Journal of International Medical Research
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Journal of International Medical Research 2013 41: 1342 originally published online 26 June 2013
DOI: 10.1177/0300060513487649

The online version of this article can be found at:
http://imr.sagepub.com/content/41/4/1342

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Clinical Note

Journal of INTERNATIONAL MEDICAL RESEARCH

Journal of International Medical Research
41(4) 1342–1349

DOI: 10.1177/0300060513487649
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Comparison of cardiac output derived from FloTrac™/Vigileo™ and impedance cardiography during major abdominal surgery

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Abstract

Objectives: Impedance cardiography (ICG) is a noninvasive technique that provides reasonably accurate measurements of cardiac output, but the usefulness of ICG in patients undergoing open abdominal surgery has not been validated.

Methods: Cardiac output was measured while patients underwent open gastrectomy using an ICG monitor (*niccomo*™; ICG-CO); the results were compared with those measured using a FloTrac™/Vigileo™ monitor (Flo-CO), which measures cardiac output by analysing the arterial waveform. Data collection commenced at the beginning of anaesthetic induction and continued until the patient was awake. Data were compared using the Bland–Altman analysis, and the clinical significance of the difference between the two methods was evaluated by calculating the percentage error (%).

Results: Eleven patients were monitored during surgery. The bias of the Flo-CO and ICG-CO values was −0.45 l/min. The upper and lower limits of agreement were 0.96 l/min and −1.85 l/min, respectively. The percentage error was 28.5%. Electrocautery induced interference that transiently impaired the performance of the ICG monitor.

Conclusions: ICG provided useful information in evaluating the cardiac output of patients during abdominal surgery.

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Keywords
Cardiac output, impedance cardiography, *niccomo*™, continuous haemodynamic monitoring, FloTrac™/Vigileo™

Date received: 5 March 2013; accepted: 12 April 2013

Introduction

During surgical procedures on patients with cardiovascular disease, monitoring the cardiac output is greatly beneficial for the management of anaesthesia. The most commonly used method for monitoring cardiac output is the thermodilution method, which uses a pulmonary arterial catheter. However, this method is invasive, has a high risk of complications and is influenced by the ability of the person undertaking the procedure.[1] Therefore, considering the risks and benefits associated with its use, the thermodilution method is reserved for limited situations; it is infrequently used during the monitoring of anaesthesia in common surgical procedures. Cardiac output monitors that use various noninvasive methods have been developed, which has resulted in cardiac output being relatively accurately monitored without the need for the thermodilution method.[2]

Impedance cardiography (ICG) is a noninvasive procedure that measures cardiac output by attaching four electrodes (in pairs of two) at each side of the patient's neck, and on the left and right sides of the chest.[3] Microelectric currents flow through the chest cavity through the electrodes, with the changes in impedance (caused by the changes in the thoracic aortic blood volume and blood flow during the electric current) being measured. Various types of information, such as continuous stroke volume (SV), cardiac output, systemic vascular resistance (SVR) and thoracic fluid content, can be observed through these changes in impedance.[3] Since research on impedance cardiography began, in the 1940s, there have been continual questions regarding its accuracy. However, as signal processing techniques reduce artifacts in the impedance signal, and the mathematical formulae that calculate SV are improved, a relatively accurate value (similar to the cardiac output values from the thermodilution method) can be obtained.[4–7] However, ICG is not used widely during surgery because of the limitations associated with its use, such as the various surgical manipulations undertaken, the relatively large amounts of fluid administered, acute bleeding and frequent electrocautery, which might interfere with the impedance measurements, depending on the type of surgery.[8]

FloTrac™/Vigileo™ is an advanced and minimally invasive monitoring device that measures cardiac output by analysing the arterial waveform; the value of this analysis has been proven, compared with the thermodilution method during surgery or in the intensive care unit.[9] After an upgrade to third-generation software, further improvements in the accuracy of arterial pressure waveform-derived cardiac output have been reported.[10,11]

This current clinical study compared the monitoring of cardiac output using ICG and FloTrac™/Vigileo™ in patients undergoing laparotomy, where there was frequent use of electrocautery and surgical manipulation inside the abdomen.

Patients and methods

Patients

The study enrolled consecutive patients, classified as American Society of Anesthesiologists physical status 1–2 who were scheduled to undergo open gastrectomy, with an arterial catheter inserted to monitor blood pressure, in the Department of Anaesthesiology and Pain Medicine, Ilsan Paik Hospital, Inje University, Goyang, Republic of Korea, between September 2012 and February 2013. Patients with heart valve conditions or pulmonary diseases were excluded.

The research was approved by the Clinical Research Ethics Committee of Ilsan Paik Hospital (approval number: IR-3-1205-021). All patients were visited before induction of anaesthesia, in order to explain the research being conducted and to obtain their written informed consent.

