Detection of pulmonary hypertension by Doppler echocardiography of the inferior vena cava in chronic airflow obstruction

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ABSTRACT  Pulsed Doppler echocardiography of the inferior vena cava is an accurate method for the diagnosis of tricuspid regurgitation and impaired right ventricular compliance, two features of pulmonary hypertension. The purpose of this study was to assess the value of Doppler echocardiography of the inferior vena cava for the detection of pulmonary arterial hypertension in patients with chronic obstructive lung disease. Pulsed Doppler echocardiography of the inferior vena cava and right heart catheterisation were performed in 29 patients with severe chronic obstructive lung disease. The mean pulmonary arterial pressure was 27 (10) mm Hg for the entire group; 62% of patients (18/29) had pulmonary arterial hypertension (mean pulmonary arterial pressure > 20 mm Hg). An adequate Doppler signal could be obtained in 25 of the 29 patients (86%). Pulsed Doppler echocardiography of the inferior vena cava gave normal results in 10 patients and disclosed tricuspid regurgitation in seven patients, impaired right ventricular compliance in seven patients, and both of these abnormalities in one patient. An abnormal Doppler echocardiogram of the inferior vena cava (tricuspid regurgitation or impaired right ventricular compliance, or both) predicted the presence of pulmonary arterial hypertension with a sensitivity of 87% and a specificity of 80%. These results suggest that pulsed Doppler echocardiography of the inferior vena cava may be a useful though imperfect method of detecting pulmonary arterial hypertension in patients with chronic obstructive lung disease.

Introduction

The presence of pulmonary arterial hypertension in patients with chronic obstructive lung disease is associated with a poor prognosis. The survival rate of such patients may be improved by long term domiciliary oxygen therapy. Right heart catheterisation is the reference method for the diagnosis of pulmonary arterial hypertension but this invasive technique is not always well tolerated in patients with chronic obstructive lung disease and cannot be repeated frequently to detect pulmonary arterial hypertension. There is a need for non-invasive methods to allow the accurate detection of pulmonary arterial hypertension in these patients. Electrocardiography and thallium-201 myocardial scintigraphy are limited by poor sensitivity, especially in patients with moderate pulmonary arterial hypertension, and right ventricular radionuclide angiography lacks specificity for detecting pulmonary arterial hypertension in patients with chronic obstructive lung disease. The value of echocardiography is very limited in these patients because of the poor penetration of ultrasound as a result of lung overinflation. Recently cardiac continuous wave Doppler ultrasound has been used to estimate the systolic pulmonary artery pressure from the velocity of a tricuspid regurgitation jet in patients with acquired and congenital heart diseases. In a high percentage of patients, however, even those with pulmonary arterial hypertension, the absence of tricuspid regurgitation precludes the estimation of pulmonary artery pressure.

Pulsed Doppler recordings of inferior vena caval blood flow offer an indirect approach to the assessment of right heart haemodynamics. They have been
shown to be accurate for the diagnosis of tricuspid insufficiency\textsuperscript{10} and impaired right ventricular compliance.\textsuperscript{12} As these recordings are based on a subcostal view they could be of value in patients with chronic obstructive lung disease, in whom parasternal views are difficult to achieve. The aim of this study was to evaluate the feasibility of this recording in patients with chronic obstructive lung disease, to analyse changes in inferior vena caval blood flow, and to study the relation between these changes and pulmonary hypertension.

**Methods**

**Patients**

The present study included 29 consecutive patients with chronic obstructive lung disease (20 of them men) who were referred for right heart catheterisation. The patients had either chronic bronchitis, characterised by cough and sputum during at least three consecutive months for each of two consecutive years, or emphysema, characterised by dyspnoea with radiological evidence of emphysema and functional evidence of airways obstruction (FEV\textsubscript{1}/FVC < 55%). Three patients had left heart disease also, cardiomyopathy in two and prior myocardial infarction in one. No patient had rheumatic or congenital heart disease. Atrial fibrillation was present in two patients. The patients were in a stable condition during the previous three weeks and at the time of the study.

