Manual versus automatic detection of aortic annulus plane in a computed tomography scan for transcatheter aortic valve implantation screening

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Abstract

OBJECTIVES: Precise measurements of aortic annulus dimensions are crucial for prosthesis size selection in patients undergoing transcatheter aortic valve implantation (TAVI). The so-called effective diameter (derived from area) measured in multislice computed tomography (MSCT) images has evolved to be the most precise measurement tool. Usually, the operator must manually adjust the aortic annular plane. Syngo Aortic ValveGuide (Siemens Healthcare) is a new software tool that allows for automatic aortic root reconstruction and annular plane detection. The aim of this study was to compare the effective diameter measured in automatically detected and manually adjusted annular plane.

METHODS: Seventy-three raw image datasets of preoperative TAVI MSCT scans were analysed using our institutional gold standard (3Mensio Valves™) with manual annular plane adjustment and using Aortic ValveGuide with automatic annular plane detection. The aortic annular circumference was manually marked for both software tools, and the effective diameter was calculated using the formula: effective diameter = 2 × \(\sqrt{\frac{\text{circumferential area}}{\pi}}\).

RESULTS: Automatic annulus plane detection using Syngo Aortic ValveGuide worked well in all MSCT scans. Minor manual adjustment of the detected plane was necessary in only 3 patients. The mean effective aortic annulus diameter was 23.1 ± 2.4 mm for 3Mensio and 23.3 ± 2.4 mm for Syngo Aortic ValveGuide. Bland-Altman analysis of both imaging software tools showed good agreement (mean difference of 0.16 mm and limits of agreement of −0.48 to 0.80 mm).

CONCLUSIONS: Effective aortic annulus diameter measured with Syngo Aortic ValveGuide, as a new imaging software that allows for automatic aortic annular plane detection, shows good agreement to gold standard measurements. Automatic annulus plane detection might reduce the effort for MSCT analysis and may lead to more reproducible aortic annulus measurements. Aortic ValveGuide is part of the DynaCT and in future aortic annulus dimension measurements may be feasible during intraoperatively acquired DynaCT.

Keywords: Transcatheter aortic valve implantation • Sizing • Aortic Annulus • Multislice computed tomography

INTRODUCTION

As transcatheter aortic valve implantation (TAVI) is a ‘closed heart’ procedure, no direct measurement of the aortic annulus can be performed in contrast to conventional aortic valve replacement (AVR) where direct measurement of the decalcified aortic annulus is performed to choose the appropriate aortic valve prosthesis. Therefore, precise preoperative imaging is absolutely mandatory in TAVI procedures. A significant sizing mismatch can lead to fatal complications, such as valve embolization, paravalvular leaks or even annular rupture [1–3]. In the early period of TAVI, the largest end-systolic diameter in transoesophageal echocardiography (TEE) was defined as the gold standard for annulus measurement [4, 5] with the lack of 2D visualization of the complex 3D geometry of the annulus. Therefore, multislice computed tomography (MSCT) evolved as a routine screening tool for TAVI evaluation, offering 3D images of all relevant anatomical structures such as the aortic annulus [6–10]. Owing to the fact that the aortic annulus is not a circular but rather an oval structure, exact measurement is important. Computed tomography (CT) offers direct measurement of the diameter (minimum, maximum) as well as the calculation of the diameter based on the area of the aortic annulus which turned out to be one of the most precise measurement techniques.
techniques correlating best to ‘real’ intraoperative aortic annulus sizing [6, 8]. One key step of aortic annulus measurement in MSCT is detecting the annular plane, which is defined as the most caudal attachment of the three native aortic cusps (so-called nadirs) [8, 9]. At conventional MSCT workstations, detecting this plane requires manual detection and segmentation of the aortic root together with manual adjustment in all three planes to localize the annular plane. In clinical practice, this is time consuming, requires high expertise in imaging and is associated with a learning curve, which may lead to inconsistent results. One semi-automatic imaging tool for aortic root assessment is 3Mensio Valves™ (3Mensio Medical Imaging BV, Bilthoven, Netherlands) [11], which is routinely used in our centre.

Syngo Aortic ValveGuide (Siemens, Inc., Erlangen, Germany) is a software tool for fully automatic aortic root assessment with automatic detection of all relevant anatomical ‘landmarks’ including aortic annulus plane for TAVI patients. It is part of the DynaCT package and not yet separately available. The aim of this study was to compare effective aortic annulus diameters measured by our institutional gold standard vs Syngo Aortic ValveGuide measurements.

