Validation Study on Cardiac Output and Index Determination in Impedence Cardiography on Postoperative Cardiac Patients in Critical Care

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Abstract—The gold standard in determination of cardiac output is highly invasive and expensive in use. An accurate and reliable method, non-invasively and affordable, would improve hemodynamic management. This study is for validation of a new module in impedance cardiography to improve the accuracy in cardiac patients. Heart rate, Cardiac output/ index, and stroke volume have been determined simultaneously by thermodilution (Swan Ganz, right heart catheterisation) and impedance cardiography (VasoScreen3000 with integrated ACM module) from postoperative patients who underwent open heart surgery in intensive care unit. 34 measurements were successfully taken, on 22 patients. High agreement in heart rate and acceptable agreement with strong correlation in Cardiac output/ index and stroke volume was found. The mean difference in cardiac output was -0.44 (SD 1.06) L/min (-0.31 (SD 0.63) L/min/m² for cardiac index), correlation after Pearson was r CO = 0.67 (p < 0.001). In this study, the appearance of mechanical ventilation affects the accuracy of impedance measurement. We concluded that impedance cardiography is a reliable and accurate method for determining cardiac performance, and is practical to use and without any discomfort to the patients.

Keywords—Impedence Cardiography, Postoperative Cardiac Patients, Cardiac Output and Index Determination

I. INTRODUCTION

Cardiovascular disease is one of the leading causes of mortality in most of the developed countries [1]. Although invasive techniques, such as Thermodilution, Picco or Lido, give satisfactory results on the estimation of cardiac output and stroke volume, they are not suitable for long-term or repeated measurements because of their invasive nature [2-6][2, 3, 4, 5, 6]. Nevertheless, the invasive hemodynamic assessment is often used after an acute cardiac episode, like coronary artery bypass graft or valve repair or replacement [7] in patients under critical care. If there were an accurate, reliable, non-invasive method for determining cardiac output and other parameters available, surgical patients after open heart surgery would benefit [8]. Several methods are capable to determine those parameters in fundamental different ways, from non-invasive to highly invasive. However, the gold standard is the thermodilution method (Swan Ganz), which, thus its questioned positive effect of its highly invasive nature in critical ill patients and its lack of clinical outcome benefits [9] is used routinely in clinics and hospitals to determine cardiac performance [3].

Impedance cardiography (ICG) is a non-invasive method to determine hemodynamic parameters by changes of resistivity in the thorax, via four dual sensors applied on the neck and thorax, during the cardiac cycle. The signal shows the mechanical activity of the heart. During systole, the signal is mostly generated by volume changes taking place in the aorta. During diastole, blood volume changes in the large veins and the pulmonary aorta may also contribute to ICG waveforms, especially in case of pathological changes [10] [11]. In the past decade, impedance cardiography was improving its performance with the goal to replace highly invasive techniques in hemodynamic monitoring. In this context, a new module was introduced by the German company medis. GmbH, Ilmenau, Germany. In cases of arterial stiffness or reduced elasticity of the aorta, the left ventricular ejection time (LVET) is detected falsely caused by the changed appearance of impedance signal. The new technology, called ACM (arterial compliance modulation) module aims the
26 patients were evaluated in 39 measurements, all in supine position with necessary treatment for their individual health status. No patients were excluded at the basis of structural or functional heart disease. Excluded are patients in unstable hemodynamic condition. Required sample size for a significance of 0.05 and power of 80% are 30 samples. All patients were Indonesian.

B. Analysis

Analysis was performed in SPSS (PAWS Statistics 18). The agreement between both methods for heart rate, cardiac output/index and stroke volume was assessed by mean bias, the SD and the 95% confidence limits (Bland Altman). The linear relationship between thermodilution and impedance cardiography was determined graphical and calculated with linear regression and the correlation by Pearson. A t-test was performed to identify the statistical similarity means. α was set as 5% and H0 states that the means of both samples were equal. Outliers were classified.

III. RESULTS

A. Heart Rate

The mean heart rate and standard deviation in thermodilution and impedance cardiography was 90.00 (SD 14.60) 1/min and 89.38 (SD 12.76) 1/min. Mean difference between the two devices therefore is 0.62 (SD 4.19) 1/min. The correlation coefficient after Pearson is rHR = 0.957 (p< 0.001). Limits of agreement are 8.36 and -7.59 1/min. T-test shows a result of pHR = 0.397. Linear regression is shown in Fig. 3.

