Evaluation of the Aesculon cardiac output monitor by subxiphoidal Doppler flow measurement in children with congenital heart defects

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Abstract

BACKGROUND AND OBJECTIVE: To evaluate the noninvasive electrical velocimetry (Aesculon) monitor for cardiac output (CO) by subxiphoidal Doppler flow measurement in children. METHODS: CO was determined at the end of diagnostic or interventional cardiac catheterization for congenital heart defects. Standard ECG surface electrodes were attached in a vertical direction to the patients' left middle and lower neck, and lower thorax at the level of the heart and xiphoid process. Aesculon CO data were compared with a simultaneously measured CO by the subxiphoidal Doppler flow measurement technique. For each patient, measurements were repeated three times within 5 min. Whitney U-test, simple regression and Bland-Altman analysis were performed to compare CO values obtained by the two techniques. Data are given as range (median). RESULTS: A total of 36 children aged 5.7 (0.5-16.0) years were investigated. CO values obtained by Aesculon monitor [0.55-5.58 (2.62) l min] and subxiphoidal Doppler flow measurements [0.62-6.27 (3.05) l min] differed significantly between both methods (P = 0.04). Simple regression analysis revealed moderate correlation between CO values obtained from the two techniques (r = 0.5544, P < 0.001). Bias between the two methods was 0.31 l min with a precision of 1.92 l min. CONCLUSION: We conclude that electrical velocimetry using the Aesculon monitor does not reliably reflect absolute CO values as compared with subxiphoidal Doppler flow measurement.
Evaluation of the Aesculon cardiac output monitor by subxiphoidal Doppler flow measurement in children with congenital heart defects
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Results A total of 36 children aged 5.7 (0.5–16.0) years were investigated. CO values obtained by Aesculon monitor [0.55–5.58 (2.62) l min⁻¹] and subxiphoidal Doppler flow measurements [0.62–6.27 (3.05) l min⁻¹] differed significantly between both methods (P = 0.04). Simple regression analysis revealed moderate correlation between CO values obtained from the two techniques (r² = 0.5544, P < 0.001). Bias between the two methods was 0.31 l min⁻¹ with a precision of 1.92 l min⁻¹.

Conclusion We conclude that electrical velocimetry using the Aesculon monitor does not reliably reflect absolute CO values as compared with subxiphoidal Doppler flow measurement.


Keywords: cardiac output, child, heart catheterization, haemodynamics

Introduction Thoracic electrical bioimpedance (TEB) relates to changes in electrical conductivity of aortic blood flow and can be obtained from the thoracic surface to determine stroke volume and cardiac output (CO) [1]. According to the theory of TEB, erythrocytes change their random orientation in the descending aorta during diastole to an alignment at the beginning of the systole. A refined algorithm to calculate CO by TEB, referred to as electrical velocimetry, has been introduced recently [2,3]. The measurement is based on the maximum rate of change in TEB as the ohmic equivalent of mean aortic blood flow acceleration according to the Bernstein–Osypka equation, and is referred to as electrical velocimetry as implemented in the Aesculon monitor (Osypka Medical GmbH, Berlin, Germany).

The aim of this study was to compare CO values obtained by the Aesculon monitor with those obtained by subxiphoidal Doppler flow measurements.

Patients and methods

Patients With approval of the hospital ethical committee as well as written parental or patient consent, children from birth to 16 years of age, scheduled for diagnostic or interventional cardiac catheterization, were enrolled into this study. Cardiac catheterization was performed under general anaesthesia, including tracheal intubation and artificial ventilation. Detailed indication for cardiac catheterization and underlying cardiac diagnosis is given in Table 1. CO measurements were performed at the end of the cardiac catheterization procedure under steady state haemodynamics. Prior to the CO measurements, residual intracardiac or extracardiac shunts and left outflow tract obstruction were excluded by transoesophageal echocardiography or angiography or both.

Techniques Standard ECG surface electrodes were attached side-to-side in a vertical direction to the patients’ left middle and lower neck, and to the lower thorax at the left mid-axillary
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Table 1  Baseline characteristics, indication for cardiac catheterization and underlying congenital heart disease in the 36 study patients

