SPSS 17.0 (SPSS, Inc., Chicago, IL, USA) was used. Statistical significance was defined as a two-tailed *P* < 0.05.

Results

Demographics

A total of 56 patients were studied. Rotational ventriculography was performed before TAVI in 35 patients and during investigation of coronary disease in 21 patients. The clinical characteristics of patients are given in Table 1. Obesity, defined as a BMI ≥ 30 kg/m²,

was seen in 16 patients (29%). Rapid pacing was performed in 34 of 35 patients who underwent TAVI and in none of the patients who were studied for other reasons. R-angio was performed with the patient's arms beside them in all 35 patients who underwent TAVI and in the above-head position in the remaining 21. A lower volume of contrast was used for R-angio than for MSCT [36 mL (4.6) vs. 97 mL (7.7), *P* < 0.01].

R-angio image quality

Borderline or better quality images (≤ 3) were obtained in 49 out of 56 patients. Poor image quality in all seven cases was due to poor signal-to-noise ratio and/or insufficient contrast rather than motion artefact. Using simple correlation, image quality was associated with patient weight (*r* = 0.30, *P* = 0.02) and BMI (*r* = 0.38, *P* < 0.01) but not with gender, age, height, left ventricular ejection fraction, trans-aortic gradient, heart rate, or left ventricular end-diastolic pressure just before rotational image acquisition.

Poor image quality occurred in 6 of 16 (38%) patients with BMI ≥ 30 kg/m² vs. 1 of 39 (3%) with BMI < 30 kg/m², *P* < 0.01. Obesity was highly predictive of poor image quality (area under ROC curve = 0.87) with an overall optimal predictive level of ≥ 31 kg/m². A BMI of ≥ 29 kg/m² had a sensitivity of 100% and a specificity of 73% for predicting poor image quality after R-angio.

Good image quality was associated with rapid pacing during R-angio. Borderline or better image quality was seen in 33 of 34 (97%) patients who were rapidly paced and in 16 of 22 (72%) patients who were not, *P* = 0.01. In patients with BMI ≥ 29 kg/m² who were rapidly paced, the image quality was poor in 1 of 9 (11%). In patients with a BMI ≥ 29 kg/m² who were not rapidly paced, the image quality was poor in 6 of 12 (50%). In all patients with a BMI < 29 kg/m², the image quality was acceptable whether or not rapid pacing was used.

Multiple logistic regression was used to determine independent markers of good image quality. Rapid pacing and BMI were included in the final model [odds ratio (95% confidence interval), respectively, 19.6 (1.2–324.5) and 0.6 (0.4–0.9), both *P* < 0.05].

Atrial fibrillation during R-angio acquisition was present in two patients for whom the image quality was rated good and excellent, respectively. All other patients were in sinus rhythm. No association was seen between R-angio image quality and aortic root calcification.

Comparison of aortic root measurements between R-angio with MSCT

In the 49 patients with borderline or better image quality, measurements between R-angio and MSCT were highly correlated (Table 2). On the whole, the diameter measurements were similar when compared between R-angio and MSCT (Table 2).

The exceptions were the ST-junction [mean (SD): 28.1 (3.6) vs. 29.0 (3.9); mean difference (SD): -0.9 (1.6), $P < 0.01$]; the ascending aorta [mean (SD): 31.1 (3.5) vs. 32.1 (4.0); mean difference (SD): -1.0 (1.8)]; and annulus D_{\min} [mean (SD): 21.6 (2.6) vs. 22.4 (2.1); mean difference (SD): -0.8 (1.4), $P < 0.01$], which were significantly smaller when measured by R-angio compared with MSCT.

Scatter and difference plots for measurements by the two modalities showed good agreement without bias for D_{\max} , D_{area} , $D_{\text{perimeter}}$, and sinus of Valsalva diameter. At the level of the ascending aorta, ST-junction, and for annulus D_{\min} , a constant negative bias for the R-angio measurement was evident. Figure 4 shows the scatter and difference plots with limits of agreement for D_{\min} .

