Resting coronary flow velocity in the functional evaluation of coronary artery stenosis: study on sequential use of computed tomography angiography and transthoracic Doppler echocardiography

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Aims
Accelerated flow at the site of flow-limiting stenosis can be detected by transthoracic Doppler echocardiography (TTDE). We studied feasibility and accuracy of sequential coronary computed tomography angiography (CTA) and TTDE in detection of haemodynamically significant coronary artery disease (CAD).

Methods and results
We prospectively enrolled 107 patients with intermediate (30–70%) pre-test likelihood of CAD. All patients underwent CTA using a 64-slice scanner. Using TTDE, the ratio of maximal diastolic flow velocity to pre-stenotic flow velocity (M/P ratio) was measured in the coronary segments with stenosis in CTA. In all patients, the results were compared with invasive coronary angiography, including measurement of fractional flow reserve when appropriate. All analyses were done blinded. TTDE was feasible in 276 of 285 evaluated coronary segments. Significant coronary stenoses were associated with a higher M/P ratio than non-significant stenoses (3.59 ± 1.82 vs. 1.28 ± 0.60, P < 0.001). The optimal M/P ratio for detection of significant stenosis was 2.2 (area under receiver operating characteristic curve 0.92, P < 0.001). Compared with the strategy of CTA alone, sequential CTA and focused TTDE had a better positive predictive value (PPV; 61 vs. 78%) and diagnostic accuracy (93 vs. 96%, P = 0.006) without impairment of the negative predictive value (97 vs. 97%).

Conclusion
Sequential use of CTA and TTDE is feasible for combined anatomic and functional evaluation of coronary stenoses. Compared with coronary CTA alone, addition of TTDE improved PPV for detection of significant CAD.

Keywords
Coronary artery disease • Doppler echocardiography • Coronary flow • Computed tomography angiography

Introduction
Coronary computed tomography angiography (CTA) is a promising method for anatomic detection of coronary atherosclerotic plaques. Single-centre studies1 as well as multicentre studies2,3 have demonstrated its high diagnostic accuracy for the identification of >50% coronary artery stenosis in patients with intermediate likelihood of coronary artery disease (CAD). However, coronary CTA has only limited capability to assess the severity of coronary artery stenosis.4 Studies comparing coronary CTA and single-photon emission computed tomography perfusion imaging have indicated that only 40–65% of the stenoses classified...
as significant by coronary CTA are associated with myocardial ischaemia. Similarly, the correlation comparing the stenosis severity by coronary CTA and invasive coronary angiography has been only modest. Because demonstration of myocardial ischaemia is important for management decisions of patients with CAD, functional evaluation of the haemodynamic significance of stenosis detected by coronary CTA remains an important challenge.

A flow-limiting coronary stenosis causes local acceleration and turbulence of flow at the site of stenosis that is detectable by transthoracic Doppler echocardiography (TTDE). Measurement of local acceleration in coronary artery flow without pharmacological provocation by TTDE is an attractive approach for the identification of flow-limiting coronary stenosis. Studies from different groups have reported good feasibility and diagnostic performance of the technique for the detection of significant stenosis in the left anterior descending (LAD) coronary artery. Recently, visualization of the left circumflex artery (LCX) and right coronary artery (RCA) has become possible, albeit with a lower success rate than the LAD.

We hypothesized that sequential use of coronary CTA and TTDE could provide a combined anatomic and functional evaluation of coronary atherosclerotic plaques non-invasively. Anatomic information provided by coronary CTA could improve feasibility of TTDE by allowing focused analysis of certain coronary segments. Measurement of local increase in flow velocity at the site of stenosis by TTDE could in turn provide incremental information about the haemodynamic significance of stenosis. Therefore, we designed a blinded study to test the feasibility of sequential CTA and TTDE in evaluation of coronary stenoses and to compare it with CTA alone in the detection of significant CAD. We measured the maximal-to-prestenotic flow velocity ratio (M/P ratio) by TTDE in the coronary segments with stenosis in CTA. Results of CTA and TTDE were compared with the gold standard, invasive coronary angiography, including measurement of fractional flow reserve (FFR) when appropriate.