The patients had a mean (SEM) age of 61 (11) years and their forced expiratory volume in one second (FEV\textsubscript{1}), as mean (SEM) % of predicted value, was 40 (21), forced vital capacity (FVC) 73 (15) (FEV\textsubscript{1}/FVC ratio = 40 (14)), residual volume 142 (52), and total lung capacity 98 (18); arterial oxygen tension (Pao\textsubscript{2}) was 8.5 (1.5) kPa, arterial carbon dioxide tension (PaCO\textsubscript{2}) 5.7 (0.9) kPa. Seven of the 29 patients (24%) had had right heart failure in the past and 18 (62%) had had an episode of acute respiratory failure.

Inferior vena caval blood flow was also studied in 10 healthy subjects.

**Doppler Examination Technique**

We used a pulsed Doppler velocimeter combined with a two dimensional echocardiography (CGR Sonel 3-000c–Dop 150). The emission frequency of the transducer is 3 MHz. The depth of the sample volume can be set from 3 to 15 cm according to the pulse repetition rate.

The patient is placed in the supine position. The transducer is located on the epigastric area. The ultrasonic beam is oriented posteriorly and to the right to visualise the inferior vena cava behind the liver. Inferior vena caval flow is regulated by the heart and by respiration, increasing during inspiration. In some patients a suitable signal cannot be obtained within the inferior vena cava. In these circumstances the flow of a suprahepatic vein may be recorded. The suprahepatic veins lie more superficially and their flow pattern has the same characteristics as that of the inferior vena cava. As these velocities vary with intrathoracic pressures, in particular with respiration, the flow-velocity tracings must be recorded during an open glottis apnoea at the end of expiration.

**Analysis of the Inferior Vena Caval Flow Velocity**

The normal inferior vena caval flow is away from the transducer and corresponds to a negative wave. The normal flow has three components\textsuperscript{10}: a predominantly negative systolic wave (s) due to atrial relaxation and lowering of the ventricular floor, a negative diastolic wave (d), which has a smaller amplitude and corresponds to the passive filling of the right ventricle, and a positive flow reversal wave in late diastole, which is due to atrial contraction and occurs immediately after the P wave of the electrocardiogram. In the case of atrial fibrillation, the relative amplitude of s is smaller and the end diastolic reverse flow disappears. There is a delay between the cardiac events recorded on the electrocardiogram and the inferior vena caval flow-velocity owing to venous compliance.

In the case of mild tricuspid regurgitation the amplitude of the antegrade systolic flow-velocity (s) decreases. When tricuspid regurgitation is more severe, the normal negative systolic wave is replaced by a retrograde positive systolic wave\textsuperscript{10} (corresponding to the T wave of the ECG), which occurs either in late systole (moderate tricuspid regurgitation) or throughout systole (severe tricuspid regurgitation). In the presence of impaired right ventricular compliance the normal negative diastolic wave is replaced by a retrograde positive diastolic wave, which starts before the P wave of the electrocardiogram with sinus rhythm or before the QRS complex with atrial fibrillation.\textsuperscript{12} Impairment of right ventricular compliance was assessed subjectively as moderate or severe according to the importance of the positive diastolic flow.

**Cardiac Catheterisation**

Right heart catheterisation was performed with a Swan-Ganz catheter. The curve of pulmonary arterial pressure was recorded during open glottis apnoea at the end of expiration. Pulmonary arterial pressure was averaged over five beats in sinus rhythm. In atrial fibrillation beats with R-R intervals representative for the mean heart rate were chosen. Pulmonary arterial hypertension was defined as a mean pulmonary arterial pressure above 20 mm Hg. Cardiac output (Q) was measured by the thermodilution technique with
injection of iced saline solution and a commercially available computer (Edwards Laboratories COM 1).

The haemodynamic and Doppler studies were performed within three days of each other, when the subject was clinically stable and with treatment unchanged. Cardiac catheterisation and the echo Doppler study were performed with the subject supine, at rest, and without sedation. The patients' drugs were continued as usual.

The physician performing the catheterisation was unaware of the results of the Doppler study. Analysis of the inferior vena cava Doppler was made (1) by the physician performing the Doppler examination, who did not know the haemodynamic results, and (2) in a blind manner by a second physician from the Doppler traces alone.

