Evaluation of concordance among three cardiac output measurement techniques in adult patients during cardiovascular surgery postoperative care

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Received 15 January 2016; accepted 10 August 2017
Available online 30 September 2017

KEYWORDS
Transesophageal echocardiography; Cardiac output; Thermodilution; Cardiac surgery

Abstract
Introduction: The standard method for cardiac output measuring is thermodilution although it is an invasive technique. Transesophageal Echocardiography (TEE) offers a dynamic and functional alternative to thermodilution.
Objective: Analyze concordance between two TEE methods and thermodilution for cardiac output assessment.
Methods: Observational concordance study in cardiovascular surgery patients that required pulmonary artery catheter. TEE cardiac output measurement at both mitral annulus (MA) and left ventricle outflow tract (LVOT) were performed. Results were compared with thermodilution. Correlation was evaluated by Lin’s concordance correlation coefficient and Bland–Altman analysis. Statistical analysis was undertaken in STATA 13.0.

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https://doi.org/10.1016/j.medin.2017.08.001
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Results: Twenty-five patients were enrolled. Fifty two percent of patients were male, median age and ejection fraction was 63 years and 35% respectively. Median thermodilution, LVOT and MA-measured cardiac output was 3.25 L/min, 3.46 L/min and 8.4 L/min respectively. Different values between thermodilution and MA measurements were found (Lin concordance = 0.071; Confidence Interval 95% = −0.009 to 0.151; Spearman’s correlation = 0.22) as values between thermodilution and LVOT (Lin concordance = 0.232; Confidence Interval 95% = −0.12 a 0.537; Spearman’s correlation 0.28). Bland–Altman analysis showed greater difference between MA measurements and thermodilution (DM = −0.408; Bland–Altman Limits = −0.809 to −0.007), than the other echocardiographic findings (DM = 0.007; Bland–Altman Limits = −0.441 to 0.428).

Conclusion: Results from cardiac output measurement by doppler and 2D-TEE on both MA and LVOT do not correlate with those obtained by thermodilution. © 2017 Elsevier España, S.L.U. and SEMICYUC. All rights reserved.

PALABRAS CLAVE
Ecocardiografía transesofágica; Gasto cardiaco; Termodilución; Cirugía cardiaca

Evaluación de la concordancia de tres técnicas de medición del gasto cardiaco en pacientes adultos durante el postoperatorio de cirugía cardiaca

Resumen

Introducción: El cálculo del gasto cardiaco se realiza por termodilución, y su principal desventaja es el carácter invasivo. La ecocardiografía transesofágica (ETE) representa una alternativa dinámica y funcional a la termodilución.

Objetivo: Analizar la concordancia entre dos métodos de ETE y termodilución para la evaluación del gasto cardiaco.

Métodos: Estudio observacional de concordancia en pacientes de cirugía cardiovascular con requerimiento de catéter de arteria pulmonar. Se realizó medición de gasto cardiaco por ETE en anillo mitral (AM) y en el tracto de salida del ventrículo izquierdo (TSVI). Los resultados se compararon con la termodilución. La concordancia fue evaluada por el coeficiente de correlación concordancia de Lin y analizada por el método de Bland-Altman. Los análisis estadísticos se realizaron en STATA 13.0.

Resultados: Se incluyeron 25 pacientes. El 52% fueron hombres, con mediana de edad de 63 años y fracción de eyeción del 35%. La mediana de gasto cardiaco por termodilución, AM y TSVI fue de 3.25, de 3.46 y de 8.4 L/min, respectivamente. Se encontraron diferentes valores entre termodilución y AM (concordancia de Lin = 0.071; IC 95%: −0.009 a 0.151), así como entre termodilución y TSVI (concordancia de Lin = 0.232; IC 95%: −0.12 a 0.537). El análisis de Bland-Altman muestra una diferencia entre la medición por AM y termodilución importante (DM = −0.408; Bland-Altman Limits = −0.809 a −0.007), así como entre las dos medidas por ETE (DM = 0.007; Bland-Altman Limits = −0.441 a 0.428).

Conclusión: Los resultados en la medición del gasto cardiaco por doppler y ETE bidimensional tanto a nivel del anillo mitral como del TSVI no son concordantes con la termodilución. © 2017 Elsevier España, S.L.U. and SEMICYUC. Todos los derechos reservados.