**METHODS**

**Study population**

Seventy three patients who underwent our institutional TAVI-screening protocol were prospectively included into this study. The study was approved by the local ethics committee and all patients granted their written informed consent. All patients had standardized MSCT scan for TAVI access planning and aortic annulus dimension measurements. Patient characteristics are summarized in Table 1.

Table 1: Baseline characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Age (years)</td>
<td>82 ± 6</td>
</tr>
<tr>
<td>Female (n/%)</td>
<td>58.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164 ± 11</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73 ± 17</td>
</tr>
<tr>
<td>Mean NYHA functional class</td>
<td>3 ± 0.6</td>
</tr>
<tr>
<td>Mean logistic EuroSCORE (%)</td>
<td>25.5 ± 13.9</td>
</tr>
<tr>
<td>Mean EuroSCORE II (%)</td>
<td>7.2 ± 5.9</td>
</tr>
<tr>
<td>Mean STS score (%)</td>
<td>7.3 ± 3.9</td>
</tr>
<tr>
<td>Hypertension (n/%)</td>
<td>68/93.2</td>
</tr>
<tr>
<td>Diabetes (n/%)</td>
<td>42/57.5</td>
</tr>
<tr>
<td>Hyperlipoproteinemia (n/%)</td>
<td>41/56.2</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease (n/%)</td>
<td>20/27.5</td>
</tr>
<tr>
<td>Coronary artery disease (n/%)</td>
<td>50/68.5</td>
</tr>
<tr>
<td>s/p PCI (n/%)</td>
<td>30/41.1</td>
</tr>
<tr>
<td>Previous cardiac surgery (n/%)</td>
<td>16/21.9</td>
</tr>
<tr>
<td>Peripheral vascular disease (n/%)</td>
<td>22/30.1</td>
</tr>
<tr>
<td>Previous stroke (n/%)</td>
<td>10/13.7</td>
</tr>
<tr>
<td>Atrial fibrillation (n/%)</td>
<td>31/42.5</td>
</tr>
<tr>
<td>Previous pacemaker (n/%)</td>
<td>21/28.8</td>
</tr>
<tr>
<td>Mean ejection fraction (%)</td>
<td>54.6 ± 15.7</td>
</tr>
<tr>
<td>Mean aortic gradient (mmHg)</td>
<td>40.0 ± 16.1</td>
</tr>
<tr>
<td>Maximum aortic gradient (mmHg)</td>
<td>65.8 ± 25.0</td>
</tr>
<tr>
<td>Mean aortic valve area (cm²)</td>
<td>0.68 ± 0.3</td>
</tr>
<tr>
<td>Aortic regurgitation &gt;1 (n/%)</td>
<td>10/13.7</td>
</tr>
<tr>
<td>Mitral regurgitation &gt;1 (n/%)</td>
<td>7/9.6</td>
</tr>
<tr>
<td>Mean pulmonary artery pressure (mmHg)</td>
<td>48.7 ± 16.8</td>
</tr>
</tbody>
</table>

**Computed tomography**

CT scans were performed in a 64-slice dual source scanner (Siemens medical Solutions, Erlangen, Germany). Contrast enhanced scans were performed by intravenous administration of Solutrat 370 (Iopamidol, 370 mg Iod/ml, Bracco Imaging Deutschland GmbH, Konstanz, Germany) in an antecubital vein using 80–120 ml with a flow of 4 ml/s followed by a bolus of 50 ml isotonic saline with equal flow. Scan timing was coordinated by peak enhancement detection with region of interest in the ascending aorta choosing a threshold of 120 Houndsfield Units. Exposure parameters included a tube voltage of 120 kV and 320–400 effective mAs. Scan pitch was 0.2, scan rotation time 330 ms and the detector aperture was 0.6 mm.

**Institutional gold standard analysis of aortic annulus diameters**

The images were post-processed and analysed by the software application 3Mensio Valves™ (3Mensio Medical Imaging BV). After segmentation of the ascending aorta, the aortic annulus was rendered by determination of the three valve hinge points using multiplanar reformation planes followed by a computer-guided reconstruction of the resulting annular transverse plane. To calculate the effective diameter (CTeff), the luminal circumference was measured, and the software displayed the area of this circumference. The equation for the area of a disc (disc area = π × r²) was used to calculate the diameter of a disc with a corresponding area (CTeff = 2 × √(circumferential area/π)).