Table 2 Comparison of aortic root measurements between R-angio and MSCT

$n = 49$	Correlation coefficient	R-angio mean (SD), mm	MSCT mean (SD), mm	Difference: R-angio – CT mean (SD), mm
Ascending aorta	0.89**	31.1 (3.5)	32.1 (4.0)	-1.0 (1.8)**
ST-junction	0.91**	28.1 (3.6)	29.0 (3.9)	-0.9 (1.6)**
Sinus of Valsalva	0.92**	32.1 (4.0)	32.2 (4.0)	-0.1 (1.6)
Annulus				
$D_{\text{perimeter}}$	0.90**	25.5 (2.6)	25.6 (2.4)	-0.1 (1.1)
D_{area}	0.90**	24.8 (2.6)	25.0 (2.3)	-0.2 (1.2)
D_{\min}	0.85**	21.6 (2.6)	22.4 (2.1)	-0.8 (1.4)**
D_{\max}	0.87**	27.9 (2.6)	27.9 (2.9)	0 (1.4)

** $P < 0.01$.

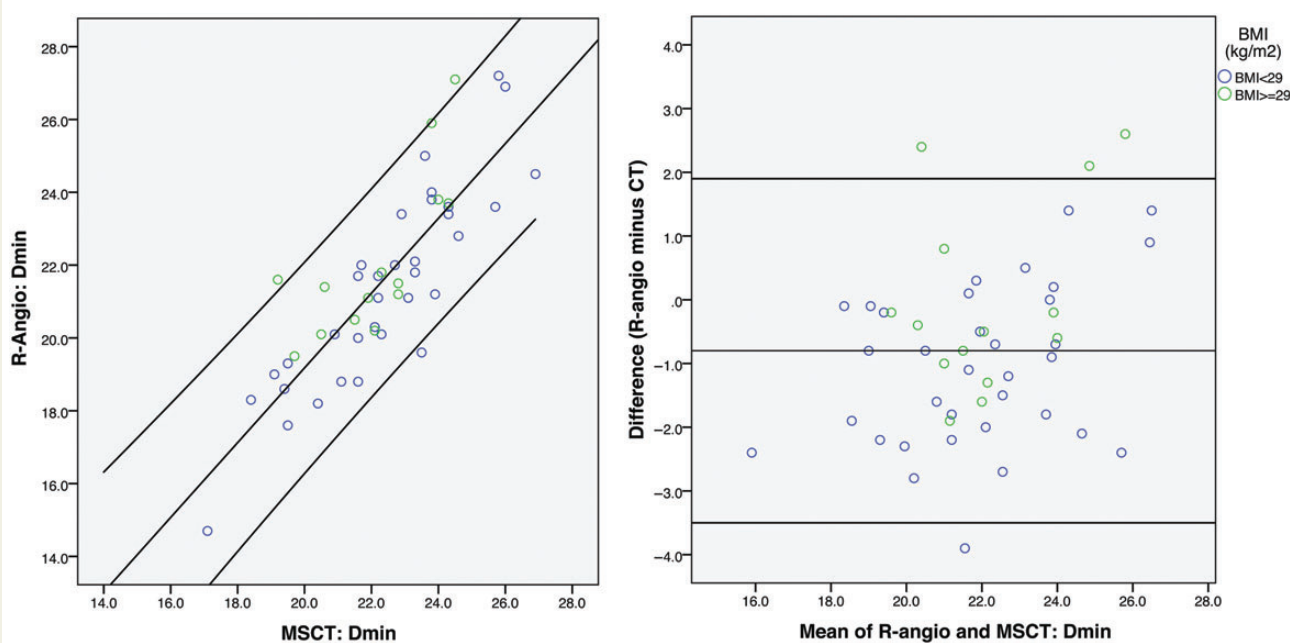


Figure 4 Scatter and difference plots of minimum aortic annulus diameter (D_{\min}) measured by R-angio vs. MSCT. For the scatter plot, the line of best fit is given by: $\text{R-angio_}D_{\min} = 1.03 \times \text{MSCT_}D_{\min} - 1.35$, $R^2 = 0.71$. BMI, body mass index.

the aortic annulus prevents full appreciation of its oval shape by 2D echocardiography.^{3,5} A number of small retrospective studies suggest that sizing by 3D imaging modality may improve outcome after TAVI.^{3,12–14} MSCT and CMRI require additional testing, whereas R-angio is immediately available in the catheter laboratory and can be performed at the time of TAVI to facilitate accurate sizing.

