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## Abstract

Angiography (or fluoroscopy) is essential for guidance during transcatheter aortic valve replacement (TAVR); however its utility to assess aortic annulus dimension is not well established. Only a few small-scale studies have compared angiographic measurements with other imaging modalities. In general, they have observed moderate correlation with multidetector row CT (MDCT) and transesophageal echocardiography (TEE). However intra- and interobserver reproducibility was only moderate with angiography and inferior to other modalities. Newer technology—such as the Paieon’s C-THV system—has been developed to help identify adequate perpendicular views to the annulus to facilitate accurate deployment and has been shown to be effective. Rotational angiography has been recently applied to TAVR, and preliminary data suggest a possible role for evaluation of aortic annulus dimensions as well as enhanced placement accuracy but more robust studies are needed. Rotational angiography has, however, been demonstrated to predict optimal projection angles reliably, with less radiation than MDCT and with limited use of iodinated contrast. These factors suggest the use of angiography and rotational angiography to be useful for assessment of aortic dimension and determination of optimal projection angles.

## Keywords

Angiography • Rotational angiography • Paieon’s C-THV system • DynaCT • Innova • 3-dimensional angiography (3DA)

## Abbreviations

LAO	Left anterior oblique
LVOT	Left ventricular outflow tract
MDCT	Multidetector computed tomography
MRI	Magnetic resonance imaging
RAO	Right anterior oblique
STJ	Sinotubular junction
TAVR	Transcatheter aortic valve replacement
TEE	Transesophageal echocardiogram
THV	Transcatheter heart valve
TTE	Transthoracic echocardiogram
2D	2-dimensional
3D	3-dimensional
3DA	3-dimensional angiography

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## Introduction

Fluoroscopy and cine-angiography are the main imaging modalities used during transcatheter aortic valve replacement (TAVR). Angiography is essential to guide femoral access, the manipulation of wires and catheters, and transcatheter heart valve (THV) positioning. They are also useful for the assessment of aortic regurgitation severity, assessment of procedural complications after THV deployment, and guidance of percutaneous access site closure for transfemoral cases. The success of these procedures relies on excellent angiographic imaging.

From early clinical experiences, it has been realized that portable fluoroscopic systems should be avoided since they do not generate images of adequate quality and have been implicated in cases of THV malposition. Angiography and rotational angiography can also be useful for pre-procedural assessment of the aortic valve complex. Recent studies however suggest that three-dimensional (3D) assessment of the annulus is essential to guide valve sizing and placement, and that use of such 3D modalities may help in reducing paravalvular regurgitation [1–4]. This chapter will review the role of angiography, rotational angiography, and adjunctive systems in the evaluation of aortic annular dimensions and optimal projection angle for TAVR.

## Angiography and Annular Measurement

The major limitation of angiography for aortic annular assessment is the two-dimensional (2D) aspect of this modality. While aortograms can be performed in multiple projections to assess different aortic planes, this technique may require significant amount of contrast and time and does not allow for a true 3D evaluation of the annulus. Angiographic assessment of the aortic annular dimension has been evaluated and compared to other imaging modalities in limited small studies, with methods used to measure annular dimension inconstant between studies.

Altioik et al. evaluated 49 patients with angiography, MDCT, transthoracic echocardiography (TTE), 2D transesophageal echocardiography (TEE), and 3D TEE [5]. In this study, two angiographic projections and a marked pigtail was used to assess annulus diameter. The sagittal plane was assessed with a 90° left anterior oblique (LAO) view and the coronal plane with a posteroanterior (PA) view. Each aortogram was done using 25 mL of contrast injected at a rate of 14 mL/s. The mean coronal diameter was significantly larger than the sagittal diameter ( $23.42 \pm 2.08$  mm vs.  $22.54 \pm 2.07$  mm;  $p < 0.05$ ). There was a moderate correlation between measurements obtained by angiography compared to those obtained from MDCT ( $r = 0.74$  for sagittal plane and  $r = 0.56$  for coronal plane). Intra- and interobserver

reproducibility was high for all other imaging modalities but was only moderate for angiography in the coronal ( $r = 0.57$  and  $r = 0.61$  for intra- and interobserver, respectively) and sagittal plane ( $r = 0.58$  and  $r = 0.56$ ).

Similarly, Kurra et al. also evaluated aortic annulus measurements obtained from angiography and compared it to MDCT in 40 patients by an alternate technique [6]. Annular dimensions were obtained from a right anterior oblique (RAO)/caudal and a LAO/cranial projection with coplanar alignment of the annulus. These investigators observed no significant difference in the dimensions obtained from the LAO and RAO projections ( $2.3 \pm 0.4$  cm vs.  $2.3 \pm 0.3$  cm;  $p = 0.67$ ). When these measures were compared with the corresponding images obtained from MDCT, there was a significant difference in the measures obtained in the RAO projection ( $2.4 \pm 0.3$  cm for angiography vs.  $2.2 \pm 0.3$  cm for MDCT;  $p = 0.029$ ) and a strong trend for those from the LAO projection ( $2.3 \pm 0.3$  cm for angiography vs.  $2.4 \pm 0.3$  cm for MDCT;  $p = 0.052$ ). The mean diameter derived from the 2 measures was, however, similar between the two imaging modalities ( $2.3 \pm 0.3$  cm for MDCT vs.  $2.3 \pm 0.4$  cm for angiography;  $p = 1.0$ ).