### Methods

#### Patients

As part of an earlier study, we prospectively enrolled 107 outpatients between 2 July and 9 August with chest pain and 30–70% pre-test likelihood of CAD based on age, sex, symptoms, and the result of the exercise test. Patients with previous CAD, atrial fibrillation, iodine allergy, unstable angina, severe renal dysfunction, heart failure, unstable asthma, or pregnancy were excluded. Six patients were excluded from the study, because of failure to perform TTDE prior to invasive coronary angiography due to logistic reasons. Thus, the final study population consisted of 101 patients whose characteristics are summarized in Table 1. The study was conducted according to the guidelines of Declaration of Helsinki, and the study protocol was approved by the ethics committee of the Hospital District of Southwest Finland and Finnish National Agency for Medicines. All patients gave their written informed consent.

#### Computed tomography angiography

All patients were scanned with a 64-row CT scanner (GE Discovery VCT, General Electric Medical Systems, Milwaukee, WI, USA) as described earlier. The average radiation dose of CTA was 7.6 mSv with prospective ECG triggering and 19.9 mSv with retrospective gating. The images were analysed by an experienced cardiologist and a radiologist using ADW 4.4 Workstation (General Electric Medical Systems) blinded to other results. The minimum vessel diameter was measured in two perpendicular planes. The degree of stenosis was expressed as the percentage of minimum to the pre-stenotic diameter. The standard 17 vessel segment template was used and vessels <1.5 mm in diameter were excluded. The stenoses >50% were classified as significant.

#### Transthoracic Doppler echocardiography

The coronary artery segments with >20% stenosis in CTA were evaluated using TTDE by cardiologists that were blinded to the severity of stenosis in CTA in a separate imaging session using Acuson Sequoia C512 ultrasound unit (Siemens Acuson, Mountain View, CA, USA) equipped with a standard 3.5-MHz transducer (3V2c). The expected anatomic course of the coronary artery segments of interest was studied using colour Doppler mapping using all possible standard and non-standard windows and views as described earlier. The velocity scale of colour Doppler was initially set to 0.24 m/s, but it was changed actively. The colour box size was reduced to maintain the high frame rate. Briefly, the left main coronary artery (LM) and proximal LAD were studied from the left parasternal short- and long-axis views focusing on area adjacent to the sinus Valsalva (Figure 1). Origin of the first septal branch of the LAD marking border between the proximal and the middle segments of the LAD could be visualized in most patients. The middle and the distal LAD basal and apical to the papillary muscle level, respectively, as well as the proximal LCX covered by the left auricle were studied from left parasternal windows at varying levels using modified short- and long-axis views focusing on the anterior inter-ventricular groove (LAD) or atrioventricular groove (LCX). The more distal parts of the LCX were studied using the apical long-axis view focusing to the lateral mitral ring and the four-chamber view focusing on the inferior mitral ring. The ostium and the proximal RCAs were seen from the left parasternal short-axis view in the area of right sinus Valsalva. The proximal and the middle RCAs were also searched from the right parasternal short- and long-axis views when the patients were lying on their right side.

### Table 1 Characteristics of study patients

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (male/female)</td>
<td>60/41</td>
<td>60/41</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64 (50–80)</td>
<td>64 (50–80)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78 (50–116)</td>
<td>78 (50–116)</td>
</tr>
<tr>
<td>Body mass index</td>
<td>26.6 (18.0–39.1)</td>
<td>26.6 (18.0–39.1)</td>
</tr>
<tr>
<td>Risk factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family history of CAD</td>
<td>43 (42.6%)</td>
<td>43 (42.6%)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>14 (13.9%)</td>
<td>14 (13.9%)</td>
</tr>
<tr>
<td>Impaired glucose tolerance</td>
<td>9 (8.9%)</td>
<td>9 (8.9%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>40 (39.6%)</td>
<td>40 (39.6%)</td>
</tr>
<tr>
<td>Hypercholesterolaemia</td>
<td>56 (55.5%)</td>
<td>56 (55.5%)</td>
</tr>
<tr>
<td>Current or previous smoker</td>
<td>26 (25.7%)</td>
<td>26 (25.7%)</td>
</tr>
<tr>
<td>Medication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statin</td>
<td>49 (48.5%)</td>
<td>49 (48.5%)</td>
</tr>
<tr>
<td>β-Blocker</td>
<td>58 (57.4%)</td>
<td>58 (57.4%)</td>
</tr>
<tr>
<td>Aspirin</td>
<td>72 (71.3%)</td>
<td>72 (71.3%)</td>
</tr>
<tr>
<td>Long acting nitrate</td>
<td>8 (7.9%)</td>
<td>8 (7.9%)</td>
</tr>
</tbody>
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E. Joutsiniemi et al.
focusing on the anterior and medial tricuspid ring. The part of the RCA passing anterior surface of the tricuspid ring until the inferior margin of the right ventricle was considered as the proximal RCA. Subcostal short-axis view focusing to the medial tricuspid ring on the inferior surface of the heart was also used. The distal RCA was visualized using the subcostal four- and two-chamber views focusing to the posterior tricuspid ring. The right posterior descending branch of the RCA was visualized using a modified apical two-dimensional view.