The feasibility of rotational aortography for the assessment of the aortic root has previously been reported.^{15,16} Yet, in our study, the pigtail catheter was placed in the left ventricle (rotational ventriculography). The advantage of rotational aortography is that the aortic valve does not have to be crossed, but this advantage is lost during TAVI procedure, where crossing the aortic valve is required. The disadvantage of rotational aortography is that the LVOT/aortic annulus is not directly imaged. Sizing is based on the dimensions of the aortic annulus, which is anatomically defined as a virtual ring with three anchor points at the most caudal attachments of the aortic leaflets. By definition, the aortic annulus lies on the ventricular side of the aortic leaflets.¹⁷ This study shows that rotational ventriculography allows measurement of the dimensions of the aortic annulus and aortic root on true short-axis images with an accuracy similar to MSCT. Another study of 99 consecutive patients reported that measurements based on either rotational aortography acquisition with rapid pacing or TEE were highly correlated ($r = 0.83$) at the level of the aortic annulus and ST-junction, but the measurements were not directly compared.¹⁵ In the present study, the correlation between MSCT and R-angio was stronger (for example, 0.90 for annulus D_{area} and $D_{\text{perimeter}}$) and the correlation increased to 0.92 when only patients with a BMI $< 29 \text{ kg/m}^2$ were considered.

We observed good agreement for most dimensions of the aortic annulus, but there was a constant bias for aortic annulus D_{min} , the ST-junction, and the ascending aorta, where the dimensions obtained from R-angio were smaller than those obtained from MSCT by $\sim 1 \text{ mm}$. In the present study, the observed difference between MSCT and R-angio may be explained by differences in the cardiac phase during image acquisition. The MSCT reconstructions were always made in the systolic phase of the RR-interval and over a period of 72 ms (temporal resolution of the MSCT scanner). In contrast, the R-angio reconstruction is based on the data obtained throughout the cardiac cycle over a 5 s period, which represents just under five cardiac cycles given the average patient heart rate of just 64 beats per second at the time of the acquisition. The duration of systole remains relatively constant, whereas the duration of diastole increases and becomes much longer than that of systole as heart rate decreases.¹⁸ Owing to the low heart rate in our population, R-angio image acquisition and 3D reconstruction represent largely the diastolic phase. It is recognized that, during systole, the diameter of the aorta stretches to accommodate the mass of blood forced into it followed by elastic recoil, resulting in smaller dimensions in diastole. A study examining the effect of cardiac phase on aortic root dimensions and the aortic annulus using MSCT in 108 patients observed a measureable decrease in the ST-junction diameter and in the minimum annulus diameter during diastole, but this difference was ameliorated for the maximum annulus diameter.¹⁹ The minimum annulus diameter

lies in an oblique sagittal orientation between the interventricular septum and the aorto-mitral fibrous continuity,⁵ so that the opening of the mitral valve anterior leaflet may contribute to a diastolic decrease in the minimum annulus diameter. Another study using MSCT to investigate the effect of cardiac cycle on different measurements of the aortic annulus in 46 patients (35 with calcific aortic stenosis) reported that the aortic annulus D_{min} and area both decreased during diastole, but the annulus perimeter did not.²⁰ These data are compatible with the concept that the annulus dimensions change largely due to the motion of the aorto-mitral fibrous continuity rather than due to elastic distention and recoil during the cardiac cycle.

