Impedance cardiography for aortic balloon counterpulsation impact assessment on patients hemodynamics during acute myocardial infarction

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Key words: acute myocardial infarction; intra-aortic balloon counterpulsation; impedance cardiography; right heart catheterization.

Summary. Background and objective. The evaluation of hemodynamics in patients with acute myocardial infarction is crucial. Intra-aortic balloon pumping or counterpulsation in patients with cardiogenic shock is supposed to be monitored exceptionally by invasive methods for assessment of hemodynamics. However, noninvasive methods might have place in monitoring these patients. The objective of the study was to evaluate the possibility of applying noninvasive methods for evaluation of hemodynamics during acute myocardial infarction complicated by cardiogenic shock and managed by intra-aortic balloon pumping.

Patients and methods. A total of 16 patients were investigated according to the study protocol. Anterior acute myocardial infarction was diagnosed in 11 (68.75%) patients, inferior – in 4 (25%), circular – in 1 (6.25%). Primary percutaneous transluminal coronary angioplasty was successfully performed in 7 (43.75%) patients, unsuccessfully – in 1 (6.25%) patient, who died within the first 18 hours. Half of patients (50%) underwent cardiac surgery within the first two weeks. Mortality rate was 68.75% (11 patients). A prospective controlled study was carried out to compare two different methods – intermittent thermodilution (ITD) and impedance cardiography (ICG) – for simultaneous cardiac output measurements in patients with acute myocardial infarction complicated by cardiogenic shock and managed by intraaortic balloon counterpulsation. Statistical analysis was performed with Bland–Altman and linear regression.

Results. Correlation coefficient was calculated comparing cardiac output values derived from ICG and ITD; it ranged from 0.24 to 0.98 in separate patients. It was observed a weak correlation of ICG and ITD measurements before initiation of intra-aortic balloon pumping – 0.24–0.27 in separate cases. The correlation improved during intra-aortic balloon pumping – 0.58–0.98 and at the termination of intra-aortic balloon pumping – 0.67–0.97. The observed correlation was more pronounced in patients not receiving high doses of inotropes and ranged 0.58–0.98 while for patients receiving high doses of inotropes correlation was less pronounced 0.29–0.5.

Conclusions. Significant correlation of cardiac output values was observed between the impedance cardiography and intermittent thermodilution techniques during intra-aortic balloon counterpulsation. Noninvasive evaluation of hemodynamic indices by continuous monitoring of impedance cardiography during acute myocardial infarction, complicated by cardiogenic shock and managed by intra-aortic balloon counterpulsation is a reliable method for further application.

Introduction

Intra-aortic balloon pumping (IABP), or counterpulsation, is a widely accepted therapeutic method of temporarily supporting patients with impaired left ventricular function. Impaired left ventricular function causes low cardiac output and inadequate coronary perfusion. Counterpulsation helps to balance the myocardial oxygen supply and demand in these patients. The hemodynamic effects of counterpulsation are immediate, predictable, and most importantly, decrease morbidity and mortality.

For more than four decades, the use of the IABP has been a major tool for providing mechanical support for the patients with failing circulation. The utilization of IABP has been traditionally reserved for critically ill patients and then only as a final desperate measure. This approach to mechanical circulatory support accounts for the substantial lag time between
intra-aortic balloon pump availability and its widespread use. The IABP was first conceived and studied by S. D. Moulopoulos, S. Topaz, and W. L. Kolff (1961–1962) and independently by R. H. Clauss, P. Missier, G. E. Reed, and D. Tice in 1962. Clinical studies were started in 1967, and A. Kantrowitz reported the first clinical experience in 1968. In 1969, large-scale clinical investigations of the IABP began with the organization of a cooperative study involving 10 institutions. With the commercial availability of intra-aortic balloons and balloon drive units, the number of institutions investigating the IABP and utilizing it clinically expanded rapidly (1).

The IABP can be initiated rapidly. For this reason, the IABP has become an important therapeutic tool in a variety of clinical settings, including emergency departments, cardiac catheterization labs, operating rooms, and intensive care units.

There is no doubt that hemodynamic changes have to be monitored during IABP. Some of parameters such as invasive blood pressure are crucial for effective counterpulsation (inflation and deflation of counterpulsation balloon), while others are optional (parameters of central hemodynamics) and help to evaluate the impact of IABP, treatment course during follow-up. This provokes a discussion if invasive methods for hemodynamic assessment might be replaced by less invasive or eventually by noninvasive techniques.

