ORIGINAL ARTICLE

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A new impedance cardiograph device for the non-invasive evaluation of cardiac output at rest and during exercise: comparison with the “direct” Fick method

Accepted: 3 April 2000

Abstract The objectives of this study were to evaluate the reliability and accuracy of a new impedance cardiograph device, the Physio Flow, at rest and during a steady-state dynamic leg exercise (work intensity ranging from 10 to 50 W) performed in the supine position. We compared cardiac output determined simultaneously by two methods, the Physio Flow (\(Q_{PF}\)) and the direct Fick (\(Q_{Fick}\)) methods. Forty patients referred for right cardiac catheterisation, 14 with sleep apnoea syndrome and 26 with chronic obstructive pulmonary disease, took part in this study. The subjects’ oxygen consumption values ranged from 0.14 to 1.19 l · min\(^{-1}\). The mean difference between the two methods (\(Q_{Fick} - Q_{PF}\)) was 0.04 l · min\(^{-1}\) at rest and 0.29 l · min\(^{-1}\) during exercise. The limits of agreement, defined as mean difference ± 2SD, were \(-1.34\), \(+1.41\) l · min\(^{-1}\) at rest and \(-2.34\), \(+2.92\) l · min\(^{-1}\) during exercise. The difference between the two methods exceeded 20% in only 2.5% of the cases at rest, and 9.3% of the cases during exercise. Thoracic hyperinflation did not alter \(Q_{PF}\). We conclude that the Physio Flow provides a clinically acceptable and non-invasive evaluation of cardiac output under these conditions. This new impedance cardiograph device deserves further study using other populations and situations.

Key words Impedance cardiography · Cardiac output · Fick principle · Exercise · COPD

Introduction

The accurate evaluation of a patient’s haemodynamic status, which includes knowledge of cardiac output, is important for clinicians in many situations. In intensive care units, the assessment of cardiac output is essential for the monitoring of patients with heart failure or shock, enabling the precise adjustment of cardiac treatments or pacing. In addition to the continuous monitoring of the electrocardiogram (ECG) blood pressure and pulse oxymetry, cardiac output monitoring during exercise and recovery periods would be of interest for assessing patient tolerance and safety. Finally, the measurement of cardiac output in patients with shortness of breath can yield useful diagnostic information.

Most of the techniques that are currently available for measuring cardiac output, such as dye dilution, thermodilution and methods based on the Fick principle (direct Fick), are invasive and require adhesion to strict conditions for accurate measurements. Doppler-echo-cardiography and measurement of cardiac output by CO\(_2\) rebreathing are the most widely used non-invasive techniques, but their accuracy during exercise remains debatable (Coates 1992; Lumb 1993). All of these techniques require an experienced operator. Two groups of methods allow the non-invasive and simple evaluation of cardiac output. The pulse contour methods are based on the relationship between stroke volume (SV) and the area subtended by the systolic part of the peripheral arterial profile, determined from finger plethysmography. SV calculated with these methods during cycle ergometer exercise showed reasonably good agreement with that obtained using Doppler echocardiography (Antonutto et al. 1995). The measurement of changes in electrical bioimpedance during the cardiac cycle has been used to estimate beat-to-beat changes in cardiac output for more than 30 years (Kubicek et al. 1966). This technique, which provides an automated and continuous measurement, is non-invasive and simple to perform. The original Kubicek equation that is used to
calculate SV has been modified by Sramek and Berstein (Berstein 1986; Sramek et al. 1983). Different devices operating on the basis of these formulae have been tested against reference methods, with divergent results. For some authors, impedance cardiography provides a reasonable estimate of the directional changes in cardiac output, but for others, impedance cardiography remains controversial with regard to its accuracy and reliability (Bloch and Russi 1997; Critchley 1998; Fuller 1992; Jensen et al. 1995; Pennock 1997). Indeed, it is likely that none of the impedance devices provide the same results. However, both the Kubicek and Sramek and Berstein equations need an evaluation of the basal thoracic impedance ($Z_0$). $Z_0$ is one of the two components of the impedance cardiography waves, and represents the steady-state mean thoracic impedance. The second component is the pulsatile variation in impedance ($\Delta Z$), which is mainly a function of variations in the volume and velocity of the thoracic aorta blood flow (Jensen et al. 1995). $Z_0$ depends upon multiple factors such as thorax morphology, homogeneity of thorax perfusion, and fluid and gas content (Berstein 1986; Jensen et al. 1995; Kubicek et al. 1966; Penney 1986; Sramek et al. 1983). The precise measurement of this variable is critical, and can be altered by perspiration, subcutaneous adiposity, and poor electrical contact (Jensen et al. 1995). Large and rapid exercise-induced variations of this parameter make its estimation more difficult in this situation (Warburton et al. 1999).