In a follow-up study, Tzikas et al. compared angiographic aortic annular measurement to TTE and MDCT in 70 patients [7]. Angiography was performed using a 6 F pigtail catheter in a coplanar view where the three cusps were aligned in the coronal plane and annuli diameters measured. Annuli diameters measured in coronal plane of MDCT (26.3 mm) were larger than with angiography (24.4 mm;  $p = \text{NS}$ ) and angiographic diameters were significantly larger than TTE diameters (22.6 mm;  $p < 0.05$ ) and MDCT in the sagittal plane (21.8 mm). Correlation between angiography and MDCT in the coronal plane was good ( $r = 0.76$ ) but only moderate when compared with TTE ( $r = 0.57$ ). Interobserver reproducibility was best with MDCT followed by angiography and TTE.

Finally, Paelinek et al. compared angiography with magnetic resonance imaging (MRI), TEE, and TTE in 28 patients [8]. A marked pigtail positioned in the noncoronary cusp was used, and the angiography was performed in a view aligning all cusps, similar to the latter description. Diameters were measured between the angiographic attachments of the calcified leaflets in systole. MRI, TTE, and TEE measurements were done using the sagittal plane. Unlike other prior studies, these investigators observed smaller annuli with angiography compared to all other modalities ( $p < 0.001$ ). The intra- ( $-0.27 \pm 0.39$  cm) and interobserver ( $-0.26 \pm 0.44$  cm) reproducibility was larger with angiography than with other modalities.

Collectively, angiographic assessment of annular dimension has been studied in limited, small-scale studies, many of which used different techniques to measure aortic annulus diameters. Several lessons have been learned from these early studies; namely, annular diameters are distinctive when obtained in different projection (sagittal vs. coronal).

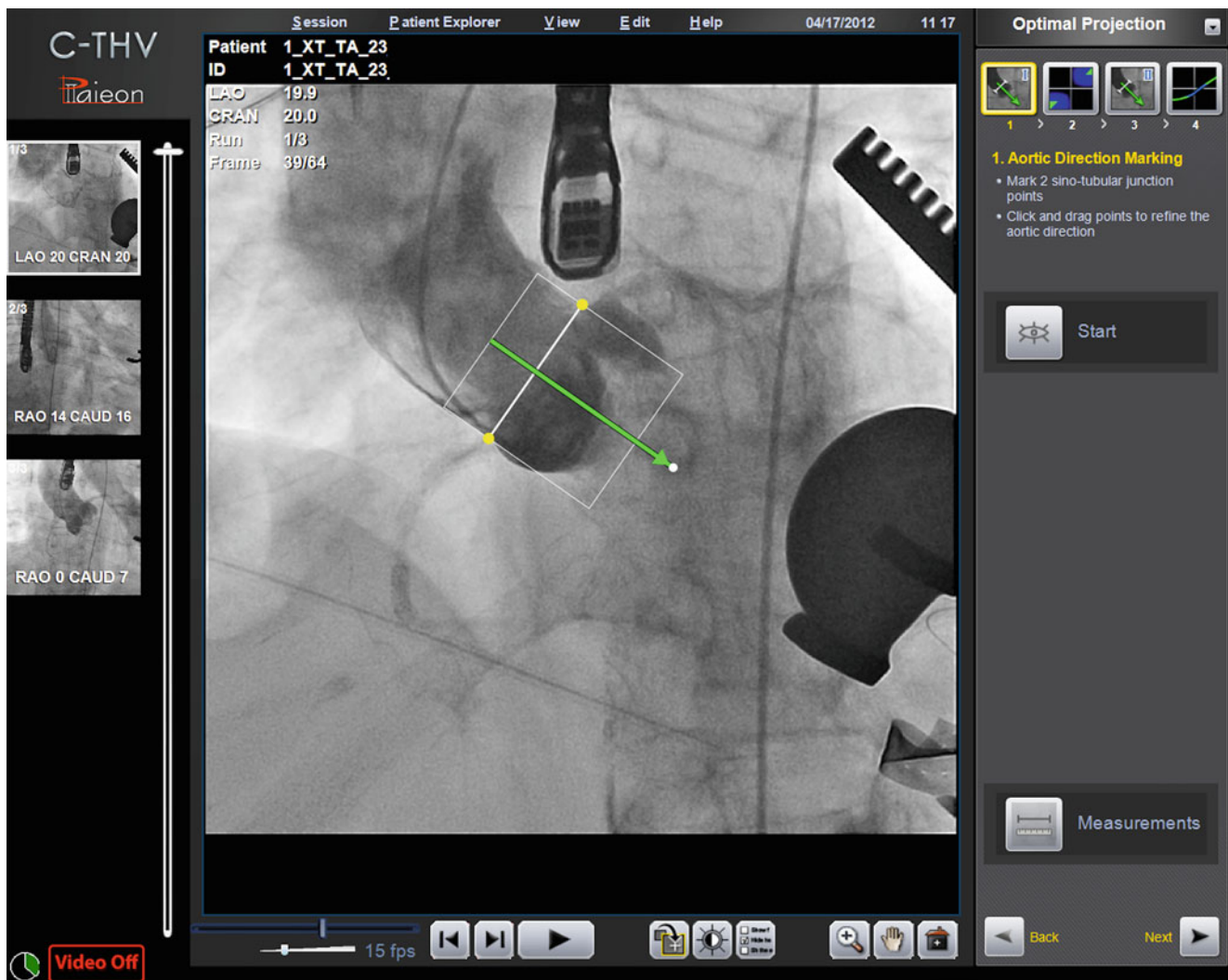
Dimensions in the coronal plane are larger than in the sagittal plane, consistent with observation from 3D TEE and MDCT. There seems to be moderate correlation between angiography and MDCT when comparing images obtained in the same plane. However, intra- and interobserver reproducibility is only moderate with angiography compared to good with MDCT. It is the authors' belief that 3D modalities such as MDCT are more reliable and robust for planning TAVR treatment.