**Effects of intra-aortic balloon counterpulsation**

Intra-aortic balloon counterpulsation gives a specific impact on cardiovascular physiology manifesting as following hemodynamic effects:

1. Augments pressure above the balloon and improves coronary artery perfusion,
2. Increases myocardial oxygen delivery,
3. Reduces oxygen consumption in the myocardium,
4. Reduces systolic pressure in the aorta,
5. Augments diastolic pressure in the aorta and mean aortic pressure,
6. Reduces end diastolic pressure in left ventricle,
7. Reduces left ventricular afterload,
8. Improves ejection fraction of left ventricle (LV),
9. Increases stroke volume (SV) and cardiac output (CO),
10. Augments blood pressure,
11. Reduces pulmonary capillary wedge pressure and systemic vascular resistance.

These effects are evaluated and monitored by traditional hemodynamic monitoring methods, among which majority are invasive. However, less invasive or noninvasive techniques might be very convenient for application (2–4).

**Application of intra-aortic balloon counterpulsation**

The indications for IABP application were widely discussed in various clinical conditions. Some of indications are unquestioned while others are still under discussion. The indications for IABP application are following:

1. Patients with acute myocardial infarction (AMI) manifesting by:
   a) Hypotension (systolic blood pressure less than 90 mmHg or 30 mmHg below baseline mean arterial pressure) unresponsive to other interventions;
   b) Low-output state;
   c) Cardiogenic shock, which is not quickly reversed with pharmacological therapy;
   d) Refractory polymorphic ventricular tachycardia, in order to reduce myocardial ischemia.
   e) Refractory pulmonary congestion (5, 6).
2. Patients scheduled for cardiac surgery under specific conditions (urgent revascularization operation for AMI and unstable angina, presence of chronically dysfunctional left ventricle, patients with the highest elevations of creatine kinase-muscle band (greater than 5 times upper limits of normal), prophylactic application for cardiac protection in patients with evidence of ongoing myocardial ischemia and/or patients with a subnormal cardiac index) (7).

Intra-aortic balloon counterpulsation should be used in addition to medical therapy for patients with ST-segment elevation myocardial infarction who have recurrent ischemic-type chest discomfort and signs of hemodynamic instability, poor LV function, or a large area of myocardium at risk. Such patients should be referred urgently for cardiac catheterization and should undergo revascularization as needed.

Patients with AMI complicated by cardiogenic shock are unchallenged candidates for application of IABP (8). More than one decade ago, several studies were published indicating that intra-aortic balloon counterpulsation improves survival in cardiogenic shock complicating AMI (9, 10).

Cardiogenic shock may result due to many reasons; however, the most common cause is following AMI. Cardiogenic shock is a physiological derangement of circulatory failure due to severe depression of myocardial function. Cardiogenic shock characterized by primary myocardial dysfunction causes the heart to be unable to maintain adequate cardiac output. These patients demonstrate clinical signs of low cardiac output, with adequate intravascular volume. CO is markedly depressed, and the compensatory mechanisms that usually maintain CO (e.g., increased heart rate,
increased preload, and increased contractility) are no longer sufficient to return systemic perfusion to a life supporting level. CO is further compromised by the loss of contributing myocardium to the contractile process. During cardiogenic shock, further deterioration occurs as a result of dysfunctional compensatory mechanisms, resulting in a vicious cycle that increases the stress on an already over-stressed myocardium (11).

Hemodynamic variables are manipulated with pharmacologic agents to break the cycle of cardiogenic shock. It is generally accepted that pharmacologic agents should be used as a first-line therapy. Drug intervention, however, cannot cause increased perfusion to the coronary artery system. In an ischemic state, the coronary arteries are already maximally dilated and are totally dependent on the perfusion gradient. The ability to autoregulate coronary flow is lost. Meanwhile, coronary perfusion might be successfully increased by application of IABP.

It is agreed that early use of IABP increases the probability of survival (9). IABP is considered if first-line medical therapies do not improve the patient’s clinical status within 2 to 3 hours. Further losses of viable myocardium can occur if inadequate perfusion is allowed to continue (12–14).

**Assessment of hemodynamics during intra-aortic balloon counterpulsation**

There is no doubt that IABP should be used with close hemodynamic monitoring. First studies indicated that the hemodynamic effectiveness of IABP is dependent upon the level of myocardial recovery or deterioration in the postcardiotomy/myocardial infarction patient. The observed effects of IABP were inversely related to the level of intrinsic myocardial function (cardiac index) and directly related to the level of peripheral vascular resistance (1).

