Transoesophageal echocardiography of aortic atherosclerosis: the additive value of three-dimensional over two-dimensional imaging

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Aims
Complex aortic atherosclerotic plaques (AAPs) carry a significant risk of embolism. Currently, two-dimensional (2D) transoesophageal echocardiography (TOE) is the principal diagnostic tool of AAPs. However, we hypothesized that the data obtained from three-dimensional (3D) imaging may improve AAPs' spatial assessment.

Methods and results
The study included 67 patients (aged 70 ± 15 years, 35 men), who had routine TEE studies. The thoracic aorta was studied from arch to distal descending aorta, using the x-plane mode (simultaneous short- and long-axis views). If focal intimal thickening (suggestive of AAP) was detected, the 3D zoom algorithm was exercised on the specific site with further post-processing on a Q-lab workstation to measure its thickness in the X, Y, and Z dimensions. The AAP contour was defined qualitatively as regular or irregular in each mode. A total of 100 AAPs were investigated. The AAP thickness estimation was significantly greater in the 3D mode than in the 2D mode (0.51 ± 0.33 vs. 0.28 ± 0.20 cm, P < 0.001). The rate of complex AAPs (defined by AAP thickness of ≥ 4 mm) was two-fold higher with 3D imaging than with 2D imaging (27% with 2D imaging alone vs. 53% with the addition of 3D imaging). The rate of irregular AAPs increased from 29 to 65% when assessed with 3D imaging compared with 2D imaging.

Conclusion
This study has shown a significant difference in the estimation of AAPs between 2D and 3D TEE. The significant shift to a more complex AAPs profile may suggest that 3D imaging is preferable for the assessment of aortic atherosclerosis burden.

Keywords:aortic atherosclerotic plaque • transoesophageal echocardiography • two-dimensional • three-dimensional

Introduction
Aortic atherosclerotic plaques (AAPs), especially when located at the arch, are one of the major causes of spontaneous and iatrogenic stroke and peripheral emboli along with atrial fibrillation and carotid atherosclerosis.1 Furthermore, AAPs are regarded as markers of the atherosclerotic burden of the vascular tree as in the coronary and peripheral arteries.2–4 A cut-off of 4 mm has been shown to be clinically relevant for risk stratification with one-third of the patients with cryptogenic stroke having large plaques (>4 mm in thickness) in the aortic arch.5,6 Moreover, this cut-off has been associated with increased 1-year incidence of recurrent vascular events (transient ischaemic attacks and minor strokes).7 In addition to the plaque thickness, other morphologic features, such as ulcerations or mobile components, have been identified to increase the embolic risk.8–10 Several imaging modalities have been integrated into the clinical use for the evaluation of AAPs, including magnetic resonance imaging and computed tomography (CT), with transoesophageal echocardiogram (TEE) considered as the leading diagnostic tool due to its favourable availability and the lack of radiation and/or contrast media compared with the other modalities.11

The introduction of three-dimensional (3D) echocardiography provides new perspectives regarding cardiac structures including AAPs. However, previous studies referred to epiaortic imaging with a transthoracic probe.12 Currently, 3D imaging of AAPs is available in a less invasive way with the introduction of newer TEE

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technology. The aim of this study was to compare two-dimensional (2D) with 3D imaging of AAPs during routine TEE study.

**Methods**

**Patients**

The study was designed to recruit prospectively consecutive in- and out-patients who were referred for a TEE study at the Echocardiography Unit, Rabin Medical Center-Beilinson Hospital, between the years 2011 and 2013. The data regarding the indication for the TEE study as well as demographic data and risk factors for atherosclerosis were obtained from the patients’ medical records. The local IRB committee approved the study protocol.

**Echocardiography protocol**

Cardiologists with specialty in echocardiography (M.V., Y.S., D.W., D.M., and A.S.) performed the TEE studies, using Philips iE33 platform (Philips Medical Systems, Andover, MA, USA) equipped with the X7-2t multi-plane transducer. After imaging the heart and its structures, the probe was advanced towards the level of the diaphragm and then gradually pulled back. Two-dimensional and three-dimensional images of the thoracic aorta were obtained, switching intermittently between the two modes. Initially, each segment of the thoracic aorta was imaged by 2D using the x-plane mode, e.g. for each cross-section of the aorta, the orthogonal view was obtained simultaneously.