Introduction

Historically, cardiac output calculation for adults has been measured through thermodilution using a pulmonary artery catheter. This became the standard measurement method around 1970, and so it remained for more than ten years, until a high frequency of complications and/or misinterpreted data were associated to high mortality rates related to this technique.1,2

The first alternative to replace thermodilution was suggested by Dr. Parisi, who measured ventricle volume and ejection fraction using a two-dimensional transesophageal echocardiography (TEE).1,3 Other methods have been proposed (e.g. arterial wave contour analysis, PICCO, transpulmonary thermodilution, transpulmonary lithium dilution),4 although they have shown questionable benefit during open-heart cardiovascular surgery.

A recent promising possibility is TEE, which allows both cardiac structure and function evaluation during perioperative open-heart surgery. However, it requires training and certain skills to be learned by the operator in order to allow him or her to interpret different results adequately, and using them to guide management and improve care for a critically ill patient.5–9

Currently, TEE cardiac output monitoring is most commonly performed through a deep transgastric long axis view and aortic ring measurement (LVOT), , procedure that requires skills, and could be associated with gastrointestinal...
testinal, bleeding and mortality risk, besides of increased costs.6,9

Considering potential risk and cost associated with aort-
cic ring measurement, we propose an alternative method
through TEE four chamber view, measuring flow across mitral
annulus (MA).

The main objective of this study is to evaluate concor-
dance among three different cardiac output measurement
methods including LVOT, MA and thermodilution.

Methods

This is a concordance observational study, approved by
the ethics committee. Enrolled patients were told before
surgery about postoperative TEE hemodynamic data anal-
ysis study and gave informed consent. Twenty-five patients
programmed to undergo cardiovascular procedures (myocar-
dial revascularization, atrial septal defect closure, aortic
or mitral valve replacement) in the Hospital Cardiovascular
de Cundinamarca are included in the study. Cardiac output,
systolic function and pulmonary pressure were measured
immediately in the postoperative period. Those patients
with esophageal diseases, prosthetic mitral or aortic valve
insufficiency and those with atrial fibrillation history were
excluded from the study.

Perioperative management

The following are simply monitored by means of a visus-
cope: pulse oximetry, capnography, invasive arterial blood
pressure, esophageal thermometer, central catheter if
the patient’s condition warrants it, and pulmonary artery
catheter to measure the cardiac output by thermodilu-
tion using the bolus thermodilution cold saline solution
technique, and using the B650 and G Caresscape monitors
from the 37B650-01 series. Transesophageal echocardiogra-
phy probe was gently moved, and the following equipment
was used: the Philips Sonos 7500 live 3D Echo and 5.0 and
6.5 MZ Omni-Plane Transducer, a one-meter long Hewlett
Packard probe M-mode, two dimensional, color-flow Doppler
echocardiography, pulsed wave and continuous Doppler, and
harmonic imaging. The anesthetic technique and the use
vasoconstrictors/inotropes were decided by the anesthesi-
ologist in charge of the case.

One cardiovascular anesthesiologist with training in TEE
certified by the European Association of Cardiothoracic
Anaesthesiologists (EACTA) performed all TEE cardiac output
measurements during the immediate postoperative period
(sternal closure), avoiding inotropic or vasopressor support
during the study.

Measurement of cardiac output on the mitral
annulus/left ventricle outflow tract

All postoperative TEE cardiac output measures were done
using the following formula; regardless the type of surgery
performed considering clinical practice standards:

\[ \text{Cardiac output} = D^2 \times 0.785 \times \text{VTI} \times FC \]

where Cardiac Output (CO)= Stroke Volume × Heart rate;
Ejection fraction or Stroke volume (SV) or Flow = AT × VTI;
Cross sectional area (AT) = D^2 × 0.785 (cm^2); \( D \) = mitral
annulus or left ventricle outflow tract; \( \text{VTI} \) = velocity time
integral (cm).