## Angiography and Optimal Projection Angle

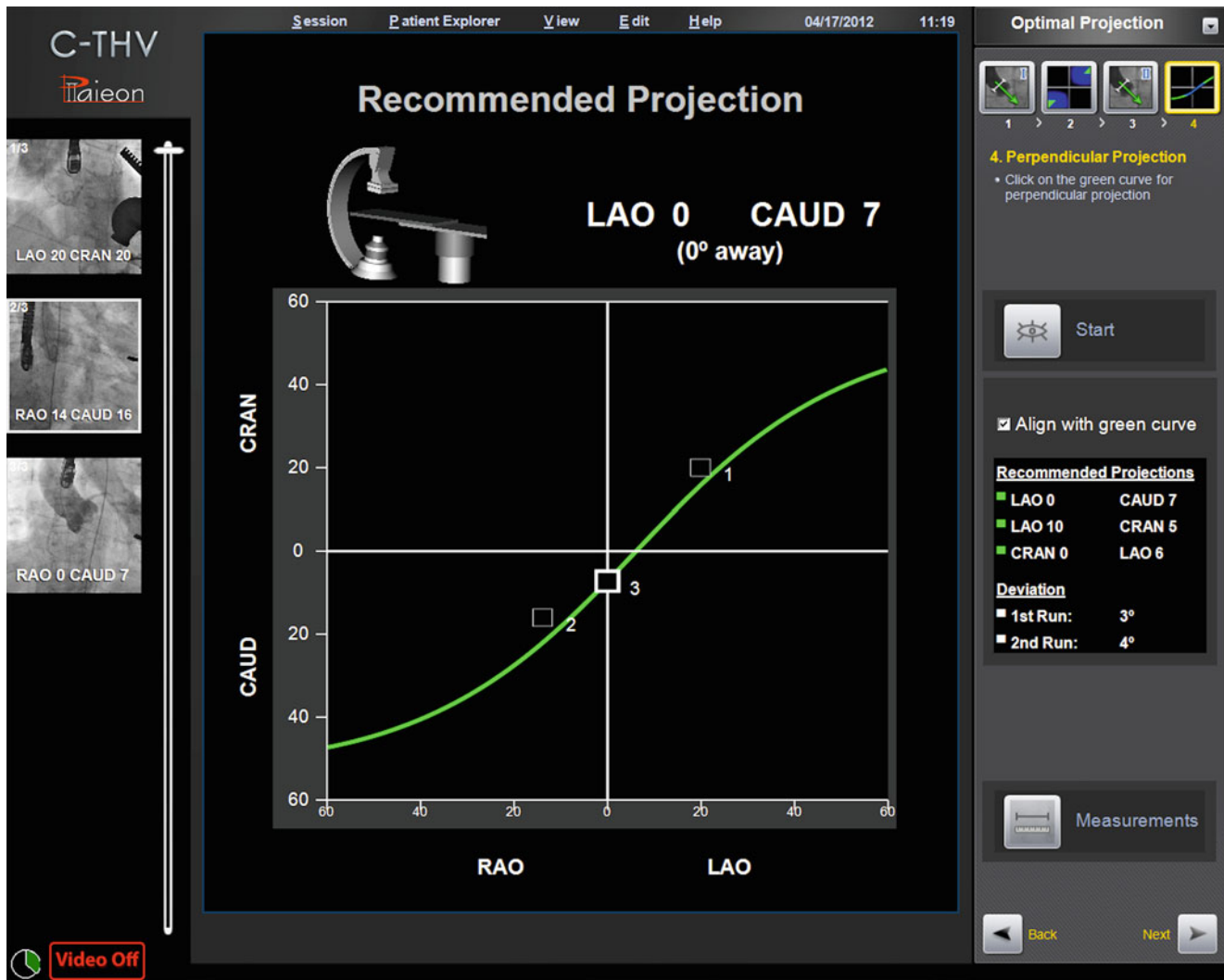
Angiography is useful not only to evaluate aortic annulus dimension but also to guide THV implantation. To facilitate optimal positioning of the THV, a perpendicular projection to the annulus plane is essential. This angle has traditionally been located by trial and error with repeated angiograms

using 10–15 mL of contrast but has also been evaluated for feasibility in limited study [9].

At present, the Paieon's C-THV system (Paieon, Israel) is a proprietary real-time angiography-based software designed to facilitate TVH implantation. It operates as a stand-alone PC workstation that is connected to the C-arm and hospital image network for image acquisition. An important clinical use for this system is to help the operator find a perpendicular projection for THV implantation. The system is based on two aortograms: a LAO/cranial and a RAO/caudal view (Fig. 30.1). With these two views, the system will generate a series of suitable angles for the operator (Fig. 30.2). This system has been studied by Tzikas et al. on 73 patients [10]. They retrospectively compared the results of the Paieon system with MDCT, wherein the mean difference in angle between both modality was  $6.6 \pm 4.9^\circ$ . Notably, the difference was significantly less if the second projection was done in the recommended zone of the system. When evaluated



**Fig. 30.1** Paieon's C-THV system using first aortogram and marking orientation of the aorta



**Fig. 30.2** Paieon's C-THV system showing multiple angle of perpendicularity based on two angiograms (#1 and 2). Angiogram #3 is on the curve and represents the projection chosen by the operator

prospectively, the C-THV system was also good at predicting working angle with a mean difference of  $5.5 \pm 3.4^\circ$  with the operator's choice.

