Right-to-Left Interatrial Shunt Causing Platypnea After Pneumonectomy*

A Recent Experience and Diagnostic Value of Dynamic Magnetic Resonance Imaging

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Shortness of breath after pneumonectomy is a common finding that has multiple causes. We report the cases of two patients with shortness of breath on assuming an upright posture (platypnea) that followed pneumonectomy; these individuals developed right-to-left shunt across a patent foramen ovale (PFO) with normal right-sided intracardiac pressures. Both contrast echocardiography and magnetic resonance imaging (MRI), including a recently introduced dynamic ultrafast imaging technique, proved helpful in diagnosing this condition noninvasively.

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| ASD = atrial septal defect; G-E = gradient echo; PFO = patent foramen ovale; RLIAS = right-to-left interatrial shunt; S-E = spin-echo |

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Shortness of breath after pneumonectomy is most commonly due to loss of the alveolar volume, restriction of the vascular bed, chest wall pain, and diaphragmatic dysfunction.1,2 Right-to-left interatrial shunt (RLIAS) with normal right heart pressures is a rare cause, with only a few cases reported in the literature. The current report presents two patients who developed RLIAS across a patent foramen ovale (PFO) following pneumonectomy and reviews relevant literature.

CASE REPORTS

CASE 1

A 67-year-old man presented with progressive dyspnea 6 months after right pneumonectomy for large-cell carcinoma. His symptoms were worse in the upright position and was partially relieved in the supine position, qualifying the symptom as platypnea. Physical examination revealed tachycardia and central cyanosis. There was no jugular venous distention. Breath sounds were normal on the left and absent on the right. The precordium was shifted to the right and there were no murmurs or gallops.

Chest radiograph revealed opacification of the right hemithorax, hyperinflation of the left lung with herniation across the midline. The ECG was normal. As presented in Table 1, room air arterial blood gases (ABG) in the sitting position revealed a PaO2 of 38 mm Hg (oxygen saturation of 71 percent) and PaCO2 of 26 mm Hg. Repeated ABG in the sitting position while breathing 100 percent oxygen showed a PaO2 of 50 mm Hg (oxygen saturation of 82.4 percent) with the same PaCO2. A right-to-left shunt was suspected and was estimated to be 27 percent using the indirect Fick equation.3 Computed tomography of the chest revealed findings related to the pneumonectomy. A perfusion lung scan showed no perfusion defect but a significant uptake of radionuclide over the kidneys and the brain, further suggesting the presence of the right-to-left shunt. An echocardiogram was technically precluded by the mediastinal shift.

A magnetic resonance imaging (MRI) examination was designed to evaluate the possibility of intracardiac shunt at either the atrial or ventricular level. For this purpose, both standard static multilevel "dark-blood" and dynamic cine "bright-blood" techniques were employed to acquire images oriented to either the body axes (eg, transaxial) or the axes of the cardiovascular structures themselves (eg, cardiac four-chamber view). Due primarily to the distorted anatomy of the cardiac structures by the rightward shift of the mediastinal contents from the right pneumonectomy, the intracardiac septae, especially the interatrial septum, could not be visualized optimally in any orientation. While the presence of a ventricular septal defect could be excluded confidently, a defect of the interatrial septum could not be diagnosed or excluded until a modification of a recently introduced dynamic near-real-time technique (eg, TurboFLASH)4 was used to assess the first-pass transit of an intravenous bolus of a standard dose of paramagnetic MRI contrast material (gadolinium-diethylenetriaminepentaacetic acid) through the chambers of the heart. Use of this technique allowed the detection of RLIAS based on visualization by blood-pool enhancement of the left atrial chamber almost simultaneously with the right atrial chamber, but prior to the enhancement of the blood pools within the right ventricle and pulmonary vessels (Fig 1).

Despite normal right-sided cardiac pressures on cardiac catheterization, 45 percent RLIAS was identified by injecting the contrast into the inferior vena cava. The RLIAS could not be identified by injecting the dye in the superior vena cava.

At open heart surgery, a PFO was detected and corrected. Postoperative ABC on room air (sitting) revealed a PaO2 of 92 mm Hg.

CASE 2

A 67-year-old man developed shortness of breath 1 year after his right pneumonectomy for large-cell bronchogenic carcinoma. His symptoms also worsened in the upright position. Results of his physical examination were normal. A chest radiograph revealed shift of the mediastinum to the right, a normal left lung, and opacification of the right hemithorax. The ECG was normal. The ABC revealed PaO2 of 47 mm Hg (oxygen saturation of 82 percent) that increased minimally to 56 mm Hg (88 percent saturation) on an FIO2 of 1.0. The shunt fraction was calculated to be 27 percent. A contrast echocardiogram with agitated saline solution suggested a RLIAS, which was found by transesophageal echocardiogram to be due to PFO.

The patient underwent transcatheter closure of the defect using a chamshell device with immediate improvement in his symptoms and a rise in the PaO2 to 88 mm Hg on room air (sitting).

DISCUSSION

Platypnea from RLIAS is an unusual event after lung resection, with only 17 cases reported to date (present cases

Table 1 — Arterial Blood Gas Measurements Before Corrective Surgery in Patient 1

<table>
<thead>
<tr>
<th></th>
<th>Sitting</th>
<th>Sitting</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of breathing before sampling, min</td>
<td>12</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>FIO2</td>
<td>0.21</td>
<td>0.81</td>
<td>0.83</td>
</tr>
<tr>
<td>pH</td>
<td>7.57</td>
<td>7.51</td>
<td>7.45</td>
</tr>
<tr>
<td>PaCO2</td>
<td>21</td>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>PaO2</td>
<td>38</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>Oxyhemoglobin saturation</td>
<td>81.5</td>
<td>82.4</td>
<td>92.3</td>
</tr>
<tr>
<td>Qs/Qt% (shunt)*</td>
<td>27%</td>
<td>27%</td>
<td>27%</td>
</tr>
</tbody>
</table>

*Estimated using the indirect Fick's equation.