Three-dimensional images were obtained from three locations: the aortic arch, the proximal descending aorta (just beyond the arch), and the distal descending aorta (just above the diaphragm). The 3D images were obtained with real-time 3D zoom mode, displaying a magnified pyramidal volume. The size of the acquired volume varied from 20 × 20’ to 90 × 90’, depending on the density setting. The 2D-based 3D images were acquired when intima was thickened (>1 mm).

The analysis of the 3D images was performed with the QLAB software (QLAB 9.0, Philips Healthcare, Andover, MA, USA), and the atherosclerotic burden of the thoracic aorta was estimated (i.e. the amount of atherosclerotic plaques that were defined as complex with the 3D imaging).

The analysis of the 3D images enabled measurements of the atherosclerotic plaque in the X–Y–Z dimensions (Figure 1). The region of interest was set at the greatest contour of the plaque. Thus, each plaque thickness was measured at its maximal thickness within the X dimension. The ‘en face’ view of the plaque (as seen from the aortic lumen, i.e. the Z dimension) enabled the control of the contour surface to be characterized (determined visually as regular or irregular). We used only the 3D zoom method as it enabled us to focus on intimal segments suspected to be erosclerotic plaques in the 2D scanning. The 3D zoom scanning enabled control of the width and lateral borders of the sector independently of the ECG; thus, stretch artefacts were avoided (as opposed to full volume imaging). The gain was adjusted in the post-processing of the images as minimum as possible to sharpen the plaque’s edges.

**Reproducibility**

Interobserver variability for the measurement of plaque thickness and regularity in 2D and 3D was assessed in a subset of 24 and 38 randomly selected TEE studies respectively. Two readers (M.V. and A.W.S.) independently measured plaque thickness and regularity without prior knowledge of the clinical data and were blinded to the previous morphometric results. For intra-observer variability, one reader (A.W.S) independently measured the plaque thickness and regularity in an identical fashion on two occasions (3 months apart) while blinded to the clinical data in a subset of 10 randomly selected TEE studies.

**Statistical analysis**

Continuous variables are presented as mean ± SD and categorical variables as frequencies or percentages. Comparisons between patients were performed by unpaired Student’s t-test and x² test for continuous and categorical variables, respectively. P < 0.05 was considered statistically significant. The validity and reproducibility were evaluated by intra-class correlation coefficients (ICC), with a significance level set at P < 0.05. Analyses were performed using SPSS version 21 statistical software (SPSS Inc., Chicago, IL, USA).

**Results**

The study included 67 patients (100 plaques). The mean age was 70 ± 15 years. Fifty-two per cent of the patients were males. The patients’ characteristics are presented in Table 1. The main indication for TEE was valve assessment. The indications for TEE are presented

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**Table 1 Patient characteristics (n = 67)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men (%)</td>
<td>35 (52)</td>
</tr>
<tr>
<td>Age, years (SD)</td>
<td>70 ± 15</td>
</tr>
<tr>
<td>Hypertension (%)</td>
<td>38 (57)</td>
</tr>
<tr>
<td>Dyslipidaemia (%)</td>
<td>33 (49)</td>
</tr>
<tr>
<td>Diabetes mellitus (%)</td>
<td>11 (16)</td>
</tr>
<tr>
<td>Smoking (%)</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Chronic renal failure (%)</td>
<td>9 (13)</td>
</tr>
<tr>
<td>Obesity (%)</td>
<td>15 (22)</td>
</tr>
<tr>
<td>Coronary artery disease (%)</td>
<td>22 (33)</td>
</tr>
<tr>
<td>Coronary artery bypass graft (%)</td>
<td>8 (12)</td>
</tr>
<tr>
<td>Cerebrovascular accident (%)</td>
<td>21 (31)</td>
</tr>
<tr>
<td>Peripheral vascular disease (%)</td>
<td>5 (7)</td>
</tr>
<tr>
<td>Atrial fibrillation (%)</td>
<td>12 (18)</td>
</tr>
</tbody>
</table>