Possible coronary stenosis was identified in the segments of interest as localized colour aliasing indicating accelerated and turbulent flow as previously described and illustrated in Figure 1. Normal coronary flow is slow and laminar and causes only weak Doppler signal, whereas turbulent and accelerated flow at the site of stenosis causes a strong signal facilitating its identification. To assess severity of coronary stenoses by TTDE, we measured maximal flow velocity by pulsed-wave Doppler at the site of aliasing and pre-stenotic flow velocity in the nearest proximal, non-aliased point of the vessel to calculate the M/P ratio (Figure 1). Blood flow velocity was measured at the beginning of diastole using pulsed-wave Doppler with 2 MHz frequency in an average sample volume of 5 mm. Multiple consecutive cardiac cycles were analyzed to find average flow velocity. The angle between flow and Doppler beam was kept as small as possible and angle correction was used. In some coronary segments, the angle between ultrasound beam and flow remained >60°, because of horizontal course of the artery. In these segments, stenotic flow velocity was approximated by the appearance of aliasing upon rescaling of the colour Doppler Nyquist limit. In addition to testing the optimal cut-off value of the M/P ratio for detection of significant stenosis in our patients, we used a predefined cut-off value for the M/P ratio (2.2) for comparison of CTA alone vs. CTA and TTDE that was based on a previous study.8

We routinely evaluated flow in the septal branches of the LAD from left parasternal short-axis views using colour Doppler in order to detect total LAD and RCA occlusions as described previously.10,14,15 Chronic occlusion results in enhanced collateral flow through septal branches that causes acceleration of flow and makes long continuous segments of flow signals visible by TTDE. In patients with non-detectable flow in either the LAD or the RCA, reversed enhanced flow from right to left in the septal branches of the LAD were considered as a marker of total occlusion in the LAD, whereas enhanced Doppler signals in normal direction were considered as a sign of total occlusion in the RCA.

Coefficient of variation for repeated measurements of the M/P ratio by the same or two independent observers in 10 stenoses varying from 30 to 95% (6, 2, and 2 in the LAD, LCX, and RCA, respectively) in four patients were 5 and 6%, respectively.

**Invasive coronary angiography and fractional flow reserve**

Within 2 weeks of CTA, after TTDE, all patients had invasive coronary angiography. All coronary angiographies were performed on Siemens Axiom Artis coronary angiography system (Siemens, Munich, Germany) and stenoses quantified using software with automated edge detection system (Quantcore, Siemens). Stenoses of >50% were classified as significant. Measurement of FFR was performed in 16 intermediate stenoses using ComboMap® pressure/flow instrument and a 0.014-inch BrightWire® pressure guidewires (Volcano Corp., CA, USA). FFR was calculated as the ratio of mean pressures distal to lesion and in the aorta during hyperaemia induced by 18 μg intracoronary boluses of adenosine. When available, the FFR value of <0.80 indicated significant stenosis irrespective of anatomical severity.

**Statistics**

Continuous variables are expressed as the mean ± SD and compared between two groups by independent sample t-test. Receiver operating characteristic (ROC) analysis was used to find optimal cut-off point of
the M/P ratio. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated for CTA alone and in combination with focused TTDE (in all lesions that were evaluated by TTDE, stenosis was classified according to TTDE findings) on patient and segment levels. McNemar’s test was performed to compare accuracy, sensitivity, and specificity of the strategy of CTA alone and in combination with focused TTDE. A P-value of <0.05 was considered as statistically significant.

