Non-invasive monitoring of central hemodynamics in acute myocardial infarction: a comparison of hemodynamic indices obtained by two different methods – impedance cardiography and transthoracic echocardiography

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Summary

Objective: Hemodynamic assessment of critically compromised patients with cardiac pathology is one of the goals of recent diagnostics and treatment strategies. Different methods for the assessment of central hemodynamics are applied in clinical practice. However, the applied methods (invasive and non-invasive) have specific advantages and disadvantages. These are discussed in the article.

Design: A prospective study presenting the first experience in a comparison of hemodynamic indices obtained by applying two non-invasive methods – impedance cardiography and transthoracic echocardiography – is presented in the article.

Methods: In the year 2003, central hemodynamics was evaluated echocardiographically and by measurements of whole body impedance in patients with acute myocardial infarction in the Cardiac Intensive Care Unit, Clinic of Cardiology, Kaunas University of Medicine.

Results: 36 patients were involved into the study. Hemodynamic indices were analysed and further calculations were made in 29 included patients. The comparison of obtained hemodynamic indices between impedance cardiography and transthoracic echocardiography showed good correlation of 0.76 in the overall study sample and 0.79 in the male group.

Conclusions: In the prospective study good correlation of stroke volume and cardiac output values between transthoracic echocardiography and impedance cardiography was observed.

Keywords: cardiography, impedance, cardiac output, myocardial infarction

Great attention is paid to the monitoring of central hemodynamics (CH) during critical illnesses: the search of optimal methods for hemodynamic evaluation seeking to determine and ground the indications for the monitoring of CH. Invasive methods for the evaluation of hemodynamics (IHM) were introduced into clinical practice in 1970, when pulmonary artery Swan–Ganz catheters (PAC) appeared in the health care market [1]. The method of thermodilution, using PAC became a “gold standard” and “protocol method” for the evaluation of hemodynamic changes [2–5]. This method remains as a reference one for the comparison of other methods’ reliability and sensitivity [2,3,6,7]. IHM was improved in 1990, when PAC for continuous monitoring were invented. Despite of this, quite many articles were published where inaccuracy and calculation errors of IHM were reported [8]. At the same time the possibility of the occurrence of complications during the application of IHM and their influence on the outcome of a patient’s health are widely discussed [9–11]. In 2003, Sandham et al published a randomized study with numerous study samples, where the influence of invasive monitoring of CH for critically ill patients was explored.
Invasive monitoring did not improve the results and outcomes of the treatment for these patients [11]. A number of pulmonary artery embolisms found in patients using PAC was statistically significantly increased in comparison with the control group in the above mentioned study [11].

Reliable methods for non-invasive or less invasive monitoring of CH have been searched for recently [2,3,12,13]. Until today, all non-invasive methods for hemodynamic monitoring and their results were compared with the “gold standard”, i.e. IHM. Some authors indicated reliability and an acceptable correlation of non-invasive methods with IHM [7,14], while others [5,15] observed a weak correlation between them and thermodilution. Differences between the obtained results were explained as the inaccuracy of non-invasive methods for hemodynamic monitoring, paying no attention to the fact that invasive methods were not precise and measurements produced errors as well [8].

There is no doubt, that absolute hemodynamic indices may be evaluated most precisely by the application of IHM, but a discussion has been started recently about the sense of comparison of invasive and non-invasive methods for the evaluation of CH. Today many authors recommend to estimate critically all characteristics and disadvantages of non-invasive techniques, but at the same time do not avoid estimation between non-invasive methods for hemodynamic monitoring. This has been supported by the recently published studies [16–20].

Impedance cardiography (ICG) is one of the recently applied techniques for the monitoring of CH. ICG is successfully applied in ambulatory and sport medicine [21]. Studies for ICG application in intensive care departments have been initiated yet [7,22,23].

Studies, where ICG hemodynamic indices were compared with indices obtained during continuous thermodilution, rebreathing technique, and transesophageal echocardiography, were published [5,14,16]. Recently prospective multi-center and meta-analysis studies evaluating ICG monitoring have been presented [14,18].