Mitral annulus

The probe is inserted at a depth of 28 – 30 cm and the
mid esophageal four chamber window at zero degrees mea-
ures the cross-section of the mitral annulus, which was the
result of measuring the diameter from edge to edge during
the diastole at the moment when the mitral valves or
prosthesis was at their maximum aperture. The probe’s sec-
ond speed was then used and it was multiplied by 0.785,
which is a quarter of \( \pi \) (3.1416). This is undertaken on the
assumption that the mitral annulus is circular and the cross
section is constantly in diastole. The cardiac output was the
product of the VTI for the diastolic mitral flow and this was
measured with pulsed wave Doppler on the coaptation sur-
face of the valve; color-flow images were used to keep the
ultrasonic beam parallel to the mitral flow. The correction
for the angle of incidence was taken into consideration for
all the measurements and was less or equal to 20°. Three
measurements were made consecutively, tracing was done
manually, and the average was multiplied by the cross sec-
tion of the mitral annulus: this gives the stroke volume that
is subsequently multiplied by the heart rate.

Left ventricle outflow tract (LVOT)

The cross section of the LVOT was measured in the mid-
esophagus in the window on the aortic valve level on the
longitudinal axis from 130 - 135°. LVOT was identified
between 5 mm and 10 mm of the aortic ring and the diam-
eter was measured from edge to edge during the diastole
at the moment when the mitral valves or prosthesis was at
its maximum aperture. The probe’s second speed was then
used and it was multiplied by 0.785, which is a quarter of \( \pi \)
(3.1416).

To measure the VTI, the probe was inserted between
45-50 cm and located in the deep transgastric window at
zero degrees from the LVOT. Color-flow Doppler was used
to keep the ultrasound beam parallel to the flow, the wave flow
Doppler was positioned directly on the LVOT, 5 mm − 10 mm
from the aortic ring, and the velocity time integral was man-
ually traced. Three different samples were gathered and the
average of the results was taken. This was then multiplied
by the second speed of the cross section and then by 0.785,
which corresponds to a quarter of \( \pi \) (3.1416). This result was
in turn multiplied by the heart rate that could be measured
at that particular moment.
**Table 1** Demographic characteristics of the included patients.

<table>
<thead>
<tr>
<th>Patients’ characteristics</th>
<th>Range</th>
<th>Median</th>
<th>P25−P75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20−79</td>
<td>63</td>
<td>56−69</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>20−65</td>
<td>35</td>
<td>30−60</td>
</tr>
<tr>
<td>C.O. thermodilution (L/min)</td>
<td>1.93−6.87</td>
<td>3.25</td>
<td>2.58−4.46</td>
</tr>
<tr>
<td>C.O. mitral annulus (L/min)</td>
<td>3.01−19.6</td>
<td>8.4</td>
<td>5.81−12.52</td>
</tr>
<tr>
<td>C.O. LVOT (L/min)</td>
<td>1.58−8.85</td>
<td>3.46</td>
<td>2.17−5.07</td>
</tr>
<tr>
<td>Surface area (m²)</td>
<td>1.32−2</td>
<td>1.58</td>
<td>1.44−1.66</td>
</tr>
<tr>
<td>EuroSCORE II</td>
<td>1.22−19.2</td>
<td>4.8</td>
<td>3.5−8.19</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>55−109</td>
<td>80</td>
<td>70−85</td>
</tr>
</tbody>
</table>

Note: C.O. = cardiac output; LVOT = left ventricle outflow tract; L/Min = liters/minute.

**Thermodilution**

With a maximum lapse of five minutes between echocardiographic measurements, the cardiac output measurement was taken by thermodilution using CVP from a pulmonary artery catheter, using the bolus thermodilution technique injecting 10 cc of cold saline solution. Three samples were taken and then a mean of the results was calculated, excluding those that were extreme (very high or very low). A second observer undertook this procedure who was not aware of the previous echocardiographic measurements.

All the data from TEE and thermodilution measurements was registered along with demographic features, procedure type and EuroSCORE II.

Statistical analysis took into consideration patients’ demographic and clinical characteristics, which were summarized with their frequencies, central tendencies, and dispersion. To calculate the correlation between two cardiac output measuring methods, Lin’s concordance correlation coefficient was used, as was the Bland–Altman limits of agreement after logarithmic transformation considering the possibility of scarcity of data and great variation of differences. The statistical analysis of the information was undertaken using Stata13.

**Results**

The demographic characteristics of the 25 patients are outlined in Table 1. The median age was 63 years (predominant age group: 51−64, 44%). The median ejection fraction was 35%; males were the prominent sex in the study (52%).