Results

The results of the haemodynamic study are summarised in table 1. The mean (SD) value of mean pulmonary arterial pressure for the entire group was 27 (10) mm Hg. Eighteen of the 29 patients (62%) had pulmonary arterial hypertension as defined.

The results of the pulsed Doppler echography of the inferior vena cava are summarised in table 2. There was no discordance between the Doppler analyses of the two physicians concerning the quality of traces, the diagnosis of tricuspid regurgitation and impaired right ventricular compliance, or the evaluation of the severity of these conditions. The flow-velocity curves of the inferior vena cava were inadequate for analysis in four patients because of obesity in two cases and impossible apnoea in one. In 25 of the 29 patients (86%) the Doppler signal of the inferior vena cava was adequate for analysis. It was normal in 10 patients and showed impaired right ventricular compliance in seven, tricuspid regurgitation in seven, and both in one patient. In all patients with impaired right ventricular compliance, the impairment of right ventricular compliance was moderate. Tricuspid regurgitation was mild in five patients and moderate in three.

In 25 patients we were able to compare the results of the pulsed Doppler echography of the inferior vena cava with the haemodynamic data (table 3). Among the 15 patients with pulmonary arterial hypertension, the results of the Doppler study were abnormal in 13 patients, showing impaired right ventricular compliance or tricuspid regurgitation or both. The inferior vena cava flow-velocity tracings were also abnormal in two of the 10 patients without pulmonary arterial hypertension. The sensitivity of pulsed Doppler echocardiography of the inferior vena cava for the diagnosis of pulmonary arterial hypertension (mean pulmonary arterial pressure > 20 mm Hg) therefore was 87% and the specificity 80%. The positive predictive value was 87% and the negative predictive value 80%. The true sensitivity for detecting pulmonary arterial hypertension for the whole group, including the patients where a satisfactory trace was not obtained, was 72% and the true specificity 82%.

Table 1 Results of haemodynamic study (mean (SD) values)

<table>
<thead>
<tr>
<th></th>
<th>All patients (n = 29)</th>
<th>Patients with PAH (n = 18)</th>
<th>Patients without PAH (n = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAP (mm Hg)</td>
<td>27 (10)</td>
<td>33 (9)</td>
<td>16 (2)</td>
</tr>
<tr>
<td>PAP (mm Hg)</td>
<td>40 (16)</td>
<td>49 (11)</td>
<td>24 (4)</td>
</tr>
<tr>
<td>PAP (mm Hg)</td>
<td>15 (8)</td>
<td>19 (8)</td>
<td>8 (2)</td>
</tr>
<tr>
<td>PWP (mm Hg)</td>
<td>11 (5)</td>
<td>11 (6)</td>
<td>9 (3)</td>
</tr>
<tr>
<td>RVSP (mm Hg)</td>
<td>41 (19)</td>
<td>48 (13)</td>
<td>24 (5)</td>
</tr>
<tr>
<td>RVEDP (mm Hg)</td>
<td>5 (4)</td>
<td>7 (4)</td>
<td>3 (3)</td>
</tr>
<tr>
<td>RAP (mm Hg)</td>
<td>6 (4)</td>
<td>7 (4)</td>
<td>4 (2)</td>
</tr>
<tr>
<td>CI (1/min/m²)</td>
<td>3.1 (0.7)</td>
<td>3.0 (0.7)</td>
<td>3.5 (1)</td>
</tr>
<tr>
<td>APR (dyn/s/cm⁻³)</td>
<td>278 (213)</td>
<td>353 (215)</td>
<td>124 (22)</td>
</tr>
<tr>
<td>TPR (dyn/s/cm⁻³)</td>
<td>434 (208)</td>
<td>540 (188)</td>
<td>248 (43)</td>
</tr>
</tbody>
</table>

PAP—mean pulmonary artery pressure; PAP—systolic pulmonary artery pressure; PAPp—diastolic pulmonary artery pressure; PWP—mean pulmonary wedge pressure; RVSP—right ventricular peak systolic pressure; RVSP—right ventricular end diastolic pressure; RAP—mean right atrial pressure; CI—cardiac index (CI = Q/body surface area); Q—cardiac output (l/min); APR—pulmonary arterial resistance (APR = \( \frac{\text{PAP} - \text{PWP}}{\text{Q}} \times 80 \)); TPR—total pulmonary resistance (TPR = \( \frac{\text{PAP}}{\text{Q}} \times 80 \)); PAH—pulmonary artery hypertension.

