Characterization of atrial septal defect by simultaneous multiplane two-dimensional echocardiography

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Received 24 January 2014; revised 24 April 2014; accepted after revision 28 April 2014; online publish-ahead-of-print 25 May 2014

Aims

The aim of this study was to assess the value of two-dimensional (2D) transthoracic simultaneous multiplane imaging (SMPI) in the evaluation of suitability for percutaneous atrial septal secundum defect (ASD) closure compared with the golden standard 2D transoesophageal echocardiography (TEE).

Methods and results

Twenty-nine patients with an ASD underwent both SMPI and TEE. Ten patients (34%) were male (age 41 ± 18 years, range 20–74). SMPI assessment of ASD size and rims included xPlane and I-rotate modes. Rims were defined as suitable for ASD percutaneous closure using a cut-off value of 5 mm. There were no significant differences between SMPI in xPlane mode and TEE regarding the sizes of the anterior–posterior dimension (13.7 ± 4.5 vs. 14.5 ± 5.2 mm) and superior–inferior dimension (13.5 ± 3.9 vs. 14.1 ± 5.0 mm, respectively). Agreement for the aortic, atrioventricular, inferior, right upper pulmonary vein, and superior rims was 100, 100, 100, 96, and 96%, respectively.

Conclusion

The SMPI technique can reliably assess the dimensions and rim size of a secundum ASD for pre-interventional selection when compared with TEE and has thus the potential to replace TEE.

Keywords

Echocardiography • Simultaneous multiplane imaging • Atrial septal defect

Introduction

The atrial septal secundum defect (ASD) is one of the most common lesions in adult congenital heart disease. In the past decade, transcatheter closure of an ASD has gradually become the treatment of choice, rather than surgery. However, not all ASDs are anatomically suitable for a transcatheter approach, as the ASD size should be limited and sufficient rims of inter-atrial septal tissue between the defect and adjacent structures are required to position the ASD device. Standard two-dimensional (2D) transthoracic echocardiography (TTE) is limited in the assessment of these rims, due to the fixed number of set cut planes and the difficulty entailed in acquiring some of them. Due to these limitations, transoesophageal echocardiography (TEE) is considered the pre-interventional imaging method of choice. Nevertheless, TEE is a semi-invasive method and is not without procedural risk, and it has the short comings of an observational blind area.

With the introduction of 2D transthoracic simultaneous multiplane imaging (SMPI), a new image modality has become available. Alongside the standard 2D images taken from the standard transducer positions, images can now also be acquired using the xPlane (bi-plane) and I-rotation (any-plane) modes, providing true orthogonal planes that can be acquired in lateral and elevation directions, and an infinite number of 2D cutting planes. The current study sought to assess the value of SMPI in measurement of ASD size and its rims.

Methods

Study population

Between March 2011 and June 2013, 39 consecutive adult patients with an ASD were referred to our centre for the evaluation of an ASD and suitability for treatment by either a transcatheter device or surgical closure. There was an indication for ASD closure when there was right heart
dilatation reflecting the significant volume overload of the right ventricle. A defect diameter of >30 mm and total or partial deficiency of rims (<5 mm) were an indication for surgical closure. The institutional review board approved the study, and informed consent was obtained from all patients.

Transthoracic 2D SMPI echocardiography

A comprehensive 2D echocardiogram with SMPI was performed using an iE33 ultrasound system (Philips Medical Systems, Best, the Netherlands) equipped with an X5-1 matrix transthoracic probe composed of 3040 elements, with a 1–5 MHz extended operating frequency range. For the evaluation of the ASD and its surrounding rims, standard views were examined including the xPlane mode in all patients and since November 2011 also including the I-rotate mode in the most recent 23 patients. In the xPlane mode, an orthogonal view can be acquired through the midline of a primary image and displayed as a secondary image. From the midline, additional secondary images can be visualized by a lateral tilt of up to maximal +30° to −30°. In the xPlane mode, the frame rate will be half of that of the original image. In the I-rotate mode, a full electronic rotation of 360° (adjustable by 5° steps) can be performed in the primary image. In contradiction to the xPlane modes, the frame rate in the I-rotate mode will not be compromised because only the secondary image is displayed.

