Prediction of Optimal Deployment Projection for Transcatheter Aortic Valve Replacement

Angiographic 3-Dimensional Reconstruction of the Aortic Root Versus Multidetector Computed Tomography

Ronald K. Binder, MD; Jonathon Leipsic, MD; David Wood, MD; Teri Moore; Stefan Toggweiler, MD; Alex Willson, MBBS; Ronen Gurvitch, MBBS; Melanie Freeman, MBBS; John G. Webb, MD

Background—Identifying the optimal fluoroscopic projection of the aortic valve is important for successful transcatheter aortic valve replacement (TAVR). Various imaging modalities, including multidetector computed tomography (MDCT), have been proposed for prediction of the optimal deployment projection. We evaluated a method that provides 3-dimensional angiographic reconstructions (3DA) of the aortic root for prediction of the optimal deployment angle and compared it with MDCT.

Methods and Results—Forty patients undergoing transfemoral TAVR at St Paul’s Hospital, Vancouver, Canada, were evaluated. All underwent preimplant 3DA and 68% underwent preimplant MDCT. Three-dimensional angiographic reconstructions were generated from images of a C-arm rotational aortic root angiogram during breath-hold, rapid ventricular pacing, and injection of 32 mL contrast medium at 8 mL/s. Two independent operators prospectively predicted perpendicular valve projections. The implant angle was chosen at the discretion of the physician performing TAVR. The angles from 3DA, from MDCT, the implant angle, and the postdeployment perpendicular prosthesis view were compared. The shortest distance from the postdeployment perpendicular prosthesis projection to the regression line of predicted perpendicular projections was calculated. All but 1 patient had adequate image quality for reproducible angle predictions. There was a significant correlation between 3DA and MDCT for prediction of perpendicular valve projections (r = 0.682, P < 0.001). Deviation from the regression line of predicted angles to the postdeployment prosthesis view was 5.1° ± 4.6° for 3DA and 7.9° ± 4.9° for MDCT (P = 0.01).

Conclusions—Three-dimensional angiographic reconstructions and MDCT are safe, practical, and accurate imaging modalities for identifying the optimal perpendicular valve deployment projection during TAVR. (Circ Cardiovasc Interv. 2012;5:247-252.)

Key Words: transcatheter aortic valve implantation ■ multidetector computed tomography ■ 3-dimensional angiography ■ cardiac DynaCT

Transcatheter aortic valve replacement (TAVR) is an established technique for the treatment of symptomatic severe aortic stenosis in patients at high surgical risk.1-2 For successful TAVR, it is important to position and deploy the valve prosthesis accurately. This is best achieved by using a fluoroscopic view perpendicular to the native valve, sometimes called the “coplanar” view. Positioning the valve prosthesis too high or low may result in embolization, coronary obstruction, or paraprosthetic regurgitation. To find the optimal fluoroscopic implant view, various imaging modalities such as multidetector computed tomography (MDCT)3-5 and repeated aortic root angiograms from different angles have been used. Three-dimensional angiographic reconstructions (3DA) of the aortic root captured from rotational C-arm fluoroscopic images6 have been evaluated in different interventional settings, for example, in endovascular aortic aneurysm repair7,8 and catheter ablation procedures.9,10 However, the value of this method for TAVR is not yet established.

We evaluated the ability and practicability of 3DA to find the optimal perpendicular valve projection for accurate positioning and deployment of valve prosthesis in TAVR and compared this method with MDCT.

Methods

Consecutive patients with symptomatic severe aortic stenosis undergoing transfemoral TAVR at St Paul’s Hospital, Vancouver, Canada, had a 3DA and a MDCT performed before the implant procedure.
WHAT IS KNOWN

- Identifying the optimal fluoroscopic projection of the aortic valve is important for successful transcatheter aortic valve replacement.
- The most common approach is to perform repeated aortic root injections, which may be time-consuming, increase radiation exposure, and require large amounts of radiographic contrast.
- Aortic root reconstructions from multidetector computed tomography have been shown to be helpful in predicting perpendicular valve view angles for accurate prosthesis positioning.

