Individual pulmonary vein imaging by transthoracic echocardiography: an inadequate traditional interpretation

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Received 24 August 2007; accepted after revision 9 January 2008; online publish-ahead-of-print 19 February 2008

Aims There existed an ambiguity in the current echo literature about the identification of the pulmonary veins imaged by echocardiography. This study was designed to identify the site and blood flow of individual pulmonary veins by transthoracic echocardiography.

Methods and results Transthoracic echocardiography was used to display individual pulmonary veins in the apical and parasternal short-axis views in 20 adult patients with atrial septal defect. Cardiac catheterization, selective angiography, and contrast echocardiography were used to identify and validate the exact site of individual pulmonary veins. The right lower and upper veins were best seen in the apical four-chamber and the near apical five-chamber views, respectively. Both left pulmonary veins were best displayed in the parasternal short-axis view. When all the individual pulmonary veins were seen simultaneously in the apical views, from left to right of the sector, they were the right upper, right lower, left lower, and left upper pulmonary veins, respectively.

Conclusion This prospective study provides a feasible method to prove that transthoracic echocardiography can visualize clearly and identify accurately the exact site of each pulmonary vein. The information should be helpful to study various pulmonary venous diseases.

Keywords
Echocardiography; Pulmonary vein; Angiography

Introduction

There has been potential difficulty in visualizing the four pulmonary veins by transthoracic echocardiography. The important factors against their imaging are the veins being located in the far field and outside cardiac structures. Up to now, no controlled study has been carried out to identify the individual pulmonary veins. Previous viewpoint in textbooks1,2 or literatures3–8 may be a subjective judgement and is not validated by other imaging techniques. Therefore, we have reason to suspect and search for an appropriate method to validate the exact site of individual pulmonary veins so as to prevent echocardiographic misinterpretation. Using cardiac catheterization, selective pulmonary vein angiography, and contrast echocardiography as control, this prospective study was designed to prove our hypothesis and to identify the site and blood flow of individual pulmonary veins by transthoracic echocardiography in adult patients with atrial septal defect (ASD).

Methods

Study patients

In this study, 20 consecutive adult patients (4 men and 16 women, aged 20–57 years, mean 37) with ostium secundum ASD and significant left-to-right shunt were referred to our institute from September 2006 to February 2007. During their hospitalization, they underwent cardiac catheterization, pulmonary vein angiography, contrast echocardiography, and/or transcatheter closure. Patients were stratified by New York Heart Association functional classification (class I–IV). Written informed consent was obtained from all patients.

Echocardiography

Clinical echocardiograms were obtained in all subjects in the left lateral decubitus position by an experienced sonographer using an Acuson Sequoia C256 (Acuson, Mountain View, CA, USA) echocardiographic imaging system equipped with a 2.0–3.5 MHz transducer. An ECG was recorded and displayed simultaneously on the image. With the use of Doppler colour flow as a guide, right lower pulmonary vein (RLPV) and right upper pulmonary vein (RUPV) were shown in the apical views and left upper and lower ones in the parasternal short axis and/or the apical four-chamber views. The right
pulmonary venous blood flow velocity was measured by placing the sample volume ~1 cm upstream in the RUPV and RLPV. All echocardiographic data were stored digitally on magneto-optical disk for subsequent off-line analysis.

Catheterization evaluation and pulmonary vein angiography

All patients were in the supine position in catheterization laboratory. Each procedure was performed with patients staying awake under local anaesthesia. Access was obtained through the right femoral vein and artery. Each patient was given intravenous injection of 3000 U of heparin, whose pressures and oxygen saturations of right and left heart chambers were obtained through cardiac catheterization. Pulmonary (Qp) and systemic (Qs) blood volume flow and shunt fraction (Qp/Qs) were calculated. The left atrium (LA) was entered through the ASD. Contrast angiogram was done by hand injection of a contrast agent through the catheter to identify the site of each pulmonary vein in the postero-anterior view of a chest radiograph.

Contrast echocardiography

After identification of the site of each pulmonary vein with the angiogram, the catheter was kept in the same position and agitated saline of 8 mL was injected by hand into each vein to visualize its site and running by contrast echocardiography. Contrast echocardiogram was obtained in the supine position by an experienced sonographer using a GE Vingmed Vivid Seven machine with a 1.7–3.4 MHz multifrequency transducer. An ECG was recorded by the sonographer using a GE Vingmed Vivid Seven machine with a 1.7–3.4 MHz multifrequency transducer. An ECG was recorded and displayed simultaneously on the image. With the use of Doppler colour flow as a guide, contrast echocardiogram of RUPV and RLPV was shown in the apical views, whereas that of left upper and lower ones was shown in the parasternal short-axis view. All echo data were dealt with as mentioned earlier.

Statistical analysis

All data were presented as mean ± SD. Statistical differences of two groups were calculated and analysed using the paired Student’s t-test. Statistical significance is set at P-value <0.05.