Measurement of the ASD dimensions

ASD dimensions were acquired by SMPI with the standard subcostal four-chamber (4CH) view as the primary image and making a lateral xPlane sweep through the inter-atrial septum to identify the secondary image with the largest ASD diameter. The end-systolic maximal diameters of the ASD were measured, with the help of colour flow mapping. The atrioventricular (AV: inferior/anterior rim between the ASD and the AV valve) and right upper pulmonary vein (RUPV: posterior rim between the ASD and the right pulmonary veins) rims were assessed from the standard subcostal 4CH view. The inferior (IVC: inferior/posterior rim between the ASD and IVC) and superior (SVC: superior/posterior rim between the ASD and SVC) caval vein rims were assessed using xPlane SMPI from the above-described standard subcostal 4CH view (Figure 1). In four patients with a poor subcostal window, the right parasternal (RPS) view and its xPlane view were used to assess the AV, RUPV, IVC, and SVC rims. The aortic rim (superior/anterior rim between the ASD and aortic valve) was assessed from the standard parasternal short-axis (SAX) view at the level of the aortic valve view and in the most recent 23 patients also with I-rotate SMPI from a standard subcostal 4CH (or RPS) view.

For all rims, the maximal rim size was measured and the measures were subsequently divided using a cut-off value of 5 mm because a rim length of <5 mm is considered unsuitable for positioning a closure device.

Two-dimensional transoesophageal echocardiography

A 2D TEE examination was performed using an iE33 ultrasound system (Philips Medical Systems) equipped with an X7-2t matrix transducer composed of 2500 elements, with a 2–7 MHz extended operating frequency range. The inter-atrial septum (IAS) was evaluated from the standard transverse (4CH) view, the longitudinal view at the level of the caval veins, and the transverse view at the level of the aorta. The end-systolic maximal diameters of the ASD were measured in the standard 4CH view and the bi-caval view, with help of colour flow mapping.

Figure 1: Assessment of the major and minor ASD diameters and main rims: the standard subcostal 4CH view (left) and its xPlane image (right) providing the superior—inferior ASD dimension and IVC and SVC rims.
**Contrast fluoroscopy**
In the patients who underwent transcatheter closure, a sizing balloon was filled with diluted contrast until the appearance of a waist and disappearance of left-to-right shunt. Once this occurred, a cine image was performed and the size of the waist was measured using the markers positioned in the balloon for calibration.

**Statistical analysis**
Continuous variables are presented as mean ± standard deviation. The paired sample t-test was done because all variables were normally distributed. For comparison of normally distributed continuous variables between two groups, Student’s t-test was used. Inter-observer variability was tested by analysing the anterior–posterior and the superior–inferior ASD dimensions and the rim cut-off values (binary) by two blinded observers (J.McG and A.v.d.B.). The results were analysed by the relative difference (expressed as the absolute difference divided by mean) and Bland–Altman method, in which biases and 95% limits of agreement were calculated. All statistical analyses were performed using SPSS version 20.0 (SPSS, Inc., Chicago, IL, USA). A P-value of <0.05 was considered significant.

**Results**
Of the 39 patients referred for ASD closure, 7 had no indication for ASD closure as there was no right heart volume overload present and 3 had an indication for surgical closure because of a defect diameter of >30 mm and total or partial deficiency of rims (<5 mm) on the basis of 2D TTE. The remaining 29 patients had evidence of substantial right heart volume overload at 2D TTE (and thus an indication for intervention), and therefore underwent not only a 2D SMPI study but also a TEE study. These 29 patients formed the final study population.

Ten (34%) patients were male, and the mean (± SD) age of the patients was 41 ± 18 years (range 20–74). Sixteen patients were suitable for percutaneous closure, 12 for surgical closure, and 1 no indication for closure.

**Diameters of ASD**
In the 16 patients who finally underwent percutaneous closure of the ASD, the SMPI dimensions of the ASD could be compared with the dimensions measured with 2D TEE, balloon sizing, and device size. As seen in Table 1, there were no significant differences between SMPI in the xPlane mode and 2D TEE regarding the sizes of the anterior–posterior dimension (13.7 ± 4.5 vs. 14.5 ± 5.2 mm) and superior–inferior dimension (13.5 ± 3.9 vs. 14.1 ± 5.0 mm). The mean echocardiographic SMPI (13.6 ± 4.2 mm) and TEE dimensions (14.3 ± 5.1 mm) were smaller than the balloon sizing diameter (16.7 ± 5.8 mm, both P < 0.05) and the actual device size (18.2 ± 6.0 mm, both P < 0.05).