Echocardiography is also used for the evaluation of hemodynamic indices and is considered as a non-invasive technique. Transesophageal echocardiography is usually chosen for studies [24]. However, this method has limitations for routine application in all patients [25]. Application of transthoracic echocardiography (TTE) may serve as a possible solution.

Theoretical background for the selection of methods for central hemodynamic evaluation and the comparison of the obtained hemodynamic indices

Patients, treated in intensive care units, are not similar according to pathology, diagnostic and treatment strategies. According to pathology, the contingent of intensive care unit patients conditionally may be divided into surgical, medical, neurological, and cardiac. Separate departments are established in large university hospitals of different European countries for the treatment of these pathologies. In order to create a proper strategy for the monitoring of CH for patients in cardiac care units (CCU), it is important to take into account that these patients are specific in some aspects:

(a) patients are conscious, sedation is not applied or applied rarely;
(b) artificial pulmonary ventilation is applied rarely. Ventilation support in a CCU is applied from 1.8 to 3 times less than in other intensive care units, according to the published data from intensive care project (ICARE; period 1992–2001; 41 hospitals involved) [26];
(c) the number of arrhythmias is increased in comparison with other intensive care units. The above mentioned aspects significantly limit the application of IHM and some non-invasive techniques for hemodynamic monitoring, such as transesophageal echocardiography. The application of IHM or transesophageal echocardiography is acceptable and convenient for sedated and intubated patients, while for conscious and non-intubated patients these methods have limitations.

It is important that continuous real-time, beat-to-beat monitoring of CH from a broad spectrum of methods and techniques for the monitoring of hemodynamics may be achieved only with the help of invasive continuous thermodilution, ICG, flowmetry (during transesophageal echocardiography), rebreathing technique and partially using pulse oxymetry calculations.

Continuous hemodynamic monitoring for non-intubated and non-sedated patients may be performed only with the help of invasive continuous thermodilution, ICG, and using pulse oxymetry calculations. Meanwhile, the application of flowmetry (during transesophageal echocardiography) and rebreathing technique for such patients is more possible in theoretical than in practical conditions.

According to the mentioned above, the application of non-invasive techniques for the moni-
toring of CH in patients with cardiac pathology is motivated.

The objective of the study is to analyse a possibility to apply non-invasive methods for CH evaluation during acute myocardial infarction (AMI) and evaluate correlation between hemodynamic indices (stroke volume and cardiac output) obtained by different non-invasive methods of hemodynamic assessment.

Design and Methods

Patients with AMI were selected for investigation during the period of year 2003 in the Cardiac Intensive Care Unit, Clinic of Cardiology, Kaunas University of Medicine. Inclusion criteria were: the first day of AMI, less than twelve hours from the onset of AMI.

Exclusion criteria were: hemodynamically important (greater than II°) aortic regurgitation, tachysystolic atrial fibrillation, an implanted pacemaker, tachycardia more than 120 beats/min, premature beats (pulse deficit more than 10 beats/min), abnormal anatomy of the heart (ventricular aneurysms).

36 patients with acute AMI were investigated. According to the protocol of the study hemodynamic data of seven patients (19.4%) were not analysed due to the exclusion criteria found. Arrhythmias occurred in four patients (57.1%) during the monitoring (atrial fibrillation, premature beats, heart rate more than 120 beats/min), left ventricle aneurysm was found during TTE investigation in one patient (14.3%), the data of two patients (28.6%) were not analysed due to technical reasons (dislocation of electrodes during the monitoring).

Hemodynamic indices of 29 patients were analysed. There were 22 men (75.9%) and 7 women (24.1%). The mean age of the patients was 63.4 ± 14.9 years (the youngest – 38, the oldest – 89.5 years old). The mean body mass index (BMI) was 28.6 ± 3.9 (ranged from 18.9 to 35.5). The mean left ventricular ejection fraction – 42.8 ± 10.6% (ranged from 68% to 28%). Fourteen patients (48.3%) had anterior, 7 (24.1%) – inferior, 4 (13.8%) – circular, 4 (13.8%) – inferior AMI together with infarction of the right ventricle. Q-wave AMI was found in 23 patients (79.3%), non-Q-wave AMI – in 6 patients (20.7%). Left ventricle insufficiency according to Killip’s classification was evaluated as class I in 4 (13.8%), as class II in 20 (69%), as class III in 1 (3.4%), and as class IV – in 4 patients (13.8%). The mean duration from the onset of pain until hospitalisation was 4.6 ± 3.8 hours (the longest – 11.5 hours, the shortest – 60 minutes). Coronarography was performed in 27 patients (93.2%), percutaneous transluminal coronary angioplasty (PTCA) – in 26 (89.5%), intravenous thrombolysis – in 1 patient (3.4%). The study conforms to the principles of Declaration of Helsinki.