WHAT THE STUDY ADDS

- Our study demonstrates that 3-dimensional reconstructions of the aortic root generated from in-laboratory, on-line C-arm rotational angiography accurately determine fluoroscopic projections perpendicular to the plane of the native valve.
- This new method automatically identifies the aortic cusps and the perpendicular valve view, requires less radiographic contrast than multidetector computed tomography, and proved to be accurate.

All patients gave written informed consent. Patients underwent MDCT during the week before and 3DA at the beginning of TAVR. In patients with a calculated glomerular filtration rate of <35 mL/min, MDCT was not performed. Two independent operators predicted perpendicular valve view angles for each method prospectively. The physician performing TAVR was aware of both prediction modalities and chose the deployment projection at his discretion, after assessing its suitability by an aortic root angiography with injection of 15 mL of radiographic contrast through a 6F pigtail catheter (Figure 1). After valve deployment, a fluoroscopic view was documented in which the prosthesis appeared to be perpendicular to the camera (Figure 2). This was achieved by rotating the C-arm so that the anterior stent struts of the prosthesis exactly overlapped the posterior. The prediction accuracy for perpendicular valve view projections was measured against the postdeployment perpendicular prosthesis view.

Three-Dimensional Angiographic Image Acquisition and Analysis

Three-dimensional angiographic reconstructions were generated from images of a C-arm rotational aortic root angiography (220°), using DynaCT (Siemens AG, Erlangen, Germany). Radiographic contrast (Optiray 320, Tyco Healthcare, Montreal, Canada) was injected through a 6F pigtail catheter placed in the noncoronary cusp (32 mL at 8 mL/s or 20 mL diluted with 40 mL normal saline injected at 15 mL/s). Immediately before and during contrast injection, rapid ventricular pacing was instituted at a rate of 160 to 180 beats per minute. A ventilator breath-hold was also used during the injection to reduce respiratory motion. Acquisition was achieved in approximately 4 seconds, and the volume set was reconstructed on a commercially available dedicated workstation (Syngo X Workplace, Siemens Healthcare, Erlangen, Germany). After automatic depiction of the aortic valve cusps, a circle was generated indicating the aortic valve plane. The reconstruction was then rotated until the circle appeared as a straight line, indicating a view perpendicular to the valve (Figure 3). Perpendicular valve projections were generated starting from 45° right anterior oblique (RAO) and going to 45° left anterior oblique (LAO) in 5° steps. The appropriate caudal/cranial angle was added until the valve lined up perpendicularly. A single operator (T.M.) experienced in 3DA, who was not aware of the predictions from MDCT, performed 3DA angle predictions prospectively.

MDCT Image Acquisition and Analysis

The MDCT examinations were performed as previously described on a 64-detector Discover HD 750 CT scanner (GE Healthcare, Milwaukee, WI). A volume of 80 to 120 mL of iodixanol 320 (GE Healthcare, Princeton, NJ) was injected at 5 mL/s followed by 30 mL of normal saline. The MDCT scanner detector collimation width was 0.625 mm, detector coverage was 40 mm, reconstructed slice thickness was 1.25 mm, and the slice interval was 1.25 mm. Gantry rotation time was 0.35 seconds and the scan pitch ranged between 0.16 and 0.20 (adjusted per heart rate). ECG-gated dose modulation was used for all cases with the peak tube current and tube voltage prescribed based on body mass index. Image data acquired were then sent to an offline workstation (Advantage 4.4 Workstation, General Electric Healthcare Wukasha, WI).