Main hemodynamic indices are CO, cardiac index (CI), SV, stroke index (SI), systemic vascular resistance (SVR).

All hemodynamic techniques are divided into invasive and noninvasive:

- **Invasive:** intermittent and continuous thermodilution, transpulmonary thermodilution – (continuous pulse contour cardiac output – PICCO™), partial carbon dioxide rebreathing techniques.
- **Noninvasive:** impedance cardiography, transthoracic and transesophageal heart ultrasound, blood pressure measurements with a Finometer.

Recently some authors suggested term “less-invasive” techniques for such as transpulmonary thermodilution, partial carbon dioxide rebreathing techniques (4).

Many studies have been published concerning the application of invasive methods for hemodynamic monitoring during IABP (15, 16). Despite the introduction of various less invasive concepts of cardiac output measurement, pulmonary arterial thermodilution is still the most common measurement technique (4).

However, neither the application of noninvasive methods for assessment of hemodynamics nor their accuracy was widely discussed. Pulmonary artery catheters (PACs) have been used to guide therapy in multiple settings, but recent studies have raised concerns that placement of pulmonary artery catheter may lead to increased mortality in hospitalized patients.

Otherwise, noninvasive techniques for hemodynamic assessment, such as impedance cardiography, showed sophisticated accuracy for further application (2, 3). Besides accuracy, an important issue of the clinical practicability of cardiac output measurement technique is the detection of the acute hemodynamic changes and critical circulatory states (4).

A noninvasive alternative method for determining CO and SVR is that of impedance cardiography (ICG). ICG measures the beat-to-beat changes of thoracic bioimpedance via four dual sensors applied on the neck and thorax in order to calculate SV (17).

The objective of the study was to evaluate the possibility of applying noninvasive methods for the evaluation of hemodynamic changes during AMI complicated by cardiogenic shock and managed by IABP and to determine the correlation and agreement between hemodynamic indices (SV and CO) obtained by two different techniques for hemodynamic assessment – ITD and ICG.

**Materials and methods**

A prospective controlled study was carried out to compare two different methods, intermittent thermodilution and impedance cardiography, for simultaneous CO measurements in patients with AMI complicated by cardiogenic shock and managed by IABP.

**Instrumentation.** The instrumentation included a PAC (7 F, Baxter™); a software for ITD measurement was Datex® CS/3 by Datex-Engstrom®; an original recording system Heartlab™ (certificate No: LS.08.02.1957) was used for ICG signal acquisition and primary analysis.

**Protocol.** According to research protocol, patients with AMI admitted within 12 hours from the onset of pain, complicated by cardiogenic shock, and managed by IABP were enrolled into the study. Patients were
selected for the investigation during the period of 2004–2005 in the Cardiology Intensive Care Unit, Clinic of Cardiology, Kaunas University of Medicine.

The inclusion criteria were: the first day of AMI, less than 12 hours from the onset of AMI, patients managed with IABP.

The exclusion criteria were: hemodynamically important aortic regurgitation (greater than II°), 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).

CO, CI, SV, and SVR were measured by both ITD and ICG methods for assigned patients. Pulmonary vascular resistance (PVR) was calculated by ITD method. Hemodynamic calculations were performed before initiation of IABP, twice per day (every 12 hours) during application of IABP, and after termination of IABP.

Swan-Ganz flow-directed triple-lumened catheter was inserted through either subclavian or internal jugular vein with continuous pressure and electrocardiographic monitoring. Selected measurements of right atrial, pulmonary artery, and pulmonary capillary wedge pressures and cardiac output/index determinations were obtained. ITD measurements were performed by the standard procedure flushing 10 ml of sodium saline injectate via proximal lumen of PAC.

ICG signal was recorded using a standard technique of eight electrodes (18, 19). SV was calculated using a modified formula suggested by W. G. Kubicek with co-authors, which was modified by B. B. Sramek (19) and D. P. Bernstein (18) with co-authors:

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

where: \(Z_0\) – baseline impedance between recording electrodes; \(H\) – patient’s height; \((dZ/dt)_{\text{max}}\) – the maximum of the first derivative of impedance; \(T_{\text{Lve}}\) – left ventricle ejection time.