Table 2 Results of pulsed Doppler echography of inferior vena cava (numbers of patients)

<table>
<thead>
<tr>
<th></th>
<th>Patients (n = 29)</th>
<th>Control subjects (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate Doppler signal</td>
<td>4/29 (14%)</td>
<td>0</td>
</tr>
<tr>
<td>Adequate Doppler signal</td>
<td>25/29 (86%)</td>
<td>10/10 (100%)</td>
</tr>
</tbody>
</table>

Doppler findings:

<table>
<thead>
<tr>
<th>Subject</th>
<th>IRVC</th>
<th>TR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>IRVC</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>IRVC and TR</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

IRVC—impaired right ventricular compliance; TR—tricuspid regurgitation.

Table 3 Comparison of pulsed Doppler echography of the inferior vena cava and haemodynamic findings in the 25 patients with chronic obstructive lung disease who had an adequate Doppler signal (numbers of patients)

<table>
<thead>
<tr>
<th>Normal inferior vena cava flow-velocity</th>
<th>Impaired right ventricular compliance and/or tricuspid regurgitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAP &gt; 20 mm Hg</td>
<td>2 (13%)</td>
</tr>
<tr>
<td>PAP ≤ 20 mm Hg</td>
<td>13 (87%)*</td>
</tr>
<tr>
<td>PAP &gt; 20 mm Hg</td>
<td>8 (80%)</td>
</tr>
<tr>
<td>(n ≤ 10)</td>
<td>2 (20%)*</td>
</tr>
</tbody>
</table>

*Significant difference (p < 0.01, \( \chi^2 \) test).

PAP—mean pulmonary artery pressure.
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There were two false positive findings. In the first case moderate impaired right ventricular compliance was observed in only two complexes. In the second case very mild tricuspid regurgitation was recorded. In one of the two patients with false negative findings, the mean pulmonary arterial pressure was only 21 mm Hg.

In the 10 healthy subjects the flow pattern of the inferior vena cava was normal.

Discussion

Right ventricular dysfunction as a result of pulmonary arterial hypertension is a common complication of chronic obstructive lung disease. The presence of pulmonary arterial hypertension has an important prognostic value as well as therapeutic implications for this disease. Patients with chronic obstructive lung disease and pulmonary arterial hypertension may benefit from oxygen therapy. Vasodilator treatment in patients with chronic obstructive lung disease may have beneficial haemodynamic effects when administered acutely. The success of long term vasodilator treatment has not been proved but may depend on the early detection of pulmonary arterial hypertension.

Most patients with chronic obstructive lung disease when clinically stable have mild to moderate pulmonary arterial hypertension with mean pulmonary artery pressures ranging from 20 to 35 mm Hg. The fact that pulmonary hypertension is relatively mild is one of the main difficulties encountered in the non-invasive diagnosis of pulmonary arterial hypertension in chronic obstructive lung disease. There is a need therefore for a sensitive and reliable non-invasive screening tool for detecting moderate degrees of pulmonary arterial hypertension in patients with chronic obstructive lung disease.

Several methods can be used to detect pulmonary arterial hypertension in chronic obstructive lung disease. The ECG criteria of right ventricular hypertrophy have high specificity (>90%) but low sensitivity (<50%). The chest radiographic assessment of the diameter of the right descending pulmonary artery is limited by low sensitivity (68%) and specificity (65%) in detecting moderate pulmonary arterial hypertension. M mode echocardiographic assessment of pulmonary arterial hypertension is limited by poor visualisation of the right cardiac structures in most patients with chronic obstructive lung disease. The feasibility of two dimensional echocardiography is also low in these patients, but may be increased by combining apical and subcostal four chamber views. Radionuclide angiography in patients with pulmonary arterial hypertension shows a decrease in the right ventricular ejection fraction but this method has poor sensitivity (55%) in chronic obstructive lung disease. The clinical value of thallium-201 myocardial scintigraphy is limited by the low sensitivity (65%) of the method in patients with moderate pulmonary arterial hypertension.