<table>
<thead>
<tr>
<th>Study group (n = 36)</th>
<th>Characteristicsa</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Age (years)</td>
</tr>
<tr>
<td></td>
<td>Weight (kg)</td>
</tr>
<tr>
<td></td>
<td>Body surface area (m²)</td>
</tr>
<tr>
<td></td>
<td>Indication for cardiac catheterization and underlying congenital heart disease (n)</td>
</tr>
<tr>
<td></td>
<td>Device closure of an atrial septal defect</td>
</tr>
<tr>
<td></td>
<td>Device closure of a ventricular septal defect</td>
</tr>
<tr>
<td></td>
<td>Dilatation or stenting or both of a pulmonary artery branch stenosis in</td>
</tr>
<tr>
<td></td>
<td>D-Transposition of the great arteries</td>
</tr>
<tr>
<td></td>
<td>Tetralogy of Fallot</td>
</tr>
<tr>
<td></td>
<td>Coil occlusion of a coronary artery fistula</td>
</tr>
<tr>
<td></td>
<td>Diagnostic catheterization for Hypertrophic obstructive cardiomyopathy</td>
</tr>
<tr>
<td></td>
<td>Pulmonary hypertension</td>
</tr>
<tr>
<td></td>
<td>Double outlet right ventricle</td>
</tr>
<tr>
<td></td>
<td>Scimitar syndrome</td>
</tr>
<tr>
<td></td>
<td>Atrioventricular septal defect</td>
</tr>
</tbody>
</table>

*a Data are given as median (range) or numbers of patients.

The electrodes were connected to the Aesculon monitor (Fig. 1). A correct signal quality was verified by visualization of the ECG and the impedance waveform. CO was calculated by transformation to the ohmic equivalent of the mean aortic blood flow acceleration and heart rate correction, as described previously in detail [2–4]. Electrical velocimetry CO was continuously displayed on the monitor and recorded as an average value over 10 valid cardiac cycles.

CO by subxiphoidal Doppler flow measurements was determined from transthoracic echocardiography. The transverse diameter of the descending aorta ($D_{Ao}$) from inner edge to inner edge in early systole was assessed at the level just below the diaphragm. An estimate of the cross-sectional area (CSA) of the descending aorta ($CSA \approx \pi \times D_{Ao}^2/4$) was calculated. Flow velocity ($V_A$) evaluation in the descending aorta was performed in the subxiphoidal view with appropriate transducers (5.0 and 3.5 MHz) on Sonos 7500 (Philips, Eindhoven, Netherlands). Optimal signal was recognized as waveform with minimal spectral dispersion and loudest auditory sound. A single consultant cardiologist performed all subxiphoidal Doppler measurements. Doppler-derived CO was calculated by using the formula:

$$CO = V_A (\text{cm s}^{-1}) \times CSA (\text{cm}^2) \times 60 \text{ s min}^{-1} \times 1000 \text{ ml l}^{-1}$$

For each patient, three consecutive CO values were measured within 5 min by subxiphoidal Doppler flow and contemporary by the Aesculon monitor. Both operators were blinded for the CO values achieved by either technique.

Statistics
The average of three simultaneous electrical velocimetry and subxiphoidal Doppler CO measurements within 5 min was calculated per patient for each technique and used for subsequent analysis. Whitney U-test, linear regression analysis and Bland–Altman analysis [5] were performed to compare median CO values obtained by the Aesculon with those obtained by subxiphoidal Doppler flow measurement. Bias was calculated from 36 paired averages as the mean difference, and precision as two SDs of differences between paired values of the two methods. Data are presented as median (range). A $P$ value of less than 0.05 was considered significant.

Results
A total of 36 children undergoing cardiac catheterization (19 girls, 17 boys) aged 0.5–16.0 (median: 5.7) years were investigated. Baseline characteristics are given in Table 1. A total of 108 paired CO measurements by Aesculon monitor and subxiphoidal Doppler flow were attained. The coefficient of variation of CO measurements was 4.8% for the Aesculon monitor and 4.3% for the subxiphoidal Doppler flow, respectively. CO values obtained by Aesculon monitor [0.55–5.58 (2.62) l min$^{-1}$] and subxiphoidal Doppler flow measurements [0.62–6.27 l min$^{-1}$] were compared using the Aesculon monitor and subxiphoidal Doppler flow measurements [0.62–6.27 l min$^{-1}$].
and in critically ill children during paediatric anaesthesia. Small vessel size, or complex cardiovascular abnormalities often preclude an assessment of haemodynamics by pulmonary artery catheter (PAC) or pulse contour analysis [6]. Moreover, these techniques are invasive, central lines bear potential risks [7,8] and repeated fluid injection during PAC thermodilution technique may lead to fluid overload particularly in infants.

The Aesculon monitor is an easy to attach, noninvasive device combined with other monitoring features (blood pressure, heart rate, saturation, temperature). The device is small, compact, as well as easy to understand and to install. To date, CO measurements derived from the Aesculon monitor were compared with transoesophageal Doppler echocardiography [9], PAC thermodilution technique [10,11] and the Fick-oxygen principle [12], indicating clinically acceptable agreement in adults but not in children (Table 2). However, in a longitudinal study in piglets [13] comparing PAC thermodilution technique with the Aesculon monitor at different settings demonstrated a good agreement for continuous trend monitoring.