During ICG monitoring, the changes of baseline chest electric impedance were recorded following calculations of SV and CO, and derivative indices, CI and SVR, were estimated (Fig. 1). Averaged CO\textsubscript{ICG} value of the last 10 seconds recorded was used for the comparison of ICG and ITD data.

All ITD and ICG measurements were made simultaneously.

**Statistical analysis.** SPSS software was used for data analysis. Statistical analysis was performed with Bland–Altman and linear regression. Correlation between the ITD and ICG techniques was determined using linear regression. A plot of the differences between techniques was done according to method described by J. M. Bland and D. G. Altman (20). Statistical calculations are presented as mean values and standard

![Fig. 1. Structure of impedance cardiography signal](image)

Z – pulse contour curve; \(dZ/dt\) – impedance curve; Phono – phonocardiographic curve; ECG – electrocardiographic curve; \((dZ/dt)_{\text{max}}\) – 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; \(T_{\text{Lve}}\) – left ventricle ejection time.

Medicina (Kaunas) 2006; 42(11)
deviation (SD).

The study was approved by the Ethics Committee for Biomedical Research of Kaunas Region (protocol number: 169/2004).

Patients. We assigned 16 patients investigated according to study protocol in Kaunas University of Medicine Hospital. There were 10 (62.5%) men and 6 (37.5%) women. The mean age was 72.8±6.4 years, body mass index – 26.7±3.1.

Anterior AMI was diagnosed in 11 (68.75%) patients, inferior – in 4 (25%), circular – in 1 (6.25%). All patients presented with Killip class IV.

Coronary angiography was performed in all patients. Two-vessel disease was diagnosed in 4 patients (25%), while three-vessel disease – in 12 (75%).

Primary percutaneous transluminal coronary angioplasty was successfully performed in 7 (43.75%) patients; 8 (50%) patients underwent cardiac surgery within first two weeks. Primary percutaneous transluminal coronary angioplasty was unsuccessful in 1 (6.25%) patient who died within first 18 hours. Ejec-
tion fraction on admission was 28.1±10.8%.

Duration from the onset of pain before hospitalization was 8.0±3.5 hours, while to primary coronary angiography or PTCA – 10.5±5.6 hours. Time from admission to IABP was 14.2±5.6 hours.

CO on the initiation of IABP was 3.6±1.2 L/min, after termination of IABP (among survivors) – 3.85±1.8 L/min, CI – 1.7±0.8 L/min/m² and 1.8±0.6 L/min/m², SV – 35.9±13.4 mL and 38.4±21 mL, SI – 17.6±6.5 mL/m² and 19.3±10.8 mL/m², respectively.

Comparing the impact of AMI localization on hemodynamic profile of the patients, no significant difference was found. The comparable data obtained by ITD method are presented in Table 1.

Correlation coefficient calculated comparing CO values derived by ICG and ITD techniques ranged from 0.24 to 0.98 in separate patients.

The main hemodynamic indices and corresponding correlation ranges in the different phases of IABP application are presented in Table 2.

The regression analysis showed that observed correlation was more pronounced in patients not receiving high doses of inotropes and ranged from 0.58 to 0.98, while in patients receiving high doses of inotropes correlation was pronounced less (0.29–0.5).

The observed correlation in the different stages of

### Table 1. Hemodynamic profile of the patients according to localization of acute myocardial infarction (among survivors)

<table>
<thead>
<tr>
<th>Hemodynamic parameters</th>
<th>Anterior on the initiation of IABP</th>
<th>during IABP</th>
<th>at the termination of IABP</th>
<th>Inferior on the initiation of IABP</th>
<th>during IABP</th>
<th>at the termination of IABP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO, L/min</td>
<td>3.64±1.4</td>
<td>3.94±1.8</td>
<td>3.8±2.1</td>
<td>3.3±0.9</td>
<td>3.2±1.1</td>
<td>3.7±1.2</td>
</tr>
<tr>
<td>CI, L/min/m²</td>
<td>1.83±0.8</td>
<td>1.96±1.0</td>
<td>1.72±1.1</td>
<td>1.7±0.2</td>
<td>1.4±0.8</td>
<td>1.9±0.3</td>
</tr>
<tr>
<td>SV, mL</td>
<td>35.6±11.6</td>
<td>35.9±16.4</td>
<td>38.5±12.5</td>
<td>36.5±9.4</td>
<td>36±19.3</td>
<td>35.8±11.1</td>
</tr>
<tr>
<td>SI, mL/m²</td>
<td>17.0±5.5</td>
<td>18.4±9.8</td>
<td>18.6±7.0</td>
<td>15.3±5.5</td>
<td>14.7±5.3</td>
<td>21±5.5</td>
</tr>
<tr>
<td>SVR, dyne*s/cm²</td>
<td>1587.2±379</td>
<td>1577.2±537</td>
<td>2176.2±665</td>
<td>1699.3±542</td>
<td>1881±622</td>
<td>1489±285.4</td>
</tr>
<tr>
<td>PVR, dyne*s/cm²</td>
<td>214.2±142</td>
<td>245.6±153.3</td>
<td>363.7±159.6</td>
<td>412.7±47.1</td>
<td>401.2±171</td>
<td>355±7.1</td>
</tr>
</tbody>
</table>