Results

Echocardiography

The data of the study of echocardiography and catheterization in all patients were summarized in Table 1. The proximal portion of the RLPV in the apical four-chamber view was seen draining into the LA almost perpendicular to its posterior aspect, and the blood flow of the vein was virtually parallel to ultrasound beam and atrial septum (Figure 1, left). Visualization of the RUPV made it necessary to tilt the transducer slightly anteriorly in the apical four-chamber view, when a portion of the left ventricular outflow tract could also be seen. Namely, lying between the apical four- and five-chamber views or near apical five-chamber view was used, which entered, in a tilting position, the right postero-medial aspect of the LA in a tilting position. DAO, descending aorta; LA, left atrium; LV, left ventricle; RA, right atrium; RL, right lower pulmonary vein; RU, right upper pulmonary vein; SV, systolic; Vmax, maximal blood flow velocity.

![Figure 1](image-url) Doppler colour flow images of both right pulmonary veins. Left, the image of right lower pulmonary vein in the apical four-chamber view with colour flow mapping showing the vein draining into the LA almost perpendicular to its posterior aspect and virtually parallel to ultrasound beam and atrial septum. Right, the Doppler colour flow image of the right upper pulmonary vein in near apical five-chamber view indicates the vein in the right postero-medial aspect of the LA in a tilting position. DAO, descending aorta; LA, left atrium; LV, left ventricle; RA, right atrium; RL, right lower pulmonary vein; RU, right upper pulmonary vein; RV, right ventricle.

The parasternal short-axis view at the level of the aorta and LA was the most ideal window to display the left upper pulmonary vein (LUPV). A length of the longitudinal section of the vein could be shown in all patients, which entered the LA through its lateral aspect in a slightly left anterior to right posterior direction (Figure 2). It might be comparatively difficult to visualize the left lower pulmonary vein (LLPV) opening into the LA. A short proximal segment of the longitudinal section of the LLPV could be visualized only in 12 patients (60%), which opened into the lateral aspect of the LA with a slightly left posterior to right anterior direction (Figure 2). Either a transverse section or being unrevealing...
Cardiac catheterization

All patients underwent cardiac catheterization without any complications. Pulmonary artery systolic pressure was 42 ± 14 mmHg. Five patients had moderate-to-severe pulmonary hypertension (pulmonary artery systolic pressure > 50 mmHg). Pulmonary-to-systemic blood flow ratio \( (Q_{p}/Q_{s}) \) was 2.1 ± 0.5.

Pulmonary vein angiography and contrast echocardiography

Angiograms of four pulmonary veins were obtained successfully in all patients. Contrast images of these veins were adequately visualized and suitable for evaluation in all patients. The angiography and contrast echocardiography of each of the individual pulmonary veins were summarized in Table 2 and also shown in Figure 4–7. The catheter could be clearly visualized in the LUPV, but was difficult to be seen in other veins.

Discussion

Using selective angiography and contrast echocardiography as control, this prospective study has proven that transthoracic echocardiography can be most helpful in the orientation of the pulmonary veins that were previously ambiguous. This provides information ensuring that each vein can be visualized accurately in both location and blood flow by transthoracic echocardiography.

Pulmonary vein angiography, intracardiac echocardiography, transoesophageal echocardiography, computed tomography, or magnetic resonance angiography are often used to assess pulmonary vein anatomy and blood flow. All four pulmonary veins can be occasionally seen draining into the LA from suprasternal view, particularly in children but rarely in the adult. Visualizing all four pulmonary veins may be very difficult from the apical and parasternal views. The traditional textbook was of the opinion that the pulmonary veins seen in the apical four-chamber view, from left to right of the sector, were the right upper, left upper, and the LLPVs, respectively, whereas the right lower one was usually not visualized in the apical four-chamber view. Investigators, on evaluating pulmonary venous flow, were in general agreement that what was displayed in the apical four-chamber view was the blood flow of an RUPV, which was considered almost parallel to the ultrasound beam.

In the study, it was found that both apical and parasternal short-axis views were the ideal ultrasound windows for evaluation of both the right pulmonary veins and the left ones, respectively. When the site of four pulmonary veins was seen simultaneously in an apical four-chamber view, displayed from left to right of the sector, they should be right upper, right lower, left lower, and left upper pulmonary veins, respectively. The blood flow of the pulmonary vein that Doppler ultrasound explores in the apical four-chamber view in the literatures should be that of the RLPV. For the majority of patients, the transducer must be tilted slightly anteriorly in order to explore the blood flow of RUPV, namely, the blood flow of RUPV should be measured in the near apical five-chamber view.