Results

Coronary angiography

No cardiac events took place between CTA and invasive coronary angiography. Thirty-four patients out of 101 (34%) had stenoses ≥50% in their coronary arteries in invasive coronary angiography. Significant lesions after invasive angiography and FFR were detected in 33 patients. In 14 of them, the lesions were either total occlusions or extremely tight (>90%) stenoses in which FFR was not possible. There were four other patients with intermediate (30–70%) stenoses in which FFR could not be performed due to scheduling or technical reasons. In patients without FFR, stenosis >50% by quantitative coronary angiography was considered positive and the vessel graded accordingly. Thus, there were 66 significant coronary artery stenoses. Of these, 39 were in the LAD, 12 in the LCX, and 14 in the RCA. Among these were six total occlusions (three in the middle LAD and three in the middle RCA). In 10 arteries (n = 8 LAD, 1 LCX, and 1 RCA), there were two consecutive stenoses. Fifteen patients had single-vessel disease, 10 patients two-vessel disease, and 8 patients multivessel disease. Only one patient had significant LM disease.

Feasibility of transthoracic Doppler echocardiography

Figure 1 illustrates the assessment of a coronary stenosis with the use of TTDE together with corresponding CTA and invasive coronary angiography. Based on CTA, 285 lesions causing luminal narrowing of >20% in 670 segments in 76 patients were evaluated with TTDE. Of these lesions, 19 were in the LM, 151 in the LAD (56 proximal, 51 middle, and 44 distal), 50 in the LCX (30 proximal and 20 middle), and 69 in the RCA (30 proximal, 21 middle, and 18 distal). There were 224 lesions (83% of the evaluated segments without total occlusion) in which the M/P ratios were quantified using the pulsed-wave Doppler recordings of flow velocity profiles. In 52 segments, either TTDE indicated the total occlusion or the M/P ratio was approximated based on colour Doppler signal due to inability to align ultrasound beam with the flow. There were eight segments in the RCA and one in the LAD in which the area of interest could not be visualized by TTDE (3% of segments).

M/P ratio vs. invasive coronary angiography

The average M/P ratio was higher in coronary segments with haemodynamically significant than non-significant stenosis (3.59 ± 1.82 vs. 1.28 ± 0.60 m/s, P < 0.001, Figure 2A). Based on ROC curve analysis, the optimal cut-off value of the M/P ratio for discriminating non-significant and significant stenosis was 2.2 (AUC = 0.92 ± 0.02, sensitivity 82%, specificity 94%, n = 224 stenoses, P < 0.001, Figure 2B).

Detection of total occlusions by transthoracic Doppler echocardiography

Based on the evaluation of flow in the septal branches of LAD, TTDE correctly diagnosed two total occlusions in both the RCA and the LAD. One occlusion in both vessels was missed.

Sequential computed tomography angiography and transthoracic Doppler echocardiography vs. computed tomography angiography alone

Coronary CTA alone showed high diagnostic accuracy for the detection significant stenosis or total occlusion on both a segment level (accuracy 93%, sensitivity 71%, specificity 95%, PPV 61%, and NPV 97%, n = 670) and a patient level (accuracy 90%, sensitivity 91%, specificity 89%, PPV 82%, and NPV 95%, n = 101) as shown in Figure 3. Most false findings were those with the detected stenosis overestimated by CTA resulting in reduction in PPV.

On a segment level, sequential CTA and TTDE provided higher PPV (78%) and better diagnostic accuracy than CTA alone (accuracy 96%, p = 0.006) without impairment of NPV (97%; Table 2, Figure 3). The false negative results (n = 8 in the LAD, three in the LCX, and three in RCA) included two total occlusions, two subtotal (>95%) stenoses, four stenoses that were 65–90%, and seven stenoses that were 50–65% by QCA. The specificity of sequential CTA and TTDE for significant stenosis was better (98%, P = 0.004), whereas sensitivity was comparable (77%, P = 0.39) with CTA alone.