The heart is relatively motionless during diastole, which may explain why rapid pacing was not essential to obtain diagnostic image quality in the present study, where the average heart rate was low. In patients with a BMI $< 29 \text{ kg/m}^2$, acceptable image quality was obtained in all patients who were not rapidly paced. In contrast, in patients with a BMI $\geq 29 \text{ kg/m}^2$, the image quality was poor in 11% of those who were rapidly paced compared with 50% of those who were not. Another study reported that image quality was good in all of the 99 patients, where rotational aortography was performed during rapid pacing.¹⁵ Although rapid pacing during rotational acquisition is relatively safe, it may occasionally result in haemodynamic instability.²¹ Interestingly, accurate dimensions of the left atrium when compared with MSCT may also be obtained using R-angio without rapid pacing.²² These data suggest that R-angio without rapid pacing may be performed in patients with a BMI $< 29 \text{ kg/m}^2$, but in patients with a BMI $\geq 29 \text{ kg/m}^2$, it is probably better not to perform rotational ventriculography if rapid pacing is not possible or clinically undesirable.

We found no effect of aortic root calcification on R-angio image quality. This is not surprising given that R-angio detects only extreme levels of calcium so that the measurements are not affected. Although calcium causes signal loss in MSCT resulting in blooming, this effect is of more relevance to measurements of small structures such as coronaries but has little or no meaningful effect on the aortic root, which is 10-fold larger than the coronaries. Other factors which have an impact on image quality, but which were not specifically investigated in the present study, are reducing the number of radiographically dense structures overlying the LVOT (arms above the head, deep inspiration) and using radiographically more dense contrast (pure instead of diluted and contrast media with a higher instead of lower iodine density). A pre-set R-angio protocol with a higher frame rate, e.g. that acquires a total of 248 projection images instead of 133 (this study), should improve contrast resolution significantly, with a proportional increase in radiation dose. The clinical situation during which R-angio is performed often determines that not all factors affecting image quality will be optimal. There is also a compromise between image quality and other risks. For example, the use of diluted contrast (50/50) is not optimal for image quality but reduces the overall contrast burden notably in patients who may be at risk of contrast nephropathy. Furthermore, the need for placing a temporary pacing wire (TPW) for the sole reason to obtain better image quality may be avoided in patients with a BMI $< 29 \text{ kg/m}^2$ and where the arms may be placed above the head. On the

other hand, a TPW is routinely placed in patients who undergo TAVI who do not already have a permanent pacemaker. A guide to different considerations for obtaining diagnostic image quality is given in Figure 6.

We did not report radiation doses because there are no specific conversion factors available for R-angio to estimate effective dose from the dose area product for the equipment and the scan protocol used.²³ During the rotational acquisition, the radiation exposure is continually adjusted to the patient thickness relative to tube angulation. Tube voltage and current are regulated to keep the entrance dose at the detector at a specified constant (0.36 µGy per frame in the program used in this study). The complete dose area product is reported for the rotational scan, but for reliably calculating the effective dose, the exposure and conversion factor for each angular view is needed. In addition, collimation to the region-of-interest would reduce the effective dose significantly. A study in 42 patients that used Monte Carlo simulation, taking into account the radiation exposure for each individual projection during R-angio acquisition and with the same C-arm system as in the present study, reported a mean effective dose of 6.6 mSv. In that study, the frame rate was higher than in the present study (total 248 vs. 133 images per R-angio acquisition) and the detector size was larger ($30 \times 40 \text{ cm}^2 = 1200 \text{ cm}^2$ vs. $20 \times 20 \text{ cm}^2 = 400 \text{ cm}^2$). If these differences were taken into account, the effective dose for R-angio in the present study would be in the vicinity of 1.2 mSv. Although such comparisons should be cautiously interpreted, the estimated exposure is very similar to that of experiments using a male Alderson Rando phantom showing that the effective radiation dose for R-angio of the heart was 1.25 mSv at an increased entrance dose of 54 µGy.²⁴

In our study, lower volumes of contrast were used for R-angio (36 mL) than for MSCT (92 mL). A study that evaluated minimal contrast use during MSCT utilized a high-pitch spiral acquisition mode in 42 patients and reported the use of only 50 mL of contrast per patient.²⁵ In that study, the aortic root was difficult to evaluate due to a combination of calcium and motion artefact in only two patients, but the image quality was deemed acceptable. These data suggest that our MSCT protocol was not optimized for contrast use. Yet, we believe that a spiral acquisition with a wide pulse window and retrospective gating provides the most reliable MSCT scanning protocol to optimize image quality in the arrhythmia-prone patients who are considered for TAVI, although at the cost of requiring more than 50 mL contrast. It may also be possible to further reduce the contrast volume used during R-angio in conjunction with rapid pacing, but further studies are needed.