The rationale for studying inferior vena caval blood flow was that this vessel is easily visualised in most patients with chronic obstructive lung disease with a subcostal view and that inferior vena caval blood flow depends directly on right heart haemodynamics. Diebold et al. using pulsed Doppler echocardiography of the inferior vena cava in 70 patients, mainly with valvular diseases, undergoing selective right ventricular angiography, showed that the method had a sensitivity of 89% and a specificity of 100% for the diagnosis of tricuspid regurgitation. If only moderate to severe tricuspid regurgitation was considered, the sensitivity and specificity were both 100%. This Doppler method also allows the extent of tricuspid regurgitation to be quantified. Flow in the superior vena cava may be used to detect tricuspid regurgitation but the reported sensitivity and specificity are lower than those reported for inferior vena caval blood flow studies. Diebold et al found a sensitivity of 90% and a specificity of 100% for Doppler echocardiography of the inferior vena cava for detecting impaired right ventricular compliance in cases of pericardial effusion.

The flow-velocity curve of the inferior vena cava was adequate for analysis in 25 of the 29 patients in our series (86%), despite the fact that all had severe chronic obstructive lung disease. The Doppler detection of tricuspid regurgitation or impaired right ventricular compliance or both allowed the prediction of pulmonary arterial hypertension in our patients with a sensitivity of 87% and a specificity of 80%.

Possible criticisms of our methods need to be considered. Firstly, the Doppler and haemodynamic studies were not simultaneous, though the delay between the two examinations was always less than three days and there was no change in clinical condition or in treatment between the two studies; secondly, this Doppler method does not allow a direct diagnosis of pulmonary arterial hypertension but detects its effects on the right ventricle—that is, tricuspid regurgitation and impaired right ventricular compliance, which we assume to be related to right ventricular dilatation and hypertrophy respectively; thirdly, Doppler echocardiography of the inferior vena cava does not allow a quantitative evaluation of pulmonary arterial hypertension or an estimation of its severity because the flow abnormalities (tricuspid regurgitation and impaired right ventricular compliance) were only mild or moderate in the patients with pulmonary arterial hypertension.

Several recent studies have shown that cardiac continuous wave Doppler ultrasound allows prediction of systolic pulmonary arterial pressure from the
peak velocity of a tricuspid regurgitation jet. The presence of cardiac Doppler detected tricuspid regurgitation, however, cannot be used to predict pulmonary arterial hypertension because it is observed in many patients with normal pulmonary arterial pressure and it is often absent in patients with moderate pulmonary arterial hypertension. In many patients the absence of Doppler detected tricuspid regurgitation precludes a quantitative estimation of pulmonary arterial pressure. Finally, poor conditions for ultrasound transmission may be a serious limitation of this method, which has not yet been validated in patients with chronic obstructive lung disease: for example, Peacock et al were unable to obtain an adequate Doppler signal with this technique in 10 of 15 patients with chronic obstructive lung disease. It has been recently shown that pulsed Doppler echocardiography of the pulmonary arterial trunk may be useful for evaluating mean pulmonary arterial pressure in patients with chronic obstructive lung disease but the high value of the standard error of the estimate precludes an accurate estimation of mean pulmonary arterial pressure in a given patient.

In conclusion, the echo Doppler of the inferior vena cava showed abnormalities—that is, tricuspid regurgitation and impaired right ventricular compliance—in a high percentage of patients with chronic obstructive lung disease and pulmonary arterial hypertension. Our data suggest that this non-invasive method, which is technically feasible in most patients with chronic obstructive lung disease, could be of value in the detection of pulmonary arterial hypertension in these patients. Further studies, including large numbers of patients with a wide range of severity of pulmonary disease and pulmonary arterial hypertension, are needed to determine the real value of this method.

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