On a patient level, sequential CTA and TTDE had accuracy of 93% (P = 0.07 vs. CTA alone), sensitivity of 91% (P = 1.0 vs.
CTA alone), specificity of 95% (P = 0.21 vs. CTA alone), PPV of 91%, and NPV of 95% (Figure 3).

There were 75 stenoses that were classified as >50% by CTA alone. In these segments, accuracy, sensitivity, specificity, PPV, and NPV of TTDE were 79, 80, 77, 84, and 72%, respectively. The nine false negative results (six in the LAD, one in the LCX, and two in the RCA) included two total occlusions, two subtotal stenoses (>95%), and two intermediate stenoses between 50 and 65% by QCA. There were 38 stenoses that were measured as 50–70% by CTA alone. In these segments, accuracy, sensitivity, specificity, PPV, and NPV of TTDE were 82, 86, 75, 83, and 80%, respectively. TTDE correctly identified 15 of 20 stenoses in the vessels with two sequential stenoses.

**Discussion**

We demonstrate that sequential use of CTA and TTDE has potential for combined anatomical and functional evaluation of CAD. Based on CTA findings, focused evaluation of diseased coronary segments is feasible by TTDE. Relative increase in resting flow velocity by TTDE can accurately discriminate non-significant and significant coronary lesions as defined by invasive coronary angiography and in a subset of patients by FFR. Compared with CTA alone, sequential use of CTA and TTDE resulted in improvement of specificity and PPV without impairing sensitivity or NPV for diagnosis of significant CAD.

**Feasibility of transthoracic Doppler echocardiography**

Previous studies have reported good feasibility, sensitivity (64–86%), and specificity (92–96%) for detection of significant LAD stenosis with the use of TTDE.8–11 Feasibility and the percentage of correctly detected stenoses in the RCA (17–62%) and LCX (37–38%) has been lower.9,10,12 Higher success rate in our study is likely explained by primary localization of stenosis by CTA allowing focused analysis by TTDE. Although TTDE provides only limited anatomical information itself, accelerated and turbulent flow at the site of stenosis creates a strong colour Doppler signal that can be easily discerned at the sites of expected course of coronary arteries. However, coronary TTDE requires specific training and good knowledge of the coronary anatomy. In our study, all examinations were performed by cardiologists who have long experience in coronary imaging, and therefore, more studies are needed to test the applicability of the method for routine use.

**M/P ratio and stenosis severity**

Our findings confirm the previous observations that the M/P ratio measuring local increase in flow velocity is an accurate and reproducible indicator of the anatomical severity of coronary stenosis. Our study also expands the previous observations, because the M/P ratio was validated for the first time with functional

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**Table 2** Diagnostic performance of sequential coronary computed tomography angiography and transthoracic Doppler echocardiography for the detection of significant stenosis

<table>
<thead>
<tr>
<th>Stenosis (n)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All*</td>
<td>66/670</td>
<td>77</td>
<td>98</td>
<td>78</td>
</tr>
<tr>
<td>LAD</td>
<td>39/218</td>
<td>82</td>
<td>96</td>
<td>82</td>
</tr>
<tr>
<td>LCX</td>
<td>12/151</td>
<td>67</td>
<td>99</td>
<td>89</td>
</tr>
<tr>
<td>RCA</td>
<td>14/214</td>
<td>79</td>
<td>98</td>
<td>69</td>
</tr>
</tbody>
</table>

There was only one diseased LM, n = number.
measures of haemodynamic significance invasive FFR measurements. We found that the M/P ratio of 2.2 was the best cut-off point to predict significant stenosis in any coronary artery that is comparable with the findings in previous studies for detection of >50% stenosis in the LAD (2.2 and 1.8). It is important to measure pre-stenotic and maximal velocities close to each other to avoid the effects of potential confounding factors on pressure gradient.