*Creatinine clearance < 60 mL/min/m².*

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The majority of AAPs were located at the descending aorta (84 plaques) and the rest at the arch. The thickness of the plaques in the X dimension (parallel to the 2D short axis of the aorta) was significantly greater when measured on the 3D-based image compared with the standard 2D image (0.51 ± 0.33 vs. 0.28 ± 0.20 cm, \( P < 0.001 \)) (Table 3). When sorted by a thickness cut-off \( \geq 4 \) mm (one of the criteria for complex AAP), 27 out of 73 AAPs (37%) measured \(<4 \) mm by 2D imaging and were measured \( \geq 4 \) mm by 3D imaging, whereas only 1 AAP measured \( \geq 4 \) mm by 2D imaging was undersized to \( <4 \) mm by 3D imaging (\( P < 0.001 \)) (Table 4). The discordance in the AAPs’ thickness in 2D imaging compared with 3D imaging was greater as the AAPs’ thickness was higher (Figure 2). The shift in AAPs’ complexity following 3D imaging is shown in Figure 3.

### Table 2  Indications for TEE

<table>
<thead>
<tr>
<th>Indication</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valve disease</td>
<td></td>
</tr>
<tr>
<td>Aortic stenosis—Pre-TAVI</td>
<td>16</td>
</tr>
<tr>
<td>Aortic stenosis—Pre-surgical AVR</td>
<td>6</td>
</tr>
<tr>
<td>Aortic regurgitation</td>
<td>3</td>
</tr>
<tr>
<td>Mitral regurgitation</td>
<td>12</td>
</tr>
<tr>
<td>Mitral stenosis</td>
<td>3</td>
</tr>
<tr>
<td>Pulmonary Stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Source of embolism</td>
<td>5</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>4</td>
</tr>
<tr>
<td>Endocarditis</td>
<td>8</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
</tr>
</tbody>
</table>

AVR, aortic valve replacement; TAVI, transcatheter aortic valve implantation.

### Table 3  Differences in AAPs’ thickness and irregularity by 2D imaging compared with 3D imaging

<table>
<thead>
<tr>
<th></th>
<th>2D image</th>
<th>3D image</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean plaque thickness, cm (SD)</td>
<td>0.28 ± 0.20</td>
<td>0.51 ± 0.33</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Number of irregular AAPs (%)</td>
<td>29 (29)</td>
<td>65 (65)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

### Table 4  AAP's thickness measured \( \geq 4 \) mm by 2D imaging and 3D imaging

<table>
<thead>
<tr>
<th></th>
<th>3D &lt; 4 mm</th>
<th>3D ( \geq 4 ) mm</th>
<th>Total</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D &lt; 4 mm (n)</td>
<td>46</td>
<td>27</td>
<td>73</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2D ( \geq 4 ) mm (n)</td>
<td>1</td>
<td>26</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>53</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

The rate of irregular AAPs increased from 29 to 65% when assessed with 3D imaging compared with 2D imaging (Table 3; Figures 4–7).

### Reproducibility of AAP measurements

Inter-observer variability showed small differences in the measurements of AAP’s thickness by 2D and 3D imaging between the two observers [ICC of 0.977 (95% CI 0.947–0.99) and 0.960 (95% CI 0.922–0.980), respectively] as well as in assessing the regularity of AAPs [ICC of 0.977 (95% CI 0.947–0.99)]. Analysis of intra-observer variability also showed small differences in the measurements of AAP.
thickness by 2D and 3D imaging [ICC of 0.989 (95% CI 0.959–0.997) and 0.987 (95% CI 0.969–0.996), respectively] with no differences in the assessment of AAP’s regularity (ICC of 1).

**Discussion**

This study has demonstrated the additive value of 3D TEE imaging of the thoracic aorta compared with the conventional 2D images. The addition of 3D imaging of AAPs has often provided new data regarding the atheromatous plaque thickness and contour. Moreover, it has doubled the rate of complex AAPs in our cohort (from 27% with 2D imaging alone to 53% with the addition of 3D imaging).