Anatomy of the pulmonary veins

The pulmonary vein orifices lie on the posterolateral (left pulmonary veins) and posteromedial (right pulmonary veins) aspects of the left atrial cavity. The LUPV and RUPV...
enter the LA in an anterosuperior direction, whereas the lower ones open into the LA perpendicular to its posterior wall.18 The upper and lower orientation of the sector in the apical four-chamber view is always described as anatomic superior and inferior relationship.1 The plane that transects the heart approximately parallel to the dorsal and ventral surfaces of the body will be referred to as the four-chamber plane.19 Such descriptions of the orientation about the apical four-chamber view may make one consider subjectively that the view was similar to a frontal plane rather than a transverse plane, which may be an important cause to misread the location of individual veins in the apical four-chamber view. Right, the contrast echocardiogram of the vein in the same view showing the vein opacified by the contrast agent. Abbreviations as in Figure 1.

Table 2 The angiography and contrast echocardiography of the individual pulmonary veins

<table>
<thead>
<tr>
<th>Contrast echocardiography</th>
<th>Angiography</th>
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<tr>
<td>View</td>
<td>Course of entering the LA</td>
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<tr>
<td>RLPV Apical four-chamber</td>
<td>Opening into the LA from its rear and almost parallel to the ultrasound beam</td>
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<tr>
<td>RUPV Near apical five-chamber</td>
<td>Draining obliquely into the LA through its right posterior aspect</td>
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<tr>
<td>LLPV Parasternal short axis</td>
<td>The vein entering LA through its lateral aspect with a slightly left posterior to right anterior direction</td>
</tr>
<tr>
<td>LUPV Parasternal short axis</td>
<td>Draining into the LA in a slightly left anterior to right posterior direction</td>
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LA, left atrium; LLPV, left lower pulmonary vein; LUPV, left upper pulmonary vein; P-A, postero-anterior; RLPV, right lower pulmonary vein; RUPV, right upper pulmonary vein.

Figure 4 Angiogram and contrast echocardiogram of the right upper pulmonary vein. Left, the angiogram showing the coursing of the vein draining into the LA in right superior to left inferior direction. Middle, the echocardiogram of the vein in the near apical five-chamber view, displaying the coursing of the vein draining obliquely into the LA through its right posterior aspect. Right, the contrast echocardiogram of the vein in the same view showing the vein opacified by the contrast agent. Abbreviations as in Figures 1 and 2.

Figure 5 The angiogram and contrast echocardiogram of the right lower pulmonary vein. Left, the angiogram of the vein showing its distal cardiac segment running along the right inferior to left superior direction, with its proximal portion entering almost perpendicular to the LA from the left to the right direction. Middle, the echocardiogram of the vein in the apical four-chamber view. Right, the contrast echocardiogram of the vein in the same view, the proximal segment of the vein opacified and draining almost perpendicularly into the LA from its rear, and virtually parallel to the ultrasound beam. C, catheter; other abbreviations as in Figures 1.

echocardiography, they should never be used as the sole diagnostic criterion.

Both right pulmonary veins are easily visualized in the apical four-chamber view and so is the left upper one in the parasternal short-axis view. However, it might be difficult for two-dimensional echocardiography to display the left lower one. Several reasons may be used to explain this to occur. First, the LLPV is covered by surrounding structures such as the descending aorta and the lung. Secondly, the ostia of both left pulmonary veins may be too close to be differentiated by the transthoracic echocardiography. Thirdly, the anatomic variant of the spatial orientation of pulmonary vein ostia may also be a cause, because the incidence of pulmonary venous anatomic variants was reported to be as high as 38%.21 However, the pathological analysis did not refer to these anatomic variants.22
dilated pulmonary veins, which made them easy to be visualized by Doppler colour flow mapping and two-dimensional echocardiography, and this, in turn, led to the dilation of the right heart, causing a change in the cardiac position that may be somewhat different from that of the patients with normal-sized heart. These may give rise to some error in the result. However, in our clinical practice, we have also observed different patient groups including those with normal-sized heart, which had similar results as stated earlier with exception that visualizing the RUPV was even more difficult than the right lower one. This confirms that the studied result can be applied without limitation.

In our practice, it may be difficult to visualize the LUPV. Fortunately, anomalous left lower pulmonary venous connection alone may be very rare.\(^2^6\,^2^7\) Another possible limitation is that transthoracic echocardiography may be difficult to obtain images of good quality, as it happens that the pulmonary veins are located in the far field. However, an experienced sonographer can adjust acoustic window to optimize the image. Transoesophageal echocardiography may be helpful to patients with suboptimal transthoracic images.

**Conclusions**

Individual pulmonary vein imaging by transthoracic echocardiography seems to be feasible. There may exist some ambiguity about the traditional point of view accepted generally. Using angiography and contrast echocardiography as control in this study, the accurate position of each pulmonary vein can be documented in the parasternal short-axis and apical views. The right lower and upper veins were best seen in the apical four-chamber and the near apical five-chamber views, respectively. Both left pulmonary veins were best displayed in the parasternal short-axis view. This expertise should be helpful to evaluate various proximal pulmonary venous diseases in their further studies.

**Conflict of interest:** none declared.

**References**