**Visualization of ASD rims**
As seen in Table 2, in the transthoracic subcostal 4CH view (or RPS view in the four patients with poor subcostal window) and TEE transverse 4CH view, the AV rim could be visualized in all patients. In the 29 patients, SMPI and TEE for assessment of the AV rim size (using the clinically relevant cut-off value of 5 mm) had a 100% agreement. With TEE, the RUPV could not be visualized in one patient; with SMPI, the RUPV was visualized in all patients. The IVC rim could be visualized in all patients with SMPI, but not in two patients with TEE. The SVC rim could not be visualized in one patient with SMPI and in two patients with TEE.

### Table 1  Atrial septal defect dimensions according to echocardiography and sizing balloon (n = 16)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>SMPI</th>
<th>TEE</th>
<th>Sizing balloon</th>
<th>Device size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior–posterior (mm)</td>
<td>13.7 ± 4.5</td>
<td>14.5 ± 5.2</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Superior–inferior (mm)</td>
<td>13.5 ± 3.9</td>
<td>14.1 ± 5.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>13.6 ± 4.2*</td>
<td>14.3 ± 5.1*</td>
<td>16.7 ± 5.8</td>
<td>18.2 ± 6.0</td>
</tr>
</tbody>
</table>

*P < 0.05 compared with sizing balloon and device size.

### Table 2  Atrial septal defect rim size when compared with TEE (n = 29)

<table>
<thead>
<tr>
<th>Rim of atrial septal defect</th>
<th>2D/SMPI technique</th>
<th>TEE visualization (%)</th>
<th>SMPI visualization (%)</th>
<th>Concordance(^{\dagger}) TEE–SMPI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV</td>
<td>Standard 4CH subcostal view(^{a})</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>RUPV</td>
<td>Standard 4CH subcostal view(^{a})</td>
<td>97</td>
<td>100</td>
<td>96</td>
</tr>
<tr>
<td>Inferior caval vein</td>
<td>Biplane SMPI subcostal SAX view(^{a})</td>
<td>93</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Superior caval vein</td>
<td>Biplane SMPI subcostal SAX view(^{a})</td>
<td>93</td>
<td>97</td>
<td>96</td>
</tr>
<tr>
<td>Aortic</td>
<td>Standard parasternal SAX view</td>
<td>100</td>
<td>100</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>I-rotate SMPI subcostal view</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

\(^{a}\)Based on patients with visible rims both in TEE and SMPI.

\(^{\dagger}\)In four patients, the RPS view was used because of a poor quality subcostal window.
In the 23 patients with all imaging techniques (2D, I-rotate SMPI, and TEE) used for assessment of the aortic rim, rim visualization was 100% for both the standard parasternal SAX view, I-rotate SMPI from the subcostal 4CH view (or RPS view in four patients), and TEE. The agreement with TEE was 100% for SMPI and 79% for the 2D TTE parasternal SAX view. In the other four patients, rim size was underestimated by the transthoracic SAX analysis when compared with TEE: 4 vs. 8 mm, 3 vs. 7 mm, and 4 vs. 6 mm and from the RPS view 4 vs. 14 mm for TEE.

Agreement on suitability for percutaneous closure between SMPI and TEE
In 26 patients, all rims could be completely assessed with both SMPI and TEE. According to SMPI, 20 of these patients were considered suitable for implantation of a percutaneous device and in all 20 patients this was confirmed by TEE (positive predictive value 100%). In six patients, one or more rims were too small according to SMPI, and in five patients this was confirmed by TEE (negative predictive value 83%).

Inter-observer agreement for SMPI measurements
The inter-observer 95% limits of agreement for the anterior–posterior dimension of ASD was −3.4 to 3.6 mm, with a bias of 0.1 mm, and a relative inter-observer variability of 10% ± SD (Figure 2). The inter-observer 95% limits of agreement for the superior–inferior dimension of ASD was −2.7 to 3.1 mm, with a bias of 0.2 mm, and a relative inter-observer variability of 7% ± SD. The inter-observer agreement, using the cut-off value of 5 mm, was for all rims 100%.