Limitations

This is a small retrospective study and the findings should be viewed as hypothesis-generating. In all patients who were rapidly paced, R-angio was acquired with the arms by patients' sides, whereas the arms were above the head in all other patients who were not rapidly paced. Owing to the substantial effect of rapid pacing on image quality, the effect on the image quality of having the arms up or down could not be investigated.

We did not observe an association between pulse rate and image quality, but the number of patients imaged without rapid pacing was small. The image quality observed without rapid pacing may not apply to patients with higher heart rates than were seen in this study. Although the diameter measurements of

<p>Essential to all acquisitions:</p> <ul style="list-style-type: none">• Isocentre on LVOT• Breath hold (ideally end-inspiratory)• At least 50/50 contrast (Visipaque 400 or an alternative with a greater iodine density)• Contrast injection at 14ml / second for 5 seconds• Simultaneous triggering of contrast injection and rotational run to ensure LVOT contrast throughout image acquisition	<p>Body mass index ≥ 29:</p> <ul style="list-style-type: none">• Rapid pacing possible<ul style="list-style-type: none">- Arms above head if possible- Consider using pure contrast- End-inspiratory breath hold if possible• Rapid pacing not possible<ol style="list-style-type: none">1. Use pure contrast2. Arms above head3. End inspiratory breath hold4. Select an acquisition protocol with a higher frame rate e.g 248 projection images per rotation instead of 1335. If points 1-4 are not desirable for procedural or clinical reasons consider not performing rotational angiography.
<p>Body mass index < 29:</p> <ul style="list-style-type: none">• Highly desirable<ul style="list-style-type: none">- Arms above head (essential if rapid pacing is not used)• Not essential but may improve image quality<ul style="list-style-type: none">- Use pure contrast- Rapid pacing- Acquisition protocol with a higher frame rate (see point 4 to the right)	

Figure 6 Steps to obtaining diagnostic image quality of the left ventricular outflow tract (LVOT) with R-angio.

the aortic root were very similar to those of MSCT, R-angio allows only a qualitative impression but not quantification of aortic root calcification, which may be an important determinant of paraprothetic regurgitation.¹⁰ MSCT also has the benefit of simultaneous assessment of vascular access routes, but coronary anatomy may not be reliably assessed due to extensive calcification, with the result that coronary angiography cannot be avoided during pre-procedural workup. An alternative approach may use R-angio in a stepwise workup strategy starting with echocardiographic screening, to exclude patients with an unsuitable aortic root anatomy, followed by invasive angiography for the assessment of coronary anatomy and vascular access, and finally R-angio performed at the time of TAVI for sizing. Such an approach may obviate the need for an additional prior 3D imaging modality (MSCT) at the cost of a modest increase in contrast requirement during TAVI.

Conclusions

R-angio of the left ventricle allows precise measurement of the LVOT and aortic root dimensions similar to MSCT. R-angio may, therefore, allow accurate sizing at the time of TAVI when another 3D modality (MSCT, CMRI, 3D TEE) is not available or not desirable. The total contrast used during R-angio using our protocol (35 mL) compares favourably with that of MSCT (92 mL). Diagnostic image quality was obtained without rapid pacing in all patients with a BMI < 29 kg/m² using diluted contrast (50%), but R-angio image quality was frequently poor in patients with a BMI ≥ 29 kg/m² when simultaneous rapid pacing was not be performed. These data are exploratory and require confirmation and further elucidation in larger studies.

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Conflict of interest: G.L. works for Siemens AG, Healthcare Sector, Forchheim, Germany.

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