The cardiac output measurement median by thermodilution was 3.25 liters/minute, while the cardiac output measurement median on the left ventricle outflow tract was 3.46 liters/minute, and on the mitral ring was 8.4 liters/minute (Fig. 1). The most common procedure undertaken was the valve replacement (48%). The majority of patients were in the group with the lowest ejection fraction that was less than 35% (Table 2).

On evaluating the concordance between the three measurements by means of Lin’s concordance-correlation coefficient, we found that there was no concordance between the three measurements. Specifically, the thermodilution values differ from the values obtained from the mitral ring flow rate (Lin concordance=0.071; Confidence Interval 95% = −0.009 to 0.151; Spearman’s correlation = 0.22) (Table 3). In addition, the values that were obtained from the LVOT showed important discrepancies with those obtained by thermodilution (Lin concordance = 0.232; Confidence Interval 95% = −0.12 a 0.537; Spearman’s correlation 0.28) (Table 3). Due to scarcity of data and great

**Table 3** Concordance coefficients in the three cardiac output measurements.

<table>
<thead>
<tr>
<th></th>
<th>Lin’s concordance correlation coefficient</th>
<th>Confidence interval</th>
<th>Spearman’s Correlation</th>
<th>Differences in measurements (standard deviation)</th>
<th>Bland–Altman Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoldilution vs. LVOT</td>
<td>0.232</td>
<td>−0.127 to 0.537</td>
<td>0.28</td>
<td>−0.007 (0.222)</td>
<td>−0.441 to 0.428</td>
</tr>
<tr>
<td>Thermoldilution vs. mitral valve</td>
<td>0.071</td>
<td>−0.009 to 0.151</td>
<td>0.22</td>
<td>−0.408 (0.205)</td>
<td>−0.809 to −0.007</td>
</tr>
<tr>
<td>Mitral valve vs. LVOT</td>
<td>0.147</td>
<td>0.017−0.270</td>
<td>0.37</td>
<td>0.401 (0.210)</td>
<td>−0.011 to 0.813</td>
</tr>
</tbody>
</table>

Note: LVOT = left ventricle outflow tract.

a CI 95% under z transformation.

b Data transformed under logarithmic transformation.

**Figure 1** Boxplot of the three cardiac output measurements.

**Table 2** Ejection fraction and EuroSCORE index II by ranges.

<table>
<thead>
<tr>
<th>Ejection fraction (EF)</th>
<th>N</th>
<th>%</th>
<th>EuroSCORE II</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal EF</td>
<td>7</td>
<td>28</td>
<td>Low (0−2)</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Lower than normal EF</td>
<td>5</td>
<td>20</td>
<td>Middle (3−5)</td>
<td>12</td>
<td>48</td>
</tr>
<tr>
<td>Low EF</td>
<td>13</td>
<td>52</td>
<td>High (&gt;6)</td>
<td>8</td>
<td>32</td>
</tr>
</tbody>
</table>

Relation between ejection fraction and EuroSCORE II. 10
Although its evaluation according to thermodilution, diac complications were measured with a more surement allowing the measurement. The limits of agreement were found as -0.408; Bland-Altman Limits = -0.809 to -0.007 (Fig. 2) than the other echocardiographic findings (DM = 0.007; Bland-Altman Limits = -0.441 to 0.428) (Figs. 3−4).

**Discussion**

Cardiac output calculation is routinely carried out by thermodilution, which presents widely disseminated and evaluated parameters.1,4,11,12 Its invasiveness and related complications led the searching for alternative techniques with lower mortality and adverse events.

Transesophageal echocardiography cardiac output measurement is an alternative in hemodynamic monitoring allowing guidance during these patients management according to cardiac output, stroke volume, preload, cardiac structure and function evaluation.7 Measurement can be taken through different routes, including pulmonary ring, aortic ring, mitral ring level, and on the LVOT with pulsed wave and continuous Doppler.5,13−15 However, differences can be found among measured routes. LVOT correlates with thermodilution,16 although its technical difficulty to align the transducer parallel in a deep transgastric window and the anteflexion that requires, is associated to increased mortality rate.1,17,18

Our study deals with this problem, obtaining an image by TEE on a window level with four chambers via the mid-esophagus at zero degrees on the mitral ring level, where the ultrasonic beam is aligned in parallel measuring the trans-mitral flow, calculating ring area diameter.