<table>
<thead>
<tr>
<th>TABLE I.</th>
<th>CHARACTERISTICS OF SAMPLE</th>
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</thead>
<tbody>
<tr>
<td>Patients Info.</td>
<td></td>
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<tr>
<td>Total number</td>
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<tr>
<td>- Male</td>
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</tr>
<tr>
<td>- Female</td>
<td>7</td>
</tr>
<tr>
<td>Age</td>
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<tr>
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<td>23.70 ± 4.60 kg/m²</td>
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</table>
B. Cardiac Output/Index

Cardiac output measurements determined by thermodilution were 4.44 ± 1.20 L/min in average, impedance cardiography was 4.88 (SD 1.37) L/min. Mean difference and standard deviation between the methods was -0.44 (SD 1.06) L/min for cardiac output and -0.31(SD 0.63) L/min/m2 for cardiac index. Pearson correlation coefficient was rCO = 0.67 (p < 0.001) for cardiac output and 0.61(p < 0.001) for cardiac index. Bland Altman plot of cardiac output in figure 1 shows, that all collected data points cluster within the confidential lines of 1.56 and -2.51 L/min (bias±1.96×SD). The t-test shows values of pCO= 0.023 and pCI = 0.009 for cardiac output and index. The linear regression is shown in Fig. 3.

C. Stroke Volume

The stroke volume determined by thermodilution is 49.71 (SD 12.20) ml and 55.19 (SD 16.67) ml obtained by impedance cardiography, mean difference is -5.48 (SD 12.05) ml. The correlation after Pearson is rSV = 0.691 (p<0.001). Limits of agreement are 18.15 and -29.08 ml, the agreement is shown in figure 2. T-test shows a result of pSV = 0.012. Linear regression is shown in figure 3.

D. Influence of Mechanical Ventilation

Mechanical ventilation on patients does influence the measurement accuracy. Comparing the differences of cardiac output from both devices, people with ventilation (23 measurements) show a lower difference (-0,12L/min) than not ventilated patients (-1.17L/min) but a greater standard deviation (SD 1.08 for ventilated patients, SD 0.58 for not ventilated) which means a higher spreading of values for single measurements. The
that the impedance parameter could alter a physician but the results need to be treaded carefully. One study suggested patients in determining cardiac output/index and stroke volume, PAC in animals [9].

determine cardiac output have smaller error to each other than to with pulmonary artery catheter and that other methods to claimed that CO changes less than 30-40% are detected unreliable [15].

Another study [9] questioned the accuracy of the gold standard method itself, in measuring cardiac output. It has been claimed that CO changes less than 30-40% are detected unreliable with pulmonary artery catheter and that other methods to determine cardiac output have smaller error to each other than to PAC in animals [9].

Our results show satisfying agreement in postoperative patients in determining cardiac output/index and stoke volume, but the results need to be treaded carefully. One study suggested that the impedance parameter could alter a physician’s plans of treatment [16]. Also the impact of mechanical ventilation is indicated, but need to be proven in further studies.

IV. DISCUSSION

Standard impedance cardiography is a noninvasive method that provides continuous beat-to-beat measurements of hemodynamic parameters, is economical and easy to use. Nevertheless, so far it is not the method of choice if exact measurements of cardiac output in postoperative patients are needed, because of the lack of correlation compared to the gold standard and highly invasive method of thermodilution. Recent developments aim to improve accuracy, which needs to be proved by studies like this, to ensure the reliability of new methods. Postoperative patients after open heart surgery in critical care are mostly provided with the pulmonary artery catheter, to obtain their hemodynamic performance with thermodilution method. These patients had been measured with both devices, thermodilution and impedance cardiography, with new ACM module simultaneously, and showed acceptable accuracy and high correlation for the parameter cardiac output/index and stroke volume. The agreement and correlation of heart rate was very high.

The impact of mechanical ventilation in impedance measurements shows that impedance cardiography measurements can be influenced by other mechanical equipment in the treatment plan of the patient. The impact is not yet clear because of the insufficient number of measurements and need to be clarified in further studies.

Although the ACM module increase the accuracy of impedance cardiography, compared to usual impedance measurements [12], the principle of measurement set certain limitations in detecting right and left ventricular filling pressure [13] [14]. Moreover, impedance cardiography does not provide information about intra cardiac pressure like thermodilution, but about fluid trending and myocardial contractility [13]. Other known limitations are aortic valve regurgitation and septic shock [15].

Another study [9] questioned the accuracy of the gold standard method itself, in measuring cardiac output. It has been claimed that CO changes less than 30-40% are detected unreliable with pulmonary artery catheter and that other methods to determine cardiac output have smaller error to each other than to PAC in animals [9].

V. CONCLUSION

Impedance cardiography nowadays cannot be considered as accurate as the gold standard itself, but this, and other researches, show a high correlation and accuracy of the non-invasive device. It is overall an easy to use, user independent, continuous beat to beat measurement, which has big advantages for patients and hospitals. Our study indicates that the measurements with impedance cardiography are adequately accurate and highly correlated with thermodilution measurements on postoperative patients. The method decreases the discomfort of patients, which are already highly injured after open heart surgery. Once, the electrodes are applied, impedance cardiography delivers continuously hemodynamic parameters without additional personnel effort. With respect of the limitations of this method, impedance cardiography could be used in clinical treatment in replacement of highly invasive methods. The impact of mechanical ventilation has to be considered in further studies.

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