**Aortic annulus measurements using Syngo Aortic ValveGuide**

The raw MSCT image datasets were imported into the Syngo Aortic ValveGuide workstation and the software automatically reconstructed a 3D image of the aortic root. The workstation screen shows three orthogonal intersection planes and the 3D volume rendering (Fig. 1). Syngo Aortic ValveGuide offers some additional, automatically detected landmarks (Fig. 1): the most caudal attachment of the three aortic valve leaflets (nadirs), the right and the left coronary ostium, the aortic valve commissures and a centre-line through the ascending aorta. Based on these automatically detected landmarks, some additional information is projected onto the 3D image. All landmarks are manually adjustable, if necessary. The landmarks can be cross-checked by clicking the button ‘show landmarks’. After checking all landmarks, the operator can automatically switch to the aortic annular plane (Fig. 2) and Syngo Aortic ValveGuide allows for aortic annulus measurements. Effective aortic annulus diameter was then calculated similarly to the 3Mensio Valves™ system.

**Statistical analysis**

Statistical analysis was performed using SPSS™ statistical package 20 (IBM Corp.). Quantitative variables were expressed as mean (standard deviation = SD) or median (interquartile range) and qualitative variables as percentages. Annulus diameters were tested for normal distribution using Kolmogorov-Smirnov test.
The different diameter measurements in the same patient were compared using Student’s t-test for paired data. Pearson’s correlation coefficient was calculated. Bland–Altman plots with 95% limits of agreement (mean difference $\pm 1.96 \times SD$) were used to compare the different imaging techniques. All statistical tests were two-sided. Differences were considered statistically significant at $P < 0.05$.

**RESULTS**

**Study population**

Of the 73 patients who underwent TAVI screening, 54 underwent successful TAVI procedures. Of the resulting 19 patients, 5 underwent conventional AVR, 10 underwent conservative treatment, 2 underwent valvuloplasty and 2 died prior to the TAVI procedure. No patient was excluded from TAVI due to annular reasons. Two patients underwent conventional AVR due to intermediate risk profile, 2 due to concomitant CABG and 1 wanted conventional AVR.

**Annulus measurements**

Automatic annular plane detection using Syngo Aortic ValveGuide worked well in all MSCT scans. In 3 patients, the contrast of one of the nadirs was poor, and the automatic detected landmark had to be adjusted by the operator. These were only minor manual adjustments of 1 and 2 mm, respectively.

Mean effective aortic annulus diameter was $23.1 \pm 2.4$ mm for 3Mensio and $23.3 \pm 2.4$ mm for Aortic ValveGuide ($P < 0.001$). 95% confidence interval for the difference of 0.2 mm was 0.08–0.24 mm. Normal distribution testing using Kolmogorov–Smirnov showed a significance of 0.2. Correlation coefficient was 0.995 ($P < 0.001$) (Figs 3 and 4).

Bland–Altman analysis of both imaging software tools showed good agreement with mean difference of 0.16 mm and −0.48 to 0.80 mm limit of agreement (Fig. 5).
DISCUSSION

TAVI evolved to a highly standardized routine procedure for the treatment of elderly high-risk patients with severe aortic valve stenosis with worldwide increasing numbers of implantations [12–14]. One key step for successful TAVI is optimized patient selection in terms of preoperative anatomical screening. Imprecise anatomical measurements of the aortic annulus can lead to severe intra-procedural complications such as annular rupture, valve embolization and significant paravalvular leaks [1–3]. Especially paravalvular leaks might have been underestimated in the early period of TAVI, while, nowadays, it became obvious that significant leaks are associated with worse outcome [15]. A second lesson learned while gaining more TAVI experience is that 2D TEE does not respect the 3D oval shape of the aortic annulus and might lead to imprecise aortic annulus diameter measurements [6, 16, 17]. Three-dimensional TEE becomes more and more available and seems to better reflect the annular anatomy than 2D TEE [18–21], and is a useful tool for aortic annulus diameter measurement. In addition, MSCT has been established as a technique for precise measurement of the complex 3D geometry of the aortic annulus including its calcification [6–10, 22]. One major advantage of MSCT in TAVI screening is the option to screen femoral access, coronary distance and aortic annulus all in one.

Manual measurement of the aortic annulus at conventional CT workstations requires experienced users due to some complex steps of analysis. The key step is the detection of the annular plane, which requires several adjustments in each of the three orthogonal planes. This leads to a high inter-individual variance and maybe to non-reproducible results [23]. Furthermore, it can be a time-consuming procedure. To improve the situation, a standardized software tool, 3Mensio Valves™ (3Mensio Medical Imaging BV) became clinically available. It was one of the first semi-automatic imaging tools for aortic root assessment [11]. Over the past years, it has evolved to our institutional standard for analysing TAVI-screening MSCT scans.