In the study presented here, we test a new impedance cardiography device, the Physio Flow PF-03 (Manatec Biomedical, Macheren, France). The development of this device has resulted from technical improvements in both the hardware (a new generation of analog technology allows the Physio Flow to improve signal filtering and stability, and provides better data processing) and software. The basic equation for calculating SV has been modified profoundly in order to overcome the difficult evaluation of variables such as blood resistivity ($\rho$), the distance between recording electrodes ($l$), and the $Z_0$ used in the Kubicek and Sramek-Berstein equations. The direct Fick method, considered to be one of the most reliable methods for cardiac output measurement, was chosen as the reference technique. Cardiac output was measured simultaneously by the Physio Flow ($Q_{\text{PF}}$) and by the direct Fick ($Q_{\text{Fick}}$) methods at rest and during a mild exercise in patients who were referred to our department for right cardiac catheterisation. The patients had either chronic obstructive pulmonary disease (COPD) or sleep apnoea syndrome (SAS). Since impedance cardiography has been considered to be inaccurate in patients with emphysema, we also examined the effects of thoracic hyperinflation on the impedance cardiography measurement of cardiac output.

## Methods

### Subjects

Forty patients who were referred to our department for right cardiac catheterisation agreed to participate in this study, which was approved by the Institutional Review Board. Twenty-six (65%) patients had COPD, and among those, 16 had emphysema. Fourteen patients (35%) had severe SAS without other respiratory symptoms. After measurement of their physical characteristics, spirometry was performed to measure the subjects' vital capacity (VC) and forced expiratory volume in 1 s (FEV$_1$). Functional residual capacity was measured using the helium dilution technique, and/or thoracic gas volume was measured with the aid of a total body plethysmograph (Bodyscope, Ganshorn Medizin Electronic, Münsterstadt/Niderlaus, Germany). Total lung capacity (TLC) and residual volume (RV) were then calculated. Pulmonary function tests are expressed as percentage of the predicted values based on age, height and gender (Quanjer et al. 1993). The patients' characteristics are presented in Table 1.

### Protocol

Measurements were performed in the morning, 2–3 h after breakfast, in an air-conditioned room. The patient remained supine throughout the preparation for cardiac catheterisation. Direct Fick and Physio Flow measurements were recorded simultaneously by two investigators in a blind fashion. Two cardiac output measurements were performed, one at rest, and one during a mild exercise carried out in a supine position on an electromechanically braked bicycle ergometer. The workloads were low, ranging from 10 to 50 W according to the patient’s fitness, so as to stay below the patient’s ventilatory threshold and to allow the patient to reach a steady-state condition. Cardiac output measurement was performed during the 6th min of the exercise test, a steady-state condition [e.g. stable oxygen consumption, ($\dot{V}O_2$) and cardiac frequency ($f_c$)] being obtained in most patients at the 3rd min. To test the repeatability of the cardiac output measurement at rest, in ten patients, a second evaluation by the two methods was performed 5 min after the first.

### Measurement of $\dot{Q}_{\text{Fick}}$

A catheter (Flexopulmocath Plastimed, 4F) was inserted under sterile conditions into the pulmonary artery via the antecubital vein or, rarely, via the femoral vein. The catheter was advanced while monitoring simultaneously ECG and intravascular pressure (Physiosgard SM 785). A Potts-Cournand needle was inserted into the brachial artery for arterial blood gas analysis. Expired gas was

<table>
<thead>
<tr>
<th>Disease</th>
<th>Number of subjects</th>
<th>Gender (M/F)</th>
<th>Age (years)</th>
<th>Body mass (kg)</th>
<th>Height (cm)</th>
<th>VC (% predicted)</th>
<th>FEV$_1$/VC (%)</th>
<th>TLC (% predicted)</th>
<th>RV/TLC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COPD</td>
<td>26</td>
<td>22/4</td>
<td>58.9 (10.6)</td>
<td>70.6 (13.3)</td>
<td>168 (6)</td>
<td>80.6 (22.7)</td>
<td>57 (25)</td>
<td>107.7 (16.4)</td>
<td>51.8 (13.5)</td>
</tr>
<tr>
<td>SAS</td>
<td>14</td>
<td>13/1</td>
<td>54.7 (4.3)</td>
<td>94.1 (24.1)</td>
<td>169 (8.7)</td>
<td>106.0 (12.4)</td>
<td>89 (9)</td>
<td>100.9 (9.7)</td>
<td>32.1 (5.2)</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>35/5</td>
<td>56.8 (9.5)</td>
<td>78.5 (20.7)</td>
<td>168 (7)</td>
<td>88.9 (23.1)</td>
<td>71 (23)</td>
<td>105.1 (14.2)</td>
<td>44.3 (14.7)</td>
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