Duration of hospitalization was 16.8±7.9 days. The mean duration of treatment in Cardiology Intensive Care Unit was 7.4±4.3 days. Mortality rate was 68.25% (11 patients), while 5 (31.3%) patients were successfully discharged for outpatient follow-up, of which 3 (18.8%) after treatment in the department of Cardiology and 2 (12.5%) after surgical treatment in department of Cardiac Surgery.

Results
A total of 109 paired measurements were carried out in 16 patients in accordance of different IABP stages.

Correlation coefficient calculated comparing CO values derived by ICG and ITD techniques ranged from 0.24 to 0.98 in separate patients.

The main hemodynamic indices and corresponding correlation ranges in the different phases of IABP application are presented in Table 2.

The regression analysis showed that observed correlation was more pronounced in patients not receiving high doses of inotropes and ranged from 0.58 to 0.98, while in patients receiving high doses of inotropes correlation was pronounced less (0.29–0.5).

The observed correlation in the different stages of
IABP application (a – on the initiation of IABP, b – during IABP, c – after termination of IABP) is presented as regression plots (Fig. 2).

Level of data agreement is presented as Bland–Altman plots analogously (Fig. 3). The Bland–Altman analysis shows that as the average cardiac output increases, the difference between the methods increases during the application of IABP.

The Bland–Altman and the regression analysis demonstrated that the values of cardiac output obtained using ICG method were higher than those obtained using ITD, except the values obtained during the application of IABP.

**Discussion**

Patients, treated in intensive care units, differ according to pathology, diagnostic and treatment strategies. Patients in intensive care units conditionally may be divided into surgical, medical, neurological, and cardiac, according to predominant pathology. Separate departments are established in a large university hospital. In order to develop a proper strategy for the monitoring of central hemodynamics in patients of cardiac care units, it is important to take into account following specificities:

1. Patients are conscious; sedation is not applied or applied rarely;
2. Artificial pulmonary ventilation is applied rarely. Ventilation support in coronary care units is applied 1.8 to 3 times less frequently than in other intensive care units, according to the published data from Intensive Care Antimicrobial Resistance Epidemiology Project (ICARE; period – 1992–2001; 41 hospitals involved) (21);
3. The incidence of arrhythmias is increased in comparison with other intensive care units.

The above-mentioned aspects significantly limit the application of invasive techniques and some non-invasive techniques for hemodynamic monitoring, such as transesophageal echocardiography. The application of invasive techniques or transesophageal echocardiography is acceptable and convenient for sedated and intubated patients, while for conscious and nonintubated patients these methods have limitations.

Of importance, continuous real-time, beat-to-beat monitoring of hemodynamics 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 – impedance cardiography.


<table>
<thead>
<tr>
<th>Hemodynamic parameter</th>
<th>On the initiation of IABP</th>
<th>During IABP</th>
<th>After termination of IABP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ITD</td>
<td>ICG</td>
<td>ITD</td>
</tr>
<tr>
<td>CO, L/min</td>
<td>2.8±1.3</td>
<td>4.2±1.4</td>
<td>3.9±1.1</td>
</tr>
<tr>
<td>CI, L/min/m²</td>
<td>1.2±0.3</td>
<td>1.8±0.7</td>
<td>1.7±0.5</td>
</tr>
<tr>
<td>SV, mL</td>
<td>26.8±8.2</td>
<td>40.4±14.2</td>
<td>34.4±10.8</td>
</tr>
<tr>
<td>SVR, dyne*s/cm⁵</td>
<td>1532.3±426.4</td>
<td>1321.7±347.8</td>
<td>1637.3±434.7</td>
</tr>
<tr>
<td>Correlation coefficient CO&lt;sub&gt;ITD-ICG&lt;/sub&gt;</td>
<td>0.24–0.27</td>
<td>0.58–0.98</td>
<td>0.67–0.97</td>
</tr>
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</table>

**Table 2. Changes of patients’ hemodynamic profile before application, during IABP, and after termination of IABP**

Medicina (Kaunas) 2006; 42(11)
CO_{ITD} via PAC have been documented (23). In the study published by J. M. van de Water et al., linear regression analysis of the intramethod CO comparisons clearly revealed a wider variability and less agreement in the CO_{ITD} compared to the case with the CO_{ICG} (17).