Detection of complex plaques in the aorta is of clinical importance as the association between complex AAPs and the risk of embolization is well established as well as the association between AAPs burden and mortality in patients undergoing cardiothoracic surgery. Furthermore, the risk of cerebral or peripheral emboli complicating invasive cardiac interventions is not negligible. As the scale of these procedures has been in constant rise during the past decade, accurate characterization of AAPs carries an important clinical implication and may be essential for the risk assessment of atherosclerotic complications prior to invasive cardiac intervention. In particular, this may have a special clinical relevance in transcatheter aortic valve implantation, where the delivery
of a relatively bulky device through the aortic lumen of elderly patients with high probability of diffuse vascular atherosclerosis might be a major contributor to the risk of periprocedural embolization.\(^{22–25}\) It is noteworthy that the presence of AAPs on TEE is an independent predictor of stroke and thrombo-embolism (RR 2.1) in patients with atrial fibrillation.\(^{26}\) Moreover, it is a component of the CHA\(_2\)DS\(_2\)-VASc score for the risk of stroke in patients with atrial fibrillation and may be an indication for treatment with anticoagulation according to recent guidelines for the management of atrial fibrillation.\(^{27}\)

The current study has indicated that assessment of AAPs differs significantly between the two imaging modalities. As the analysis of the 3D images with the QLAB software enables us to scan the plaque and measure its most thickened area as opposed to 2D imaging, we believe that the measurements are underestimated by 2D images compared with 3D images. Both 2D and 3D imaging examine the same aortic segment. However, the ability of the 3D imaging to process a ‘pyramidal’ section of the aorta (in contrast to the narrow 2D view) allows a more accurate spatial description of the plaque, which is essentially a 3D structure. Indeed, a very meticulous scanning (changing the scanning angles to and fro) with a very careful retrieval of the probe may improve the estimation of the plaque’s dimensions. It is certainly easier and more accurate with the use of 3D zoom imaging by capturing a 3D section of the aorta followed by post-processing measurement of the plaque at its maximal thickness. Furthermore, we believe that 3D imaging enables a unique view of the plaque morphology (the z axis). The presence of caverns and crypts in the upper surface of the plaque (defined by us as an ‘irregular plaque’) may be valuable in addition to the traditional parameters of complex plaques (thickness, ulceration, and mobile component) and enable a better estimation of the risk of embolization for the specific AAP. Of note, this is in line with a recent study by Piazzese et al.,\(^ {28}\) which has shown the superiority of AAP assessment by a 3D TEE algorithm over the plane 2D TEE assessment. Nevertheless, the prognostic value of these data merits further validation.

In summary, our data have demonstrated that the shift from 2D to 3D imaging is associated with an increased rate of diagnosis of

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**Figure 6** AAP in the aortic arch (arrow): a flat plaque as seen in 2D image (left) is in fact protruding and irregular when seen in the 3D–Z dimension (right).

**Figure 7** A protruding plaque in the descending aorta. The entire contour of the complex plaque is seen in the Z dimension and clearly underestimated in the 2D image.
higher risk profile AAPs (thickness and irregularity). We anticipate that once our findings are validated, 3D data may influence risk assessment prior to endovascular procedures and possibly the mode of action during these procedures (e.g. changing access from transfemoral to trans-axillary in transcatheter aortic valve implantation).

Limitations

Our study has several limitations. This was a relatively small-sized, single-centre study.

Additionally, in this study we could not compare our observation to another gold standard imaging modality. To our knowledge, there is no clear consensus regarding the gold standard imaging of aortic plaques. A recent expert statement regarding non-coronary atherosclerosis pointed TEE as the customary imaging mode for aortic atheroma. Benyounes et al. have compared CT angiography and TEE performances for the detection of aortic arch atheroma and have found that CT angiography is very specific but lacks sensitivity for the detection of at-risk aortic plaques (defined as plaque thickness ≥4 mm or ulcerated plaque).

Another limitation of TEE in the detection of AAPs pertains to those located at the posterior aspect of the aorta (i.e. the near field). All the AAPs analysed in this study were detected in either the anterior aortic wall or the sides. Additionally, the study was designed so that 3D imaging was obtained from intimal thickening identified primarily by 2D imaging.

Finally, the post-processing of 3D images may alter the real surface contour (e.g. due to gross changes in the image gain). We made changes in the 3D image gain to improve clarity of the image, though kept the change in gain very subtle to avoid over-smoothening of intimal surface.

Conclusions

This study has shown a significant difference in the estimation of AAPs thickness and surface irregularity between 2D and 3D TEE. The significant shift to a more complex AAPs’ profile may suggest that 3D imaging is preferable for the assessment of aortic atherosclerosis burden.

Conflict of interest: None declared.

References