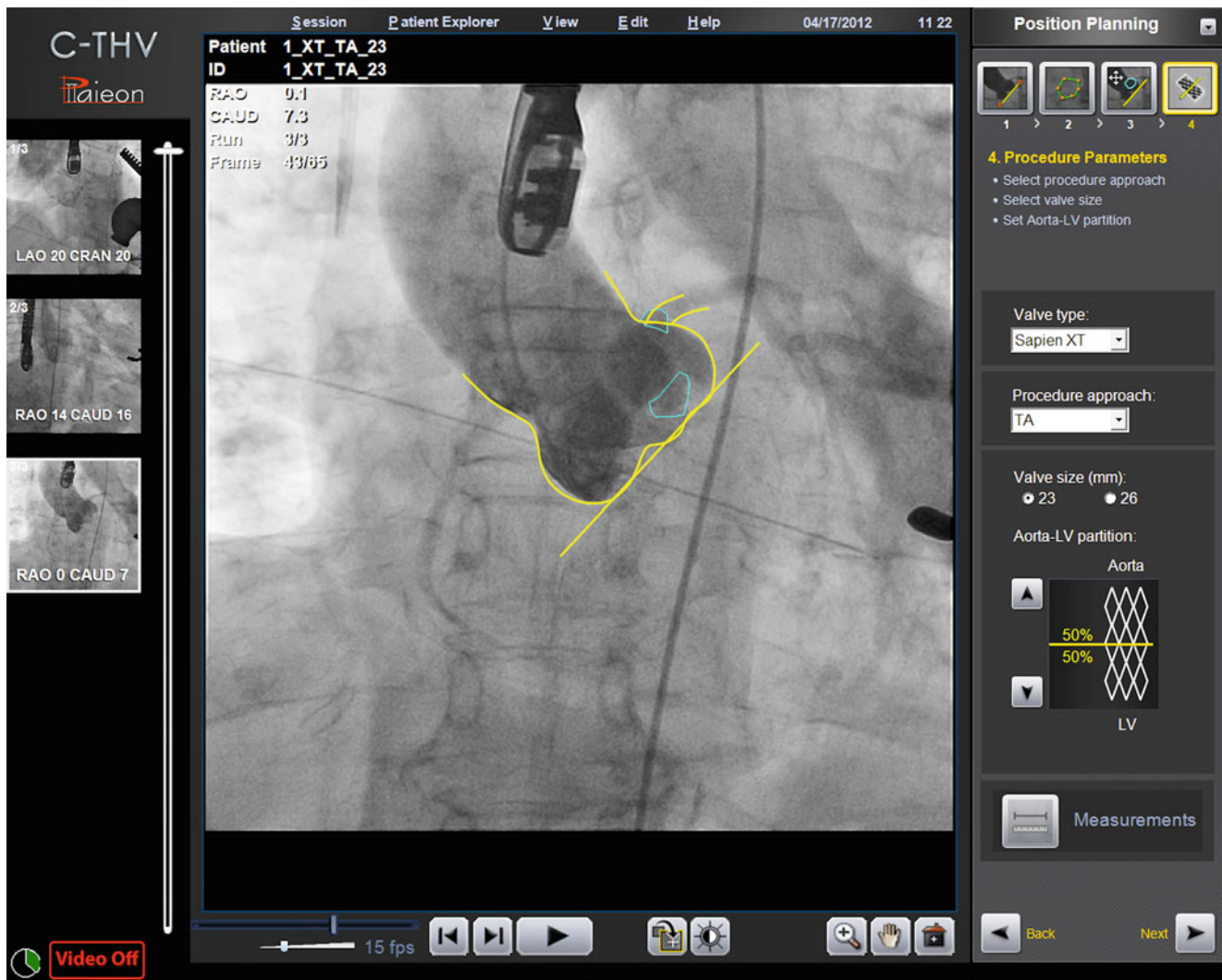
The C-THV system can also be used as an adjunctive imaging tool during valve positioning. Its ability to track calcification with real-time fluoroscopy allows the system to display a target line representing the aortic annulus plane (Fig. 30.3). During THV positioning, a yellow line denotes the annulus, while two green lines localize to the zone of the THV that is to be positioned at the annular level (Fig. 30.4).

Finally, the C-THV system allows post-deployment measurements in order to assess THV expansion (Fig. 30.5). This modality has not yet been validated clinically although in rare cases has allowed operators to recognize THV

under-expansion. Given these attributes, the Paieon system has been used as a research tool to evaluate additional stent expansion after balloon expandable THV post-dilatation [11].

## Rotational Angiography

Rotational angiography is a technology that utilizes an X-ray tube and flat panel detector system to acquire and allow construction of 3D images of both vascular and soft tissue structures. This is accomplished by rotating the C-arm around the patient ( $200\text{--}220^\circ$ ) while collecting an array of equally spaced 2D X-ray projection images and then using algorithms to reconstruct a 3D image. This