ICG signal was recorded using standard technique of 8 electrodes (Figure 1) [22,23,27–29]. Stroke volume (SV) was calculated using a modified formula suggested by Kubicek et al [30], which was modified by Sramek [29] and Bernstein et al [27]:

\[
SV = \frac{(0.17H)³}{4.2} \times \frac{(dZ/dt)_{max} \times T_{Lve}}{Z_0},
\]

where:

\[
Z_0 \quad \text{baseline impedance between recording electrodes};
\]
Figure 2. Structure of impedance cardiography signal. Z – pulse contour curve; dZ/dt – impedance curve; Phono – phonocardiographic curve; ECG – electrocardiographic curve; dZ/dt_{max} – maximal value of the first derivative of the impedance curve; A – opening of the aortic valve; B – maximal systolic value; X – closing of the aortic valve; C – opening of the pulmonary valve; T_{lve} – left ventricle ejection time.

During ICG monitoring, changes of baseline chest electric impedance were recorded following calculations of SV, cardiac output (CO) and derivative indices – cardiac index (CI) and systemic vascular resistance (SVR) were estimated. Averaged ICG SV value of the last 10 minutes recorded (60 SV moment values) was used for the comparison of ICG and TTE data (Figure 2).

The same CH parameters were assessed by TTE. Left ventricular end-diastolic volume (LVEDV), left ventricular end-systolic volume (LVESV) and ejection fraction (EF) were estimated using a modified biplane Simpson’s method from apical four- and two-chamber views. SV was considered to be the difference between LVEDV and LVESV. If there was a significant mitral regurgitation (hemodynamically significant regurgitation was considered to be at least grade 2/4), we calculated regurgitant volume using a proximal isovelocity surface area (PISA) method and subtracted it from the calculated SV. There was a simultaneous ECG recording. SV was also assessed by an alternative method measuring a time velocity integral in the left ventricular outflow tract, based on equation that stroke volume is equal to the product of the area (the cross-sectional area through which velocity is recorded, in this case – the aortic valve area) and the time velocity integral.

The comparison of hemodynamic indices was made at the end of the first day of AMI.

ICG parameters were recorded using a “Heartlab” equipment. Two-dimensional echocardiography was performed on an “Acuson Sequoia” ultrasound machine with a 3.5 MHz transducer.

Data collection and statistical analysis were performed using Microsoft Excel and SPSS software.

Results

SV values were recorded during ICG monitoring and TTE investigation. It was found that SV_{ICG} values ranged from 27.5 ml up to 149.6 ml in different patients (the mean value – 73.4 ± 31.9 ml), while SV_{TTE} values – from 19.1 ml up to 57.8 ml (the mean value – 44.5 ± 11.4 ml). CI calculated from ICG data ranged from 1.2 up to 4.2 l/min/m^2 (the mean value 3.4 ± 1.1 l/min/m^2), meanwhile CI calculated from TTE data ranged from 0.8 up to 3.2 l/min/m^2 (the mean value – 2.6 ± 0.7 l/min/m^2). Systemic vascular resistance (SVR) was evaluated from ICG data only and ranged from 1122.2 to 1731.4 dyn·sec·cm^{-5} (the mean value – 1412 ± 248 dyn·sec·cm^{-5}).