Traditionally, new CO monitors were evaluated using thermodilution technique by a PAC or using the Fick principle. Both techniques measure blood flow through the lungs and have their limitations [14]. The strength of the presented study is that the electrical velocimetry, a correlate of aortic blood flow, is compared with aortic Doppler flow measurements. Assessment of CO by Doppler flow has intensively been done from the oesophagus. A review from 25 published reports [15] has indicated good correlation between CO derived from oesophageal Doppler probes and the PAC thermodilution technique in adults. Studies in paediatric patients investigating the accuracy of oesophageal Doppler flow measurements are limited, but found clinically accurate estimates of CO [16,17].

Unfortunately, we were not able to demonstrate an acceptable agreement between CO values obtained by the Aesculon monitor and subxiphoidal Doppler flow measurement. Potential explanations for this disagreement are technical, patient-dependent or user-dependent factors. Assessment of the electrical velocimetry using the Aesculon monitor may be altered by left outflow tract obstructions. However, left outflow tract obstructions were excluded by transoesophageal echocardiography or angiography or both prior to the CO measurements in our study cohort. Further sources of patient-dependent errors are related to the principle of measuring CO by the electrical velocimetry. Inaccuracy may result from lung expansion caused by intermittent positive pressure ventilation, thoracic volume overload due to pleural effusion or pulmonary oedema, arrhythmias or other ECG abnormalities, as well as hyperdynamic sepsis. New approaches for optimized electrode position on the patient’s surface less dependent on...
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Table 2 Summary of the literature evaluating reliability of cardiac output measurements derived from the Aesculon monitor

<table>
<thead>
<tr>
<th>Reference method</th>
<th>Study cohort</th>
<th>r</th>
<th>Bias</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schmidt et al. [9]</td>
<td>TOE Doppler</td>
<td>37 adults</td>
<td>0.86</td>
<td>0.18</td>
</tr>
<tr>
<td>Suttner et al. [10]</td>
<td>PAC thermodilution</td>
<td>74 adults</td>
<td>0.83</td>
<td>0.01</td>
</tr>
<tr>
<td>Tomaszak et al. [11]</td>
<td>PAC thermodilution</td>
<td>50 children</td>
<td>0.89</td>
<td>0.66</td>
</tr>
<tr>
<td>Noroz et al. [12]</td>
<td>Fick-oxygen principle</td>
<td>32 children</td>
<td>0.97</td>
<td>0.01</td>
</tr>
</tbody>
</table>

PAC, pulmonary artery catheter; r, correlation between measurements; TOE, transoesophageal echocardiography.

The CO assessment by Doppler flow measurement itself may bear technical and patient-dependent sources of error, especially in the assessment of the correct aortic diameter. Small differences in diameter produce a large difference in CSA. Aortic diameters and changes in the aortic shape in patients with congenital heart disease may alter flow patterns and influence subxiphoidal Doppler flow measurements, which may be considered as a limitation of this study. The challenge to accurately measure the aortic diameter in adults due to low sonographic window quality did not account for our paediatric patient population. We encountered optimal sonographic windows in paralysed patients; Doppler signals were generally easy to obtain and to recognize. However, user-dependent factors may be taken into account. Whereas the Aesculon monitor is easy to apply and user-independent, the Doppler method is highly dependent on the user and his/her skill. To limit the impact of technical and user-dependent errors for the Doppler method, a single, well experienced cardiologist performed subxiphoidal measurements.

Clinical implications

The Aesculon monitor allows continuous online measurement and trend analysis, whereas the Doppler method allows an intermittent measurement to assess CO. On the basis of our results and limitations mentioned above, the Aesculon monitor, as a beat-to-beat monitor, provides an estimate on the haemodynamic situation with a graphic display over time. However, it does not seem a valuable tool to accurately determine CO values in paediatric patients.

Conclusion

CO measurements derived by the Aesculon monitor do not reliably reflect subxiphoidal Doppler-derived CO measurements in children with congenital heart defects. However, this noninvasive technique applied by minimal user expertise even in resuscitation situations may be used for an objective assessment of haemodynamic trends, such as detection of deterioration and monitoring of the efficacy of interventions. These potential benefits may compensate for precise determination of CO values with invasive and more time-intense techniques.

Acknowledgements

The present study was supported by EMDO Foundation (Zurich), Theodor-Ida-Herzog-Egli Foundation (Zurich) and by the UBS Donation (University Children’s Hospital Zurich).

There are no conflicts of interest.

References


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