Discussion
Patient selection for percutaneous closure of an ASD relies on two essential criteria: maximal ASD diameter and tissue rim length. A defect diameter of >30 mm and total or partial deficiency of rims (<5 mm) exclude patients from referral to percutaneous ASD closure. The main finding of this study was that the SMPI technique could reliably assess the dimensions and rim size of a secundum ASD for pre-interventional selection when compared with 2D TEE.

ASD diameter
As an ASD may be oval or slit like in shape, it is important that both the major and minor axis of the defect are visualized. Through a thorough 2D TTE multiview examination of the inter-atrial septum from the subcostal 4CH view, an experienced sonographer may record sufficient data to decide whether a patient is suitable for percutaneous ASD closure. However, one is never completely sure whether the true orthogonal plane of the defect has been crossed and the maximum superior–inferior diameter measured. For the less experienced sonographer, it is technically demanding to image the subcostal SAX (lateral) view for the superior–inferior diameter. Incorrect measurements may easily be made, and defects that are not within the oval fossa and not seen in the standard subcostal 4CH view could be missed. TEE is superior to TTE in evaluating an ASD not only because of its superior image quality, but also because of its multiplane character. Once the largest diameter has been visualized in the transverse (4CH) view, a true orthogonal plane can be acquired with a simple 90° rotation. The same results may now be achieved with transthoracic SMPI. Once the largest diameter of the ASD has been identified from the standard subcostal 4CH view, the true orthogonal plane of the defect can be acquired in the xPlane mode and the superior–inferior diameter measured in the same heartbeat as the anterior–posterior diameter. As shown in this study, no significant differences in the two diameters were seen between SMPI and TEE. As well known, the anterior–posterior and superior–inferior dimensions measured with SMPI in the xPlane mode and TEE were both significantly smaller compared with balloon sizing (a stretch diameter) and the actual device size.

An additional benefit of SMPI over standard TTE is that the diagnoses of an ASD become less operator dependant. Also a controlled
sweep across the inter-atrial septum, with the xPlane mode, from the standard 4CH subcostal view allows defects outside the oval fossa (which are often missed) to be detected more easily (Figure 3).

**ASD rims**

To ensure stability of the closure device and to avoid encroachment on surrounding structures, an adequate rim size of septal tissue (>5 mm) around the defect is of vital importance. Apart from one SVC rim, all rims could be assessed with SMPI. The AV rim was evaluated from the standard subcostal 4CH view (or in a few patients with a poor subcostal window from the RPS view); in full concordance with TEE. The RUPV rim was also evaluated from the standard subcostal 4CH view. Only one RUPV rim showed a discrepancy in cut-off measurement between SMPI and TEE (3 mm at SMPI vs. 6 mm at TEE). Underestimation of this rim, which appeared thin and floppy at TEE, may have been caused by reduced transthoracic image quality. The SVC and IVC rims were measured from an xPlane image taken from the standard subcostal 4CH view. The IVC rim could be visualized in all patients with SMPI, in full concordance with TEE. The SVC rim that was scored absent was most likely due to it being in alignment with the ultrasound beam and its position in the far-field in combination with reduced transthoracic image quality (the RUPV rim was also underestimated in this patient). In the patient in whom the SVC rim could not be visualized, this was also true for the TEE so maybe this was due to the rotation of the heart itself rather than the technique.

Assessment from the standard parasternal SAX of the aortic rim is known for its inaccurate measurement, as was shown in six patients in our study. As seen in Figure 4A, misinterpretation of the IAS as being intact and signal dropout due to the inability to evaluate the aortic rim perpendicularly will result in inadequate assessment. 16,18,19 I-rotate from the subcostal 4CH and RPS view resulted in a more perpendicular visualization of this rim and perfect correlation with TEE. With the ASD centred on the midline of the sector, a complete 360° rotation around the defect can be performed and the full extent of the rims evaluated (Figure 4B).
Clinical implications