A 3-dimensional volume-rendered transparent reconstruction of the thoracic aorta was performed using a transparent display to help mitigate the negative effects of significant valve calcification. Transverse axial images were reformatted into a double oblique transverse projection, using the oblique tools available on the workstation. Points were then deposited at the most inferior aspects of the valve cusps. From these points, a triangular trace was created that connected the 3 points corresponding to the most inferior aspect of the aortic cusps. A single radiologist (J.L.) with extensive cardiac MDCT experience, who was not aware of the predictions from 3DA, reviewed all cases. Angles were determined by manually rotating the 3-dimensional aortic reconstructions to discern the appropriate projection. Perpendicular valve projections were generated going from 45° RAO to 45° LAO in 5° steps. The angle was deemed appropriate when the triangle was not evident and was replaced by a line, suggesting that the 3 deposited points were in line.

Data Processing and Statistical Analysis

All analyses were performed with the use of SPSS software (version 17, SPSS Inc, Chicago, IL). Continuous variables are expressed as mean ± SD values. Categorical variables are described by frequencies and percentages. Comparison of continuous variables was performed by a t test. Linear regression lines by the least-squares method were drawn for every single patient for the predicted perpendicular valve view projections for 3DA and MDCT separately. The distance from the regression line to the final perpendicular post implant valve view was calculated for the cranial/caudal and RAO/LAO orientations (Figure 4). The shortest distance from the postdeployment perpendicular prosthesis view to the regression line of predicted perpendicular valve projections was calculated by combining the Pythagorean theorem and Euclid heights and sides theorem for both methods and each patient. Correlations are expressed by Pearson correlation coefficient. All statistical tests were 2-tailed, and a value of P<0.05 was considered statistically significant.

Figure 1. Aortic root angiogram. The aortic root angiogram confirms the predicted perpendicular valve projection showing all 3 cusps separately and in line. N indicates noncoronary; R, right coronary; and L, left coronary cusp.
Results
Forty consecutive patients with symptomatic severe aortic stenosis undergoing transfemoral TAVR had a preimplant 3DA and 68% of them also had a preimplant MDCT. All but 1 patient had adequate image quality for reproducible angle predictions. One-to-one capture during rapid ventricular pacing was achieved in all patients at rates between 160 to 180 beats per minute. Hypotension and a reduction in pulse pressure were transient in all patients. No patient had renal failure requiring hemodialysis after 3DA or MDCT using 20 to 32 mL or 80 to 120 mL (P<0.001) of radiographic contrast, respectively.

Valve deployment was performed at mean 4.9±6.0° LAO and 8.8±6.6° caudal. The mean postdeployment perpendicular prosthesis view was 4.6±6.4° LAO and 12.7±9.2° caudal (Figure 5).

There was a significant correlation between 3DA and MDCT for predictions of perpendicular valve view angles (Figure 5; \( r = 0.682, P<0.001 \)). The correlation was significant for angles close to midsagittal projections as well as for extreme RAO/LAO angulations.

Regression lines of the predicted angles were drawn for every patient and method (Figure 4). The mean distance from the regression line to the postdeployment perpendicular prosthesis view was 7.5±6.5° RAO/LAO and 7.1±6.4° cranial/caudal for 3DA and 11.7±7.5° RAO/LAO and 10.9±6.9° cranial/caudal for MDCT (\( P = 0.006 \) and \( P = 0.015 \), respectively). The shortest distance from the postdeployment perpendicular prosthesis projection to the regression line was 5.1±4.6° for 3DA and 7.9±4.9° for MDCT (\( P = 0.01 \), Figure 6). The mean difference between the 2 methods was 4.6±3.5°. There was a weak but significant correlation of this distance between the 2 methods, indicating that accuracy may be patient-dependent rather than method-dependent (\( r = 0.468; P = 0.043 \)), which may be caused by different patient characteristics (eg, aortic root calcifications). The slope of the regression lines were 0.96±0.21 for 3DA and 0.97±0.18 for MDCT (\( P = 0.974 \)), and their zero-crossings were 14.1±10.4° caudal for 3DA and 11.3±9.6° caudal for MDCT (\( P < 0.001 \)). This is to say that the regression lines were parallel, but the lines of 3DA were shifted about 3° more caudal to the MDCT lines, which may be caused by patient positioning. The mean distance from the implant angle to the postdeployment perpendicular prosthetic view was 1.9±4.6° RAO/LAO and 5.1±7.2° cranial/caudal. The shortest distance from the implant angle to the postdeployment perpendicular prosthetic view was 6.1±8.1°.