SV values obtained from ICG and TTE were compared and it was found that the values recorded during ICG monitoring were statistically significantly higher (mean – 73.4 ± 31.9 ml) in comparison with analogous values from TTE investigation (mean – 44.5 ± 11.4 ml) (p < 0.001).
Q- and non-Q-wave AMI SV values were compared during the study. SV_TTE values differed insignificantly (for Q-wave AMI the mean SV_TTE value was 45 ± 11.9 ml, for non-Q-wave AMI – 43.4 ± 5.4 ml). The difference was more expressed during ICG monitoring. Higher SV_ICG values were recorded in patients with Q-wave AMI (mean SV_ICG – 77.9 ± 33.8 ml) than in patients with non-Q-wave AMI (mean SV_ICG – 59.6 ± 22.9 ml), but the difference was not statistically significant (p = 0.11).

SV values were compared according to different localizations of AMI. SV_TTE values differed significantly (the smallest mean SV_TTE value was found in patients with anterior AMI – 44.7 ± 9.3 ml, the highest – in patients with inferior AMI accompanied by infarction of the right ventricle – 46.2 ± 3.9 ml). The difference of SV values was more expressed during ICG monitoring. The smallest SV_ICG values were found in patients with circular AMI (mean ST_ICG – 56.8 ± 28.6 ml), the highest – in patients with inferior AMI (mean ST_ICG – 87.2 ± 35.6 ml). Due to a small study sample statistically significant difference was not found between the groups (p = 0.23) for ICG measurements as well. SV values according to the localization of AMI are presented in Table 1.

SV values obtained during ICG monitoring and TTE investigation were compared between each other. The correlation coefficient of SV values obtained from ICG and four-chamber TTE view reached 0.76 (Figure 3). In the men’s group it was 0.79, but a very weak SV correlation was observed in the women’s group – 0.32. The correlation of SV values was less expressed (r = 0.45) in patients with BMI > 29 and < 19, independently of the gender.

The less expressed correlation of SV values was found between ICG and TTE, when SV values were obtained from two-chamber TTE view and by averaging SV values obtained from four- and two-chamber view (Table 2).

During the study SV values from TTE investigation were evaluated by the alternative calculation method – measuring blood flow in the out-flow tract of the left ventricle. According to this calculation method SV_TTE values ranged from 49 ml up to 101.9 ml in different patients (mean – 67.6 ± 17 ml). In this case, the comparison of ICG and TTE SV values showed a weak correlation between the methods (r = 0.37).

### Table 1.

<table>
<thead>
<tr>
<th>MI localization</th>
<th>SV_ICG (ml)</th>
<th>SV_TTE (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>73.4 ± 32.9</td>
<td>43.5 ± 14.4</td>
</tr>
<tr>
<td>Inferior</td>
<td>87.2 ± 35.6</td>
<td>44.9 ± 9.3</td>
</tr>
<tr>
<td>Circular</td>
<td>56.8 ± 28.6</td>
<td>44.7 ± 1.7</td>
</tr>
<tr>
<td>Inferior + right ventricle</td>
<td>74.1 ± 36.0</td>
<td>46.2 ± 3.9</td>
</tr>
</tbody>
</table>

MI – myocardial infarction; SV_ICG – stroke volume, obtained by impedance cardiography; SV_TTE – stroke volume, obtained by transthoracic echocardiography.

**Discussion**

Timely assessment of CH in patients with acute cardiac illness has an important role in choosing the adequate treatment, monitoring its effect, cardiovascular system function and its changes,
homeostasis [2,3,6,22,23,31–33]. CH measurements may be successfully made using invasive and non-invasive methods. However, the choice of an adequate method for hemodynamic monitoring in patients with acute cardiac illness in intensive care units remains an open problem [2].

Now there is a tendency towards non-invasive hemodynamic measurements in patients with cardiac pathology, especially when hemodynamic parameters are relatively stable. Non-invasive CH methods cause no or considerably less complications, but have relatively less accuracy often dependent on investigator’s experience. Invasive hemodynamic measurements are recommended for patients with severe cardiac illness and unstable hemodynamics or before an operative treatment. However, it is very important to take into consideration errors of invasive CH measurements [8].