Syngo Aortic ValveGuide (Siemens, Inc.) is a prototype software tool allowing for fully automatic aortic root assessment with automatic detection of all relevant anatomical landmarks including the aortic annular plane for TAVI patients. The user imports the raw MSCT dataset into the workstation and all key steps are processed automatically within a few seconds until a complete 3D aortic root model together with the three orthogonal conventional MSCT planes are displayed on the screen. The user can check all detected landmarks by just clicking a button and can manually adjust the landmarks if their position is not absolutely precise. After checking the landmarks, just clicking on another button directly displays the aortic annular plane, and the measurements can be performed in the usual fashion. The aortic annulus can be circumscribed by individual dots and the software automatically shows the minimum, maximum and mean diameter, the area and the circumference of the annulus. The effective diameter based on area and circumference is also directly displayed.

The present study is the first to evaluate the Syngo Aortic ValveGuide for aortic annulus measurements and compares the results to an established semi-automatic analysing tool.

In our study, the user confirmed all automatically detected landmarks, including the annular plane. In 3 patients, only minor manual adjustments of one of the three nadirs was necessary, due to poor contrast. This indicates that the automatic detection of the landmarks and the resulting 3D aortic root model work precisely.
and reproducible. However, a short cross-check by the operator by just clicking on the landmark button is mandatory. The analysing time after importing the raw dataset was <2 min until the aortic annulus was measured, whereas the measurements using 3Mensio Valves™ take about 3 min.

The mean difference between the effective aortic annulus diameter measured by Syngo Aortic ValveGuide and 3Mensio Valves™ was 0.2 mm only. Although this difference was statistically significant according to t-test analysis, a difference of 0.2 mm should not be considered as clinically relevant. Also, the correlation coefficient of 0.995 indicated good concordance of these two techniques. Bland–Altman analysis confirmed these findings with a mean difference of 0.16 mm and –0.48 to 0.80 mm limit of agreement.

These results strongly indicate that Syngo Aortic ValveGuide allows for precise measurements of the aortic annulus diameter with similar results to the institutional gold standard 3Mensio Valves™. The automatic detection of the annular plane works precisely and is reproducible. It further helps to minimize the time-consuming step of manual detection of the respective planes. The option of manual adjustment of the detected landmarks allows for optimizing the measurement although manual adjustment was necessary in three patients only. Syngo Aortic ValveGuide may allow for aortic annulus measurements even for inexperienced users and centres that start their TAVI program.

Syngo Aortic ValveGuide is part of the DynaCT (Siemens, Inc.), a rotational angiography that can be performed during the TAVI procedure [24, 25]. At the moment, DynaCT is mainly used for detecting the optimal implantation angulation by contrasting the aortic root. Future developments of DynaCT will lead to contrasting the left ventricle and then aortic annulus measurements can also be performed using Syngo Aortic ValveGuide. This might make intraoperative annulus sizing feasible, similar to intraoperative sizing during conventional AVR. Further developments of Syngo Aortic ValveGuide may lead to automatic detection and measurement of the annulus itself with automatic calculation of the effective diameter.

Limitations

This is a single-centre study describing the first practical experience with Syngo Aortic ValveGuide aortic annulus measurements. To confirm these results, further multicentre studies should be performed with larger number of patients. Like any other imaging tool using a contrast agent, the analysis depends on good contrast of the relevant anatomical landmarks.

In conclusion, these first experiences with Syngo Aortic ValveGuide aortic annulus measurements showed promising similar results for effective aortic annulus diameter measurements compared with the established 3Mensio Valves™ software. The automatic annular plane detection works precisely and reproducibly; however, it must be cross-checked by the operator. Syngo Aortic ValveGuide may lead to less effort for MSCT analysis and allows inexperienced users and centres to measure the aortic annulus diameters in a fast and safe manner.

Conflict of interest: none declared.

REFERENCES


APPENDIX. CONFERENCE DISCUSSION

Dr A. Hossien (Swansea, UK): In your presentation you proposed a new method for detecting the effective diameter automatically. I think the software is an important tool in helping the surgeons and cardiologists to choose the right prosthesis size, and it is an advanced method towards developing a more accurate method. You compared it with the manual detection method. I would like to ask you two questions:

Five of your patients underwent conventional aortic valve replacement. Did you compare between direct instrument sizing and your preoperative detection, either automatically or manually, just to give the method more validity? Secondly, in three patients from the automatic detection group, you mentioned the contrast doses in your study. Do you think that contrast doses influence the image quality and the image processing?