However, the information obtained from 25 patients did not show concordance among three cardiac output measurements (thermodilution, MA and LVOT). Of the three measurements estimated, the closest were those that came from thermodilution with the flow through TSVI, showing a concordance between them but without being consistent for all the patients.

From our results, we cannot recommend thermodilution replacement by any of the other measurements derived from TEE. We can only suggest to monitor trends based on the initial value and during subsequent measurements, taking advantage of the complementary information that the TEE offers, which thermodilution alone does not.

Our results are similar to those presented by Bettex et al. They found that cardiac output evaluation was 9.57 L/min (range of 6.4 – 12.5 L/min) compared with thermodilution.1 Likewise, Muhiudeen’s study measured cardiac output by cross section diameter at a pulmonary ring level and found a modest correlation with thermodilution, but no correlation was found at the mitral ring level, as well as an important dispersion of the data close to zero (r = 0.24).13 Conversely, Cabrera et al. found a strong correlation between cardiac output measurement on the mitral ring level among Chilean population (Pearson’s R = 0.92); however, this study measured an area on a transgastric level at zero degrees with a light anteflexion. This provided a transversal view of the mitral valve during ventricular diastole, which is calculated using a planimetric measurement under an elliptical model and not a circular one.15,19,20
Cabrera et al. suggested that mitral stenosis, severe mitral insufficiency or insufficiency in prosthetic valves could be a constraint for the application of this technique, including only patients undergoing myocardial revascularization. However, the authors of this study used a different technique for cross section measurement than they did when they measured the mitral ring by planimetric measurement in the transgastric window with a level of anteflexion, considering that cross section diameter measurement is a primary limitation for the mitral ring as it might overestimate cardiac output.

Study strengths include that all three measurements were done in a similar way, with high quality windows, following the same steps, and with a difference of no more than five minutes between TEE and thermodilution measurements. Other hemodynamic influences were avoided, and similarity in demographic characteristics for ejection fraction and type of surgery were documented. In order to avoid possible bias, TEE results were kept apart from those from thermodilution.

One of the limitations of this study was that the electrocardiogram was not available; therefore, it could not be included with the TEE image during the measurement at the precise moment of the rapid diastolic filling peak. This could generate an estimated variability of up to 12% in the mitral ring area size. Also, the fact that the probe was not continuously available meant that the size of the sample could not be improved, being a small sample size another limitation of the present study. However, the sample obtained was sufficient to observe differences in concordance among measurement methods. We also note that thermodilution, as the standard practice, is susceptible to errors given that it is not the reference standard to measure cardiac output; it has been quantified that this process can overestimate the output by up to 15%. It was, however, necessary to make the comparison with this measuring method, as it is the most commonly used for patients who undergo cardiac surgery.

Studied population had a mean ejection fraction of 39.8% and was predominantly intermediate to high-risk patients according to EuroSCORE II. The former analysis being important, considering that myocardial wall movement abnormalities may alter up to 40% the two-dimensional volume evaluation, and may be related to a high degree of variability in the results.

According to TEE calculations to estimate cardiac output, heart rate is an important determinant for variation. If tachycardia is present, a TEE-cardiac output measurement overestimation may happen. This consideration should be taken into account in patients with altered heart rate.

Our findings showed that results on a mitral ring level are dispersed respect to thermodilution and LVOT; with a 5.8 L/min difference compared to thermodilution. However, during difficulties for catheter introduction, lack of training or when clinical conditions preclude TEE-transgastric window, MA four chamber method may offer a cardiac output estimation, information about left ventricle inflow related to ejection fraction deterioration and be monitored over time, compared with thermodilution and LVOT.

Transesophageal echocardiography cardiac output measuring methods might be of complementary value during heart surgery, taken into account their limitations, during postoperative monitoring.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Acknowledgements

Special thanks is given to the Anesthesiology Department led by Dr. Jorge Córdoba, the Cardiology Department, Dr. Álvaro Rodríguez for his unconditional tutoring, to the Department of Epidemiology directed by Dr. Leonardo Olaya, and especially to Dr. Leonidas Cely who is Scientific Director of the Hospital Cardiovascular del Niño de Cundinamarca. He allowed us to undertake the study and offered us the possibility to pioneer many more studies in this institution that wholeheartedly supports the vulnerable population in our country – Colombia.

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Evaluation of concordance among three cardiac output measurement techniques