Discussion
Fluoroscopy is the imaging modality typically relied on during valve positioning and deployment in TAVR. Ideally, the native valve is imaged in a perpendicular view, where the valve is seen in profile with all 3 cusps in line and distinctly visible (Figure 1). When the valve is viewed from above or below and not seen in profile, positioning of the prosthesis

Figure 2. Postdeployment prosthesis projections. Postdeployment projections of balloon-expandable aortic valve prostheses are shown with the deflated balloon catheter still in place. A, The anterior struts are not superimposed on the posterior struts; B, they are perfectly superimposed, indicating a perpendicular view of the valve prosthesis.

Figure 3. Three-dimensional aortic root reconstruction. This 3-dimensional aortic root reconstruction (3DA) shows red dots on the bottom of the aortic cusps, a green dot for the right coronary ostium (RCO), a blue dot for the left coronary ostium (LCO), and a yellow line indicating the centerline of the ascending aorta. A, All 3 cusps are depicted separately. However, it is unsuitable for transcatheter aortic valve replacement (TAVR) because without a perpendicular valve projection, the annular plane in relation to the prosthesis will not be identifiable. B, Perpendicular valve view with all cusps separately depicted in 1 plane, which is optimal for TAVR. The red circle below the annular plane, becoming a straight line, indicates that the projection is perpendicular to the valve. The seeming fold in the aorta is the pigtail catheter placed in the noncoronary cusp. LAO indicates left anterior oblique.
during deployment is likely to be less accurate and the risk of malpositioning is increased. The most common approach to finding a perpendicular view is to perform repeated aortic root injections. However, this can be difficult, time-consuming, and increase radiation exposure and require large amounts of radiographic contrast. In patients with unusual anatomy, such as severe kyphoscoliosis or an unfolded aorta, it may be impossible to find a satisfactory implant angle using multiple aortic root angiograms and TAVR may be performed under suboptimal fluoroscopic projections, whereas aortic root reconstructions from MDCT have been shown to be helpful in predicting perpendicular valve view angles and may lead to more accurate prosthesis positioning.\textsuperscript{4,11}

Our study demonstrates that 3-dimensional reconstructions of the aortic root generated from in-laboratory, on-line C-arm rotational angiography can accurately assist in determining fluoroscopic projections perpendicular to the plane of the native valve. Three-dimensional angiographic reconstructions correlated well with MDCT, which has previously been demonstrated to be of clinical value. Our study showed that both methods were safe, practical, and accurate for planning and performing TAVR.

The contrast requirements for 3DA were less than for MDCT (20–32 mL versus 80–120 mL, $P<0.001$). With the traditional method of repeated aortic root angiograms, usually 10 to 15 mL of contrast is injected. Because it is rare to find a satisfactory projection with the first or second shot, the contrast requirements of the traditional method easily exceed those of 3DA. Whereas the C-arm spin for 3DA takes only 4 seconds, multiple aortic root angiograms from varying angles may be more time-consuming. For these reasons, 3DA and MDCT have become first-line methods for prediction of optimal implant projection in our institution.

Although no adverse effects were noted with either method, patients with severely impaired renal function did not undergo MDCT. Furthermore, there seems to be significant potential to reduce contrast in 3DA even further below the requirements of MDCT.

Because MDCT uses intravenous contrast, both the aortic root and the left ventricle are opacified, obscuring...
the native leaflets and valve plane. However, with 3DA, contrast is delivered directly into the aortic root while the left ventricle remains unopacified, facilitating imaging of the native leaflets and valve plane. Therefore, in 97.5% of patients, 3DA image quality was sufficient for angle predictions.