Dr Van Linden: To answer the first question, this seems to be a very good idea. I think you mean that we should compare our annulus measurements. I didn’t say it in this talk, but the CT scans were just screening CTs. So not every patient underwent TAVI. There were some patients who decided that they didn’t want any treatment, and some underwent conventional AVR. So I did not compare the conventionally measured aortic valve prosthesis to the annulus measurements we did before, but that’s a good idea. But I think I cited our own paper. Three years ago, my colleague, Joerg Kempfert, presented here at EACTS a study where we prospectively did that. So we compared the direct measurements during conventional aortic valve replacement with the effective diameter measured on CT scan.

So, of course, to prove that I could do it again, I think we found this relation, that the effective diameter seems to be the most precise compared to intraoperative directly measured aortic annulus sizes.

Regarding the second question, of course if you do a CT scan, the better the contrast, the better your measurements. But I think, at least in a centre with, let’s say, qualitatively a very good CT scanner, you don’t need that much contrast. So for the routine CT scan, it is about 80 to 100 cc of contrast, and I think that’s, hopefully, the same in all centres.

And we do the CT scans at least three or four days, or even more, prior to the planned TAVI. So I think the contrast agent during the CT scan should not influence the renal function during the TAVI procedure. But, of course, you are dependent on a good-quality CT scan. If the contrast is not good in the LVOT or in the aortic root, these measurements may not be possible because usually there is so much calcification. But the automatic detection also works with the coronary ostia; there are many, many spots that are automatically detected that may be dependent on a good contrast.

Dr C. Huber (Bern, Switzerland): It is very important to move forward with the sizing tools we have at hand. It is all about sizing in regard to the outcome of TAVI. I have a follow-up remark about the comment that was just made about comparison with intraoperative findings:

Surgery is presented as the gold standard, but there might be a few things where surgery may not be the gold standard, for example in relation to the measuring/sizing technique. In order to measure the intraoperative aortic annulus, you need to put a ring or a cylinder into a given cylinder (aortic root). That, by definition, means that your sizing tool needs to be smaller than the real diameter. So I’m not sure you can really compare those data. TEE, TTE, and CT measurements have previously been compared to intraoperative sizing but nevertheless, I don’t think it’s the right way of comparing this as a gold standard.

Dr Van Linden: You mean comparing intraoperative direct measurement to whatever, TEE or CT?

Dr Huber: It is certainly interesting to perform comparison measurements, but I would like to say we should be careful with interpretations of the measured diameters. In surgery the annulus is measured by inserting a circular geometric structure into the aortic root. That, by definition, will have to be smaller than the annulus itself, otherwise, you won’t be able to forward it down into the annulus.

Dr Van Linden: Maybe I can comment on that. Like I said, in Dr Kempfert’s paper from 2012, we dealt with that problem. If you do your measurements on CT scan, you have to decide, ‘what do I define as the annulus?’. So if you take every calcified spot, maybe you get a larger annulus, instead of leaving out some spot and saying, ‘okay, this is not the annulus anymore, this is so much calcification’. Therefore when we did the study in 2011 (published in 2012) we did it on the decalcified annulus, of course, because I think we all know you can only measure intraoperatively after decalcification.

And I think the oval shape is always the problem. But to use the cylindrical measurement tool, that was the idea. If a cylindrical measurement tool is placed into an oval-shaped annulus, although there are some calcifications, you can still manipulate the annulus. So you make it round, and then you have this kind of effective diameter. You look for the circle that compares, or is equal to your oval-shaped annulus.

But, of course, there is always some bias, for example, if you do not decalcify an area, or if you measure in the CT scan an area that does not belong to the annulus. But I think nowadays, with more and more TAVI experience, I think we as surgeons also think more about annulus sizing and get a better feeling for that.

Dr W. Schiller (Bonn, Germany): You showed that the software tools are comparable, but you used preoperative CT, cardiac CT scans. In your conclusions, you bring up the DynaCT. Is the quality of the DynaCT comparable to the quality of the preoperative high-resolution cardiac CT?

Dr Van Linden: Yes, it is, but the problem at the moment is you don’t have LV or contrast at DynaCT. So the conclusions were also looking towards a future perspective.

Nowadays, it is not possible because to measure the aortic annulus, you need contrast in the aortic root and in the LV. And at the moment, with the conventional DynaCT, you just have a pigtail in the aortic root, so you have no LV contrast. But we are working on that. But if the resolution is high enough, you can do it.