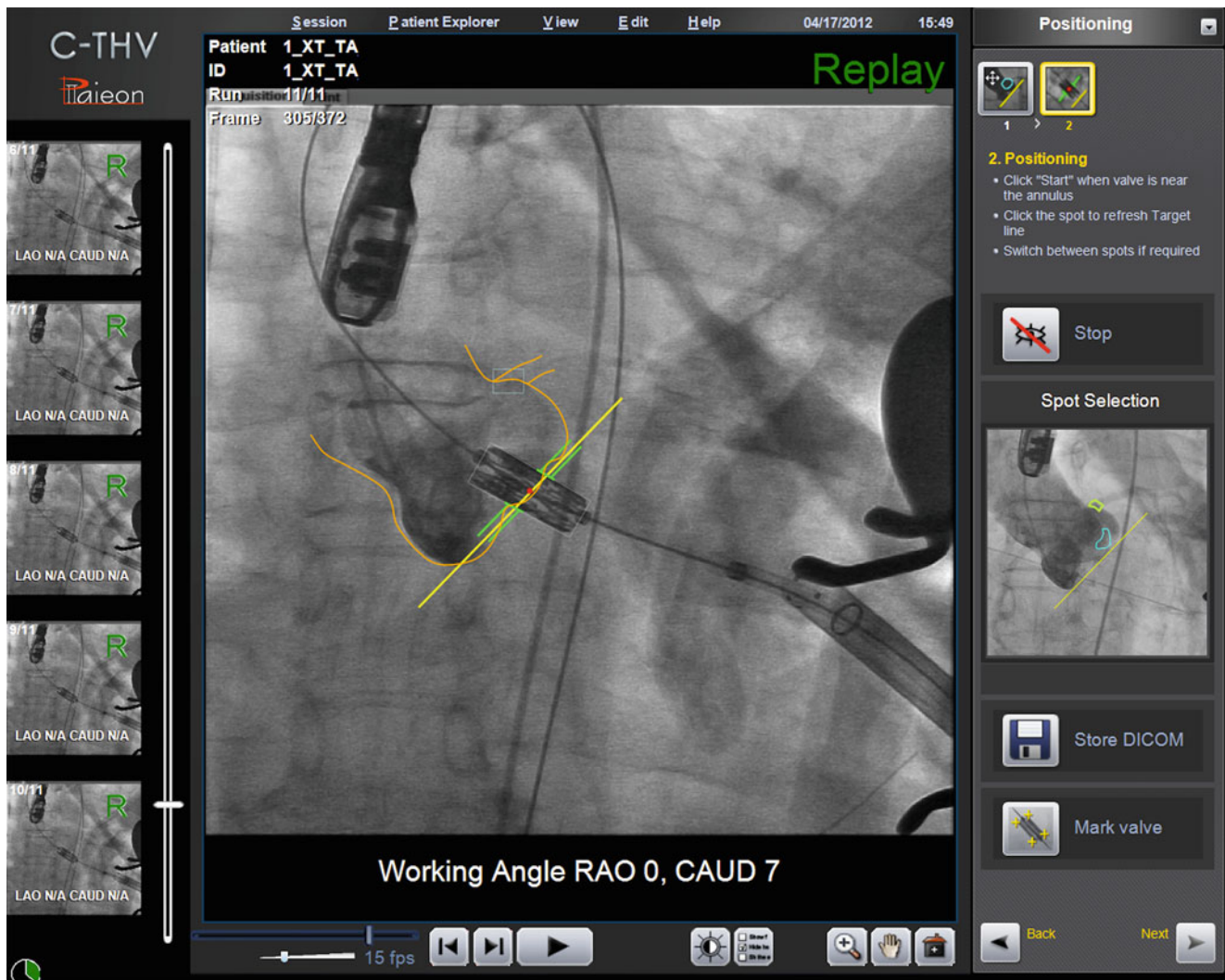


**Fig. 30.3** Paieon's C-TVH system showing contour tracking and the annulus target line

technology is now available from many manufacturers of cardiac catheterization laboratory suites: Siemens AG (Erlangen, Germany), GE Healthcare (Chalfont St Giles, UK), and Philips Healthcare (Best, the Netherlands). While this technique was at first limited to imaging high-contrast structures such as bone and contrast-filled vessels, the availability of flat panel detectors has enabled the ability to obtain CT-like images of soft tissue. This technology has recently been adapted for imaging dynamic structures such as the beating heart [12].

This adaptation of rotational angiography to the beating heart consists of making multiple sweeps (as opposed to the single sweep used for imaging static structures) while recording the ECG—such that a single arc of image data can be collected for one phase of the cardiac cycle

via retrospective gating—and a 3D image for that phase can then be reconstructed. Rotational angiography has been successful at imaging heart structures including the four cardiac chambers, pulmonary outflow tract, pulmonary veins, and proximal coronary arteries. With the use of rapid ventricular pacing during aortography, single-sweep imaging of the ascending aorta can be performed with excellent resolution. This new technology has now been applied to TAVR. It has been combined with software dedicated to identify the plane of the aortic annulus and aortic dimensions in various packages (Syngo X Workstation, Siemens Healthcare; Innova 3D cardiac, GE Healthcare; HeartNavigator, Philips Healthcare). Evidence of its utility predicting projection angles and for annular dimension assessment is accumulating.