Sequential computed tomography angiography and transthoracic Doppler echocardiography in detection of coronary artery disease

Numerous single- and multicenter trials have consistently shown that coronary CTA has a particularly high NPV—close to 100%—which makes coronary CTA as an excellent tool for exclusion of CAD in patients with a low-to-intermediate pre-test likelihood of disease. However, coronary CTA has only limited capability to comprehensively characterize the severity of coronary artery stenoses. Typically, coronary CTA tends to overestimate the degree of stenosis, especially in the presence of densely calcified plaques resulting in the relatively low PPV. Prior to elective revascularization, a test for ischaemia is strongly recommended by cardiovascular practice guidelines. Our results provide the first demonstration that functional evaluation of coronary stenoses identified by CTA by TTDE can improve accuracy and PPV of the detection of severe stenoses defined by invasive angiography when compared with strategy of CTA alone. TTDE is widely available bedside technique with no radiation exposure, and thus, further studies on the clinical value of the M/P ratio in comparison with other functional tests in evaluation of equivocal lesions detected by CTA seem warranted.

Limitations

Since a limited number of lesions were evaluated by FFR in this clinical study further investigations comparing the M/P ratio with invasive haemodynamics are warranted in the future. Studies on larger patient population are needed to confirm our segment level findings in the patient level. There was only one significant LM stenosis, the number of evaluated lesions in the RCA and LCX was small as compared with LAD and segments <1.5 mm in diameter were excluded. Thus, the value of sequential CTA and TTDE in these settings needs further clarification. Furthermore, the effects of total occlusions and consecutive stenoses need to be clarified in larger sample of patients. In order to avoid additive effect of consecutive lesions on the M/P ratio, we measured proximal flow velocity as close as possible to the stenotic flow.

We used the 17-segment model and predefined criteria for each coronary segment in order to match TTDE and CTA evaluation of stenosis. In the real life, this could be facilitated by inspection of stenoses in the actual CTA images by cardiologists performing echocardiography that was not allowed by our blinded study protocol.

Conclusions

Combination of coronary CTA and TTDE is a feasible approach for anatomical and functional evaluation of atherosclerotic lesions. Evaluation of flow velocity by TTDE accurately identifies lesions that cause significant stenosis as assessed by invasive coronary angiography and in a subset of patients, by FFR measurement. The finding that sequential CTA and TTDE have better PPV than CTA alone suggests that studies on the clinical value of this combination in the diagnosis of CAD are warranted in the future.

Acknowledgements

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Conflict of interest: None declared.

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References


**An unusual case of amaurosis fugax due to papillary fibroelastoma of cor triatriatum**

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A 58-year-old woman with no significant medical history presented to us with a transient left-sided visual loss. Apart from previous smoking, she had no risk factors for cerebrovascular event.

On examination, she had a regular heart rate of 64/min and a blood pressure of 120/90 mmHg. Neurological and cardiorespiratory examinations were unremarkable. Chest radiograph, electrocardiogram, laboratory data, and computed tomography head were unrevealing.

A transthoracic echocardiography, and subsequently, a transoesophageal echocardiography (TOE), was performed, revealing a membrane-like echodense structure in the left atrium (LA) with attachment at the septum medially and Coumadin ridge laterally, dividing the atrium into a posterior-superior chamber where the pulmonary veins drained and an anterior-inferior portion which included the LA appendage, suggestive of cor triatriatum. In addition, a mobile echodense mass was attached to the inferior aspect of the membrane (Figure 1C and D). Three-dimensional (3D) echocardiography by TOE confirmed the membrane fanning across the LA towards the inter-atrial septum with two large orifices and further defined the mass as polypoidal and gelatinous in appearance (Figure 1A and B). A presumptive diagnosis of an embolic event due to myxoma of cor triatriatum was made.

The cor triatriatum and the mass were surgically removed (Figure 1E) and histologically, papillary fibroelastoma was observed. Postoperative course was uncomplicated and she has had no further event.

This case highlights the utility of 3D echocardiography in defining complex structure and the importance of being aware of the possible embolic complications related to exceedingly unusual co-existence of two rare entities.

Figure 1 A three-dimensional transoesophageal echocardiography en face surgical view of the cor triatriatum (A). A three-dimensional transoesophageal echocardiography view of the polypoidal mass (B). A five-chamber apical view of transthoracic echocardiography (C). Transoesophageal echocardiography: 90° mid-oesophageal view (D). Surgical photo of the cor triatriatum and the attached mass (E). White arrow, mass; CT, cor triatriatum; Ao, aorta; MV, mitral valve; IAS, inter-atrial septum; LAA, left atrial appendage; PW, posterior wall.

Supplementary data are available at European Journal of Echocardiography online.