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In all the reported cases, the usual onset of platypnea was several weeks to months after surgery, and as with the two currently reported cases, all but one of the previously described patients underwent right pneumonectomy. Among the 10 described patients for whom right pressures are available from catheterizations, 6 (60 percent) have had normal right sides pressures. Patient 1 in the current report had normal right heart pressures (pulmonary artery, 28 to 32/8 to 12 mm Hg [mean pressure, 18]).

Despite earlier notions that development of interatrial shunt required an interatrial pressure gradient, possibly resulting from mediastinal shift or from hypoxic pulmonary hypertension, or from right atrial compression, more current reports

Figure 1. Right-to-left shunting through the interatrial septum (TurboFLASH imaging of D-DTPA bolus; transaxial). The four near-real-time images represent individual cardiac cycles (earliest cycle = upper left; second-to-last cycle = lower left) at a single anatomic level corresponding to a level in Figure 1 (eg, upper right). There is no enhancement of the intracardiac blood pools. Early enhancement of the right atrial chamber is almost immediately accompanied by early enhancement of the left atrial chamber due to right-to-left shunting at the atrial level; visualization of both sides of the defective interatrial septum (small arrows) is thereby made possible. This event precedes the enhancement of the blood pools of the right ventricle, left ventricle (asterisk), pulmonary vasculature (open arrow), and descending thoracic aorta (open circle).

Figure 2. Abnormal relationship between the vena cavae and atrial (S-E; transaxial and coronal). Both the transaxial images (left) and the coronal images (right) demonstrate the smaller, fluid-filled right hemithorax associated with rightward shift of the mediastinal contents, including the trachea (asterisks) and heart. This has resulted in a reorientation of the right atrium and left atrium (circles) relative to each other. The former is compressed against the elevated right hemidiaphragm and is abnormally inferior in location relative to the left atrium. The superior vena cava (open arrows) is abnormally draped around the interatrial septum. Consequently, the plane of the interatrial septum (white arrow) is atypically horizontal, causing it to overlie the opening of the inferior vena cava (black arrows) into the right atrium.
recognize that RLIAS may result from directional "streaming" of blood from the right to left atrium. For example, Swan et al postulated the streaming of the inferior vena cava blood, because the atrial orifice of the inferior vena cava straddles the limbus of the vessel, causing part of the flow to stream directly into the left atrium via an atrial septal defect (ASD) or a PFO. After pneumonectomy, the interatrial septum may shift more to the right relative to the inferior vena cava, causing the inferior vena cava orifice to be closer to the ASD, which facilitates streaming. Also, the weight of the heart in the shifted position pulls downward on the interatrial septum, causing the oramen ovale to newly open or to widen. This mechanism may have caused platypnea in patient 1, whose shunt developed in the face of normal right atrial pressures. Indeed, the distorted anatomic arrangement of the great veins relative to the atria revealed by the static MRI images (Fig 2) in patient 1 is consistent with this hypothesis.

In addition to contributing two additional examples of postpneumonectomy platypnea to a sparse literature, the current report demonstrates the diagnostic value of two- and three-dimensional MRI techniques: the spin-echo (S-E) and the newer, but now commonly employed, gradient-echo (G-E) techniques. These two techniques are typically used to produce static "dark-blood" images from the multiple adjacent anatomic levels (eg, 14 levels) and the dynamic "bright-blood" cine image-loops composed of images acquired at a few anatomic (eg, 3) levels over multiple phases (eg, 16 phases) of the cardiac cycle. In patient 1, both multilevel S-E MRI and cine-MRI were performed as part of a routine clinical examination for a possible intracardiac shunt lesion. This case emphasizes the fact that MRI, with its wide field-of-view and lack of interference by the bones of the chest wall or the air within the lungs, can be used effectively to evaluate the central cardiovascular structures despite the extensive mediastinal shift due to pneumonectomy. While this gives MRI a distinct advantage over echocardiography, the distortion of the central cardiovascular anatomy in such patients may limit the ability of even MRI to image adequately specific structures (eg, interatrial septum) for direct visualization of a structural malformation (eg, ASD) unless specialized MRI techniques (eg, S-E and G-E) are used. Magnetic resonance imaging is otherwise known to be an effective imaging modality for detecting and delineating intracardiac shunt lesions, with limitations of the S-E technique overcome by use of the dynamic G-E technique. Nevertheless, use of a recently introduced dynamic ultrafast, near-real-time G-E MRI technique, permitting passage of an MRI contrast agent through the central cardiovascular system on a first-pass basis, was necessary to detect an RLIAS in patient 1. Early clinical experience indicates that this technique is valuable not only in detecting intracardiac shunt lesions, but is also capable of shunt quantification. To date, however, only the presence of shunting due to defects of the interatrial and interventricular septae has been reported. Thus, this report describes a new clinical application of advanced MRI.

Given the high prevalence of PFO in the general population (16 to 24 percent), and the large number of patients undergoing pneumonectomy, postoperative RLIAS is an important consideration in patients developing post-

References

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