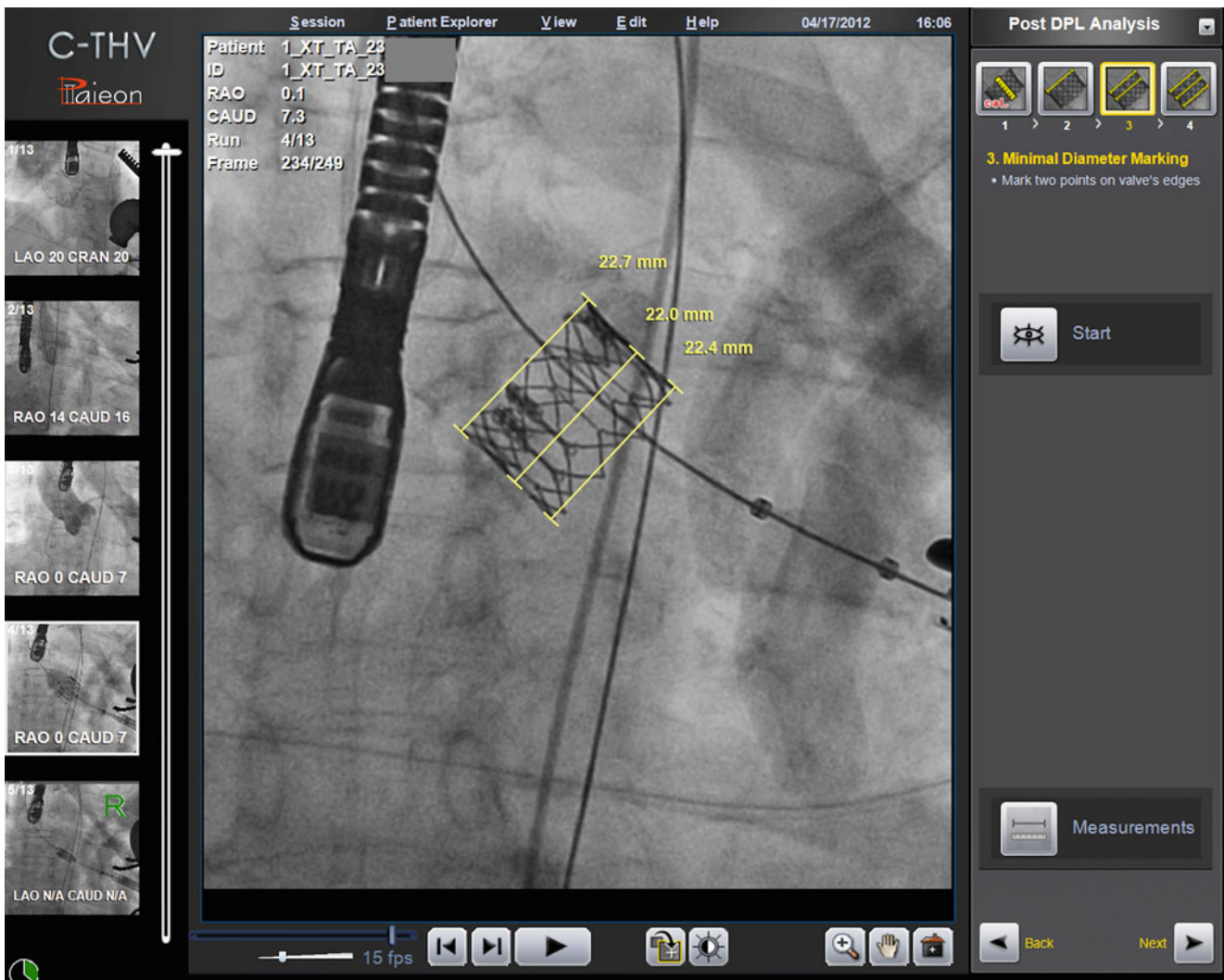
**Fig. 30.4** Paieon's C-THV system during THV positioning. The contour of the aorta and the annulus line are shown in yellow. The green lines represent the middle of the THV, which should be deployed at the

level of the aortic annulus. The system allows different configuration of the green lines (e.g., 60 % aortic, 40 % ventricular)

## Evidence Supporting Use of Rotational Angiography

Bai et al. evaluated radiation dose of MDCT compared to rotational angiography or C-arm CT, or DynaCT (Siemens AG, Erlangen, Germany) [13]. For all scanning protocols evaluated, a significant reduction in organ dose with DynaCT was observed as compared to MDCT with comparable image quality. More recently, Binder et al. evaluated the efficacy of angiographic 3D reconstruction using DynaCT to predict optimal deployment projection for TAVR and compared it with MDCT [14]. 3D angiography (3DA) images were acquired during rapid ventricular pacing (160–180 bpm) and a breath hold. A 6 F pigtail catheter positioned in the non-coronary cusp was used to inject 32 mL of contrast at 8 mL/s

(or 20 mL of contrast diluted with 40 mL of normal saline injected at 15 mL/s). Volume sets from rotational angiograms were reconstructed using a dedicated workstation (SyngoX Workstation, Siemens Healthcare, Erlangen, Germany) that automatically depicted the aortic valve cusps and generated a circle indicating the annular plane (Fig. 30.6). Predicted projections were compared with post-deployment projections showing superposition of anterior and posterior stent struts. 3DA was obtained in 40 patients (68 % also had a MDCT) with image quality was inadequate in 1 patient. There was a significant correlation between 3DA and MDCT for prediction of perpendicular views ( $r=0.682$ ;  $p<0.001$ ). The shortest distance from the post-deployment perpendicular prosthesis projection to the regression line was shorter for 3DA ( $5.1\pm 4.6^\circ$ ) than for MDCT ( $7.9\pm 4.9^\circ$ ;  $p=0.01$ ).