Our results show that, with an optimal quality SMPI echo, the diagnostic (especially in patients with defects outside the oval fossa) and pre-interventional TEE could be avoided. In children where a pre-interventional TEE is not routinely performed, SMPI would give more detailed information. In addition, it has been reported in studies that catheter closure of central ASD's can successfully be monitored by standard 2D TTE and fluoroscopic guidance.6,7,15,20 Because multiple cross-sectional views are needed throughout the procedure, SMPI can reduce the number of transducer positions and provides bi-plane (xPlane) imaging, the benefit of which has already been described with TEE, while monitoring the positioning of the device.21 I-rotate may also accurately check if all aspects of the closure device are well seated and no residual shunts are present before the final deployment of the device. As TTE monitoring is a very economical (compared with the use of intra-cardiac echocardiography) and patient friendly (compared with intra-interventional TEE monitoring necessitating general anaesthesia) imaging technique, more centres may be tempted to use it given the additional value of SMPI, especially in patients who have a good acoustic window.

Limitations

We did not compare 2D SMPI measurements with 3D TTE echo. Despite the valuable ‘enface views’, this technique is not without limitations. Difficulties in image acquisition, loss of image resolution, and ASD size being dependent on 3D gain settings may result in inaccurate measurements.3,22,23

The spatial resolution of the X5-1 matrix transthoracic probe remains somewhat inferior to the stand-alone 2D transducer and in addition the frame rate (temporal resolution) drops by half when entering the xPlane mode. This latter can be problematic for colour Doppler flow imaging that already suffers from lower frame rates in the standard (primary) 2D images. The drop in temporal resolution can be brought to a minimum by ensuring that the smallest sector able to encompass the cardiac structure of interest is used. Also this can be overcome with the I-rotate mode if the ASD can be positioned in the centre of the sector as frame rate in this mode is not compromised at all.

Two-dimensional TEE is considered the gold standard. However, in one patient the RUPV rim could not be visualized due to a very large ASD and the position of the RUPV in the corner of the sector. Also, in two patients the IVC and SVC rims were not visualized on TEE. Both TEE studies suffered from reduced image quality, and it is known that due to the extreme proximity of the IVC rim to the transducer it can be difficult to visualize.24

Finally, the motion of the heart throughout the cardiac cycle may result in the reference line not transecting the ASD at any time point in the heart cycle.

Conclusion

The SMPI technique, which allows a full electronic rotation of 360° of the ASD and displays the true orthogonal plane of the defect in the xPlane mode, can reliably assess the dimensions and rim size of a secundum ASD for pre-interventional selection when compared with 2D TEE. If the SMPI study is of optimal quality, it has the potential to replace the TEE for ASD evaluation and guidance of device placement.

Conflict of interest: None declared.

References


Postoperative dissecting ventricular haematoma: a conservative strategy with a cardiac magnetic resonance imaging follow-up

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Dissecting ventricular haematoma (DVE) is uncommon and immediate evacuation is usually recommended. A 68-year-old male patient was referred to our hospital for surgical repair of mitral valve prolapse. The mitral valve surgery was complicated by lateral ST-elevation and transoesophageal echocardiography (TEE) showed a left ventricle (LV) lateral wall thickness suggestive of DVE (Panels A and B, and see Supplementary data online). Urgent invasive coronary angiography (ICA) showed a marginal branch with negligible extra-vascular bleeding and compressed by DVE, suggesting an intra-myocardial course of the vessel (Panel C and see Supplementary data online). Based on the stable haemodynamic condition, a conservative strategy was planned. Three days later, cardiac magnetic resonance (CMR) steady-state free procession sequences showed LV lateral wall thickness with moderate reduction in LV ejection fraction (EF; 38%) (Panel D, asterisk; see Supplementary data online) with low signal surrounded by bright rim at T1-weighted images (Panel E, asterisk; see Supplementary data online), respectively. The rest perfusion demonstrated a large dark expanded area (Panel F, asterisk; see Supplementary data online) with a bright signal surrounding the haematoma at post-contrast late gadolinium enhancement sequence (Panel G, asterisk). The LV thickness was slightly decreased when compared with TEE, and therefore, the conservative strategy was confirmed. At 3-month follow-up, the patient was event free with a significant spontaneous remission of haematoma and mild improvement in LV EF (43%) (Panels H–M and see Supplementary data online). This is a rare case of DVE with spontaneous remission at follow-up.

LCX: left circumflex coronary artery; MV: mitral valve; RV: right ventricle

Supplementary data are available at European Heart Journal – Cardiovascular Imaging online.