Patient positioning during MDCT may not be identical during the TAVR procedure if the patient is positioned slightly oblique or rolled to the side. In contrast, 3DA imaging obtained in an anesthetized patient immediately before TAVR is likely to be identical during the procedure. However, prediction errors of both methods significantly correlated, suggesting that patient factors were more important than method factors (eg, specific anatomy of the aortic root). There was only a 4.6° difference for predicting the perpendicular postdeployment prosthesis view between 3DA and MDCT. Although statistically significant, this difference may not be clinically relevant. When translated to fluoroscopic views, this difference will be hardly discernible to the naked eye and probably will not lead to differing clinical outcomes.

There are infinite perpendicular valve projections. However, for a given patient, there are only 3 perpendicular angles where all 3 cusps are visualized separately. Typically, only 1 or 2 of these views can be practically achieved in the clinical setting. In our experience, the favored projection is where the noncoronary cusp appears on the left, the left coronary cusp on the right, and the right coronary cusp in the middle (Figure 1). Both 3DA and MDCT can provide predictions for this optimal deployment view, due to their ability to differentiate the aortic cusps in a 3D volume (Figure 7).

A different method to determine a coplanar view of the aortic valve was previously evaluated against MDCT predictions in a similar fashion. The software (C-THV, Paieon), which generates a line of perpendicularity based on 2 aortic root angiograms, was deemed suitable for TAVR. The difference between C-THV and MDCT was 6.6° ± 4.9°, which is close to the 4.6° ± 3.5° difference between 3DA and MDCT observed in our study. Although contrast exposure of C-THV is comparable to 3DA, the C-THV software does not serve to identify the specific angle, where all 3 cusps are visualized separately. However, because of the inherent 3D reconstruction of the aortic root, MDCT and 3DA provide this valuable information.

Although 3DA appeared to be very helpful, the role of MDCT for patient selection, planning, and performing TAVR is well established. MDCT provides additional detailed anatomic assessment of the aortic root, valve annulus, coronary ostia, iliofemoral access, and aortic atheroma and calcification. The ability to assess perpendicular, coplanar views is an added benefit.

Study Limitations
This was not a randomized trial comparing clinical outcomes with 3DA and MDCT. Because predictions from both methods significantly correlate, it is unlikely that a randomized trial would show clinical differences. Predictions were compared with the postdeployment prosthesis projection, but a tilted prosthesis may not represent the original valve plane. However, postdeployment aortic root angiograms did not show relevant tilting, and both methods were compared with the same principle. The aortic cusps and the perpendicular valve view in 3DA are automatically identified and do not have to be defined by the operator. Therefore, intraobserver and interobserver variability in 3DA is not an issue, and operators with limited experience still render reliable predictions.

Figure 6. Deviation from the postdeployment perpendicular prosthesis view. The predictions of the 3-dimensional aortic root reconstructions (3DA) were closer (5.1° ± 4.6°) to the postdeployment perpendicular prosthesis view than the predictions from multidetector computed tomography (MDCT; 7.9° ± 4.9°, \( P = 0.01 \)).

Figure 7. Different projections of a 3-dimensional aortic root reconstruction (3DA). Although 3DA projection A shows all 3 aortic cusps, the projection is far from being perpendicular to the native valve and is therefore unsuitable for transcatheter aortic valve replacement. A possible perpendicular view is projection B, but the noncoronary cusp is hidden behind the right coronary cusp, which is suboptimal for accurate valve positioning especially of balloon expandable valves. This 3DA can further be rotated to identify the optimal deployment projection as seen in view C. LAO indicates left anterior oblique.
Conclusion
3DA and MDCT are safe, practical, and accurate imaging modalities for identifying the optimal deployment projection in TAVR.

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Disclosures
Dr Webb is a consultant to Edwards Lifesciences, Phillips, and Siemens Inc. Dr Leipsic is on the Speakers’ Bureau for Edwards Lifesciences, Inc. Teri Moore is an employee of Siemens.

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