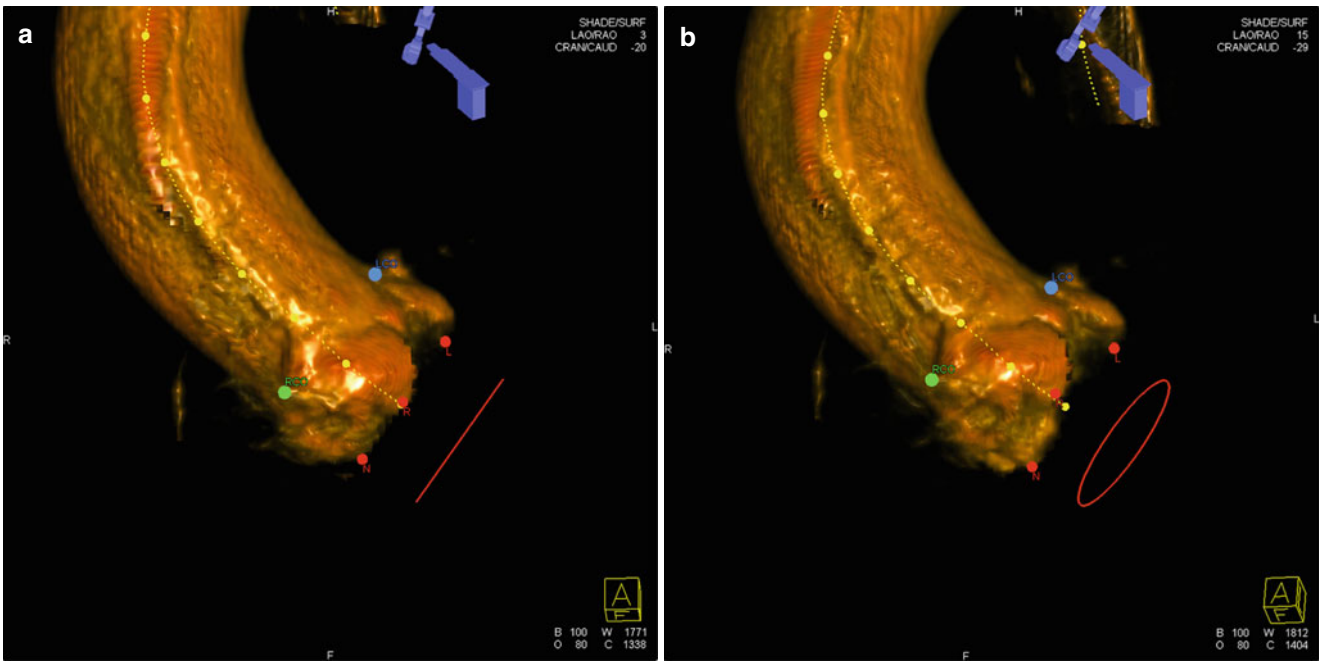


**Fig. 30.5** Paieon's C-THV system post-deployment analysis showing inflow, mid, and outflow dimension of the THV stent

Despite these small differences, this study confirmed the feasibility of 3DA to identify a perpendicular angle.

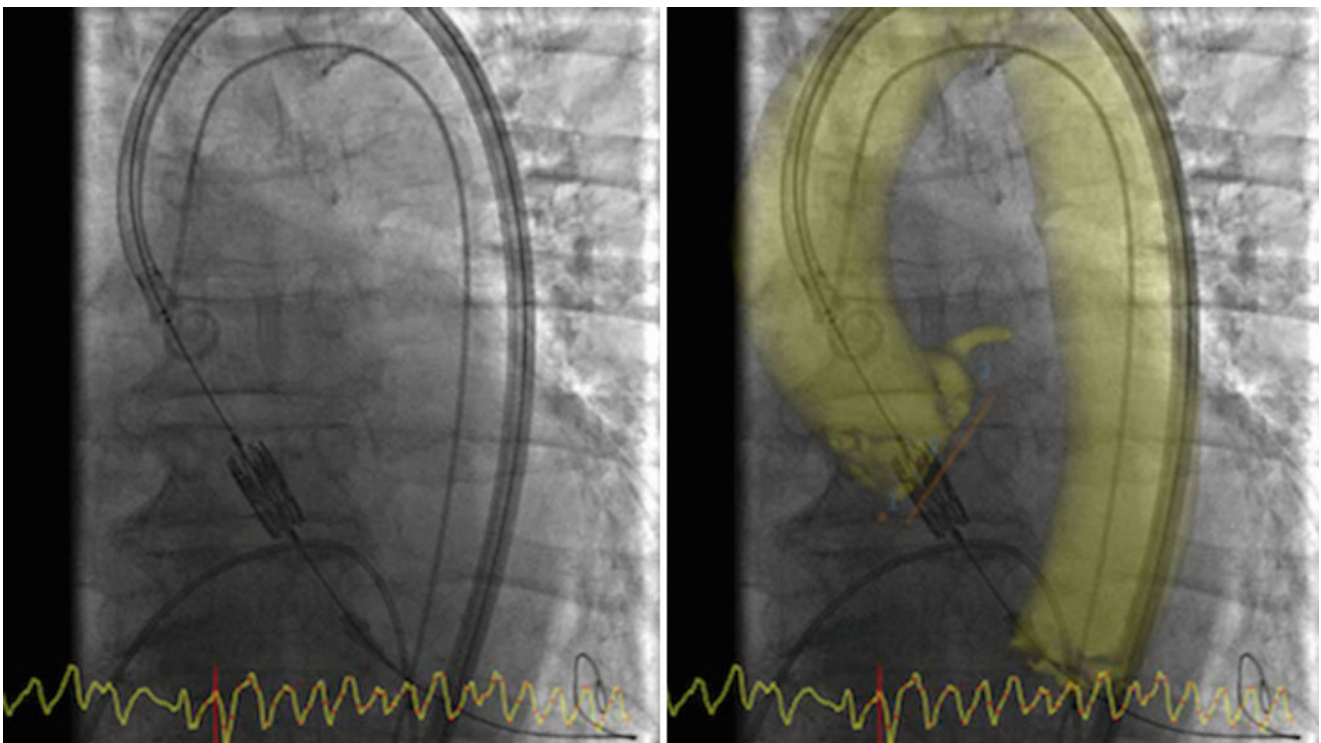
The ability to perform 3DA during the procedure ensures identical patient positioning and may explain the slight superiority compared to MDCT in this study. The Paieon's C-THV system, as mentioned above, has been demonstrated to be helpful to determine perpendicular projections. The 3DA and the Syngo software add to possibility to visualize the geographic position of each cusp, which may help further the operator to pick an adequate projection for THV implantation. Meyhöfer et al. measured aortic annulus diameter using rotational angiography and compared it with TEE in 99 patients [15]. A different fixed C-arm system (Innova 3100<sup>IQ</sup>, GE Healthcare, Chalfont St Giles, UK) with a square 30 cm flat panel detector to perform the 3D rotational angiography acquisition (Innova 3D Cardiac) (Fig. 30.7) was used. The system records 150 projections at 30 frames per second