In our study we used the ICG method for the assessment of SV applying a modified formula suggested by Kubicek et al, which was modified by Sramek [30] and Bernstein et al [27]. An alternative method to measure SV is the “area” calculation method. In a paper by Dregunas and Povilonis the correlation coefficient between SV calculated using Sramek et al’s equation and the “area” method was 0.91 \( (r = 0.91) \) [22,23]. The application of the “area” method requires the identification of principal reading points on the impedance cardiography curve – the beginning and end of systole, but when the signal of impedance cardiography is weak, there is less accuracy determining these points and increased risk of significant error [22,23].

In 2000, Barin et al. published a paper where the correlation between the ICG and thermodilution method was 0.72 [34]. However, in 2000, Hirsch et al reported only the weak correlation (0.17–0.29) between the hemodynamic parameters measured by thermodilution, ICG and pulse curve analysis methods in their study [15]. Different conclusions by different authors concerning the significance of non-invasive hemodynamic methods may be explained by heterogeneous patient groups and different study protocols [15].

In 1999, Raaijmaker et al published a meta-analysis study (13792 measurements), where the average correlation coefficient was 0.67 between ICG and other CH evaluation methods including echocardiography [18]. In 2002, Von Rueden published a review article about the correlation between ICG and other CH evaluation methods [19]. The modified data from this paper and our study are presented in Table 3.

When analysing the accuracy and significance of non-invasive methods we have to take into account some pathologic states and methodology errors that influence the results. The reasons and conditions that affect the accuracy of ICG hemodynamic measures include the following [28]:

Table 3. Correlation of hemodynamics obtained by impedance cardiography with other methods for central hemodynamics evaluation

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Contingent of patients</th>
<th>Amount</th>
<th>Method for comparison</th>
<th>( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thangaturai</td>
<td>1997</td>
<td>Intraoperative</td>
<td>23</td>
<td>ITD</td>
<td>0.89</td>
</tr>
<tr>
<td>Wo</td>
<td>1995</td>
<td>Critical care</td>
<td>68</td>
<td>ITD</td>
<td>0.86</td>
</tr>
<tr>
<td>Roessler</td>
<td>1996</td>
<td>High risk perioperative</td>
<td>28</td>
<td>ITD</td>
<td>0.89</td>
</tr>
<tr>
<td>Yung</td>
<td>1999</td>
<td>Pulmonary hypertension</td>
<td>33</td>
<td>Fick</td>
<td>0.85</td>
</tr>
<tr>
<td>Sagman</td>
<td>1999</td>
<td>Cardiac surgery</td>
<td>20</td>
<td>ITD</td>
<td>0.95</td>
</tr>
<tr>
<td>Wong</td>
<td>1996</td>
<td>Cardiac surgery</td>
<td>18</td>
<td>ITD</td>
<td>0.86</td>
</tr>
<tr>
<td>Belardinelli</td>
<td>1996</td>
<td>After myocardial infarction</td>
<td>25</td>
<td>ITD, Fick</td>
<td>0.90</td>
</tr>
<tr>
<td>Fuller</td>
<td>1992</td>
<td>Meta analysis (28 studies)</td>
<td>Not indicated</td>
<td>ITD, Dye dilution, Fick, Angiography Mean</td>
<td>0.83, 0.80, 0.65, 0.81</td>
</tr>
<tr>
<td>Raaijmakers</td>
<td>1999</td>
<td>Meta analysis (112 studies)</td>
<td>Not indicated</td>
<td>ITD, echocardiography, Dye dilution, Fick, Indirect Fick</td>
<td>( r^2 = 0.67 )</td>
</tr>
<tr>
<td>Brazdzionyte, Macas, Baksyte</td>
<td>2003</td>
<td>Acute myocardial infarction</td>
<td>29</td>
<td>TTE</td>
<td>0.76</td>
</tr>
</tbody>
</table>

ITD – intermittent thermodilution; \( r \) – correlation coefficient; TTE – transthoracic echocardiography.
2000 [36].

...non-invasive methods for hemodynamic monitoring, seeking specific indications and situations when these methods may be applied in intensive care units [15].

Conclusions

In our study impedance cardiography and transthoracic echocardiography measures of hemodynamic parameters (stroke volume, cardiac output) were significantly correlated. While in patients with little body weight or high degree obesity the correlation of these parameters measured by two different non-invasive methods was weak.

References