In our study, we observed improved correlation of ITD and ICG techniques after the improvement of patient status (during application of IABP and after its termination). This might be explained that in low-cardiac output states noninvasive methods as well as invasive methods have lower accuracy.

For many biological and clinical measurements, a true standard for accuracy does not exist. The reason for this is that, like most clinical measurements, the desired quantity of measurement is not directly accessible and/or quantifiable. Therefore, technologies are developed that measure an indirectly related quantity to that which clinicians are interested. Very often these various technologies measure two or more separate quantities for the purpose of inferring yet a separate third quantity. As such, each technology is subject to different sources of error in determining the same desired clinical measurement. And since a true reference standard does not exist, the existing accepted technology often is substituted and is defined as the reference for determining the accuracy of new technologies. CO is a prime example of such a clinical measurement (17).

On the other hand, weak correlation and lack of agreement of hemodynamic measurements obtained on the initiation of IABP might be explained by small study sample. This, as a possible reason, was also mentioned in J. Bajorat et al. study in 2005 (4).
modynamic assessment was initiated due to some non-randomized studies, which suggested that PAC use is associated with increased morbidity and mortality. The discussion is ongoing and becoming even more actual about the introduction of less invasive techniques for hemodynamic assessment. Recently the use of pulmonary artery catheters was questioned. Studies have revealed that in critically ill patients, use of the PAC neither increased overall mortality or the number of days in hospital nor conferred benefit. Despite almost 20 years of randomized clinical trials, a clear strategy leading to improved survival with the PAC has not been devised. The neutrality of the PAC for clinical outcomes may result from the absence of effective evidence-based treatments to use in combination with PAC information across the spectrum of critically ill patients (24).

It is indicated by J. D. Sandham and co-authors that patients treated with pulmonary artery catheter-guided therapy may have even increased mortality (25). The suspicion was raised that these fatalities were due to catheter-related complications and overtreatment. While cautious use of right-heart catheterization by skillful personnel should be beneficial for critically ill patients (26–28).

The goal of the Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterisation Effectiveness was to determine whether PAC use is safe and improves clinical outcomes in patients hospitalized with severe symptomatic and recurrent heart failure. The primary end point – number of days alive out of hospital over 6 months – was the same among patients with and without a PAC, at 133 vs. 135 days. This finding was consistent across demographic subgroups, with no significant differences between groups with regard to the time to death or hospitalization, the number of deaths, or the number of days hospitalized. Of note, there were no deaths related to PAC use, although in-hospital adverse events were almost twice as likely to occur among patients in the PAC group than among those in the non-PAC group, at 21.9% vs. 11.5% (24).

In the meta-analysis of 13 randomized clinical trials evaluating the use of PACs in a total of 5051 critically ill patients was found that the use of PACs had no impact on mortality or on the average number of days spent in hospital (29). According to these results, it
Conclusions

A significant correlation was observed between the impedance cardiography methods during intraarterial balloon counterpulsation and intravenous infusion methods. However, further studies are needed to better tailor therapy for both survival and quality of life.

Future trials should test noninvasive assessments and specific treatment strategies that could be used for the routine treatment of patients in the intensive care unit, patients with decompenated heart failure, or patients undergoing surgery until effective therapies can be found that improve outcomes when compared with specific treatments that were not found to improve outcomes when compared with traditional care.

The correlation of hemodynamic indices by continuous monitoring of hemodynamic indices by noninvasive methods used for cardiac output measurement was analyzed with two methods more pronounced in patients not receiving high doses of inotropes.

Our data suggest that noninvasive methods for cardiac output measurement should be considered for the routine treatment of patients in the intensive care unit, patients with decompenated heart failure, or patients undergoing surgery until effective therapies can be found that improve outcomes when compared with specific treatments that were not found to improve outcomes when compared with traditional care.