during the 5 s 200° rotation. Images are automatically sent to the post-processing workstation (Advantage Workstation, Volume Share, GE Healthcare, Chalfont St Giles, UK) and reconstructed in 3D volume. To minimize motion of the cardiac structure and minimize contrast utilization, acquisitions were performed under rapid pacing at 180 beats per minute (bpm) and during a breath hold. Injection of 50 mL of contrast at a rate of 12 mL/s was done with a 5 F pigtail catheter positioned in the ascending aorta. The investigators were able to obtain adequate images to assess annular diameter in all patients. Slightly larger annular dimensions were observed with rotational angiography ( $22.13 \pm 2.09$  mm) when compared to TEE ( $21.58 \pm 2.09$  mm), while the sinotubular junction (STJ) was similar with both modalities ( $26.22 \pm 2.71$  vs.  $26.22 \pm 2.73$ ) (Fig. 30.8). There was a good correlation between rotational angiography and TEE for annulus and STJ dimensions ( $r=0.83$ ).



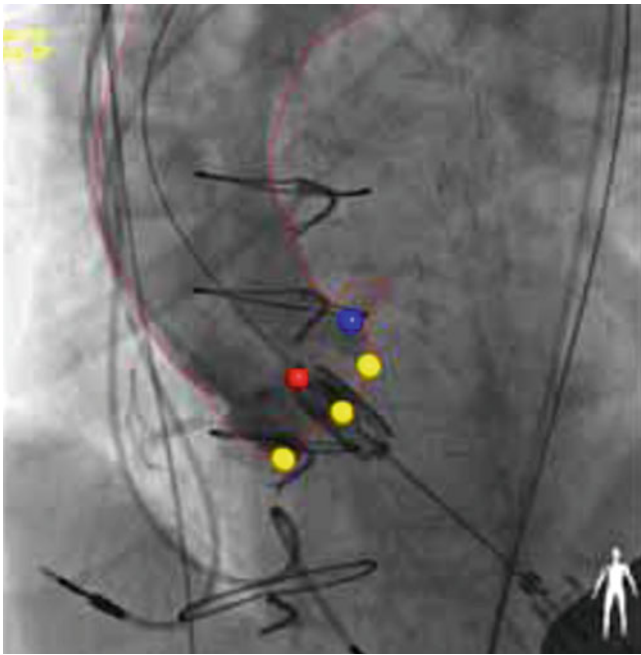
**Fig. 30.6** Rotational angiography using DynaCT and the Syngo software for 3D reconstruction. The *red dots* represent the nadir of each cusp. The *blue dot* represents the ostium of the left main coronary artery and the *green dot* the ostium of the right coronary artery. In panel (a),

all cusps are aligned on the same plane and the *red circle* is seen as a *line*. In panel (b), the *circle* is seen since the cusps are not aligned in the same plane



**Fig. 30.7** Superimposition of aortic landmark and annulus plane obtained from prior CT scan over live fluoroscopic images using the GE system





**Fig. 30.8** Superimposition of aortic landmark and annulus plane obtained from prior CT scan over live fluoroscopic images using the HeartNavigator (Philips) system. *Yellow dots* represent virtual annular ring, and *blue* and *red dots* represent the origins of the left main and right coronary arteries, respectively

### Limitations of Rotational Angiography

While this new technology seems promising for prediction of an optimal projection angles during TAVR procedures, some limitations with regard to aortic annular sizing must be considered. Similar to angiography, the techniques described above evaluate a different anatomical “annulus” than MDCT or TEE since the left ventricular outflow tract (LVOT) is not filled by contrast. Perimeter and area measurements with this technique are subject to significant intra- and interobserver variability owing to no clear anatomical delineation between the nadirs of each cusp. Different imaging protocols may be explored in the future with the pigtail across the aortic valve that would allow for injection of contrast in the LVOT and the aorta during rapid ventricular pacing to assess the ability to reproduce the measures acquired with CT. However, this may compromise the reliable identification of optimal projection angles and may require greater amount of contrast. Further studies comparing rotational angiography to MDCT are warranted before this technique should be adopted as a standard.

### Conclusion

There is growing evidence suggesting that 3D assessment of the aortic annulus is essential for appropriate THV selection. Rotational angiography has shown great promise for encouraging this evaluation, but greater clinical

evidence and larger scale studies comparing it to commonly used modalities are necessary to support its routine utilization for annular sizing.

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