Surgical and anaesthesia procedures

Patients were premedicated with 0.004 mg/kg glycopyrrolate intramuscularly 30 min before induction of anaesthesia. After arriving in the operating room, noninvasive blood pressure, electrocardiography (ECG), and pulse oximetry were monitored (IntelliVue® MP50 patient monitor; Philips Healthcare, Best, The Netherlands Philips, Netherlands). Before inducing anaesthesia, a 20 G catheter was inserted in the radial artery and connected to the FloTrac™/Vigileo™ monitor (Edwards Lifesciences, Irvine, CA, USA) with software version 1.07 (third generation). In addition, the electrodes for the ICG monitor (*niccomo*™; Medis, Ilmenau, Germany) were attached to both sides of the patient's neck and along the midaxillary line of the left and right sides of the chest, employing the xyphoid process as a reference line. The four electrodes were then connected to the *niccomo*™ device. The ICG was set to express cardiac output by taking the mean value of 16 heart beats. A dose of 1.5–2 mg/kg propofol and 0.5–1 μg/kg per min remifentanil, both administered intravenously, were used to induce anaesthesia. Rocuronium was used for muscle relaxation: 0.6 mg/kg was intravenously injected during endotracheal intubation and 0.1–0.15 mg/kg every 30 min was intravenously injected to maintain muscle relaxation. Anaesthesia was maintained with inhaled 4–6 vol% desflurane, and 0.05–2 μg/kg per min remifentanil was continuously infused intravenously. From the induction to the end of anaesthesia, systolic and diastolic blood pressure, heart rate and peripheral oxygen saturation were recorded every 5 min. Cardiac output values measured by the two monitors, FloTrac™/Vigileo™ (Flo-CO) and *niccomo*™ ICG monitor (ICG-CO), were recorded for each patient.

Statistical analyses

A Bland–Altman analysis was used to evaluate the degree of agreement between the measured values for cardiac output provided by the two monitors.[12] Using this analytical method, a graph was drawn that plotted the mean of the two measurements (Flo-CO and ICG-CO) that were measured at the same time on the x-axis, and the difference between the two values that were measured at the same time on the y-axis. Then, the bias and SD of the two measured values were calculated. Evaluating the clinical significance of the results obtained from the Bland–Altman analysis was performed by calculating the percentage error (%) based on the formula of Critchley and Critchley,[13] which doubles the SD of the differences between the two measurements and divides this value by the mean value of the two measurements, as follows:

$$\text{Percentage error} = (2 \times \text{SD})/(\text{mean CO}) \times 100.$$

The results of the two methods were considered to be equivalent when the percentage error was $< 30\%$. All statistical analyses were performed using MedCalc software package, version 12.4 (MedCalc Software, Ostend, Belgium) for Windows®.

Results

Eleven patients were included in the study; their demographic data are presented in Table 1. A total of 349 cardiac output measurements were obtained from the Flo-CO monitor and 302 cardiac output measurements were obtained from the ICG-CO monitor. Some measurements were lost due to the influence of electrocautery. Data loss from the ICG-CO monitor compared with the Flo-CO monitor had a mean ± SD value of 14.3 ± 8.0%. The range of cardiac output measurements from the Flo-CO monitor was 2.8–7.5 l/min (Table 2). The range of cardiac output measurements from the ICG-CO monitor was 3.3–6.9 l/min. Bland–Altman analysis resulted in the graph shown in Figure 1. The bias of the Flo-CO and ICG-CO measurements was −0.45 l/min, where the upper limit of agreement was 0.96 l/min and the lower limit of agreement was −1.85 l/min. The percentage error was 28.5%.

Table 1. Demographic characteristics of patients ($n = 11$) undergoing open gastrectomy who participated in a study to compare the measurement of cardiac output using a FloTrac™/Vigileo™ haemodynamic monitor and a *niccomo*™ impedance cardiography monitor.

Characteristic	Value
Age, years	64.0 ± 11.3
Sex, male/female	11 (7/4)
Height, cm	163.2 ± 5.7
Weight, kg	61.0 ± 10.5

Data presented as mean ± SD or *n* patients.

Discussion

The results of comparing the cardiac output measurements using a FloTrac™/Vigileo™ haemodynamic monitor and a *niccomo*™ ICG monitor in patients undergoing open gastrectomy showed that there was a difference in the absolute values, but the trends of the changes were similar. This provides useful information about evaluating the state of a patient during actual anaesthesia. The low bias value of −0.45 l/min and percentage error of 28.5% showed that the cardiac output measurements obtained by the two devices were statistically similar. Although the bias was only −0.45 l/min, differences in the cardiac output measurements obtained by the two devices were not consistently maintained, because the values obtained from the ICG-CO monitor were not always the higher values. The mean of

Table 2. Comparison of cardiac output (CO) as measured using a FloTrac™/Vigileo™ monitor (Flo-CO) and a *niccomo*™ impedance cardiography monitor (ICG-CO),in patients ($n = 11$) undergoing open gastrectomy.

Characteristic	Flo-CO	ICG-CO
CO measurement, *n*	349	302
Minimum, l/min	2.8	3.3
Maximum, l/min	7.5	6.9
Mean, l/min	4.7 ± 0.9	5.1 ± 0.8
Bias, l/min	−0.45	
Upper limit of agreement (95% CI of limits), l/min	0.96 (0.82, 1.09)	
Lower limit of agreement (95% CI of limits), l/min	−1.85 (−1.99, −1.72)	
Percentage error	28.5%	

CI, confidence interval.

the Flo-CO and ICG-CO measurements were calculated during a certain time-period in order to adjust the degree of change of the measurements according to physiological reasons, such as respiration. The Flo-CO measurement was the mean of cardiac output during 20 s; after 20 s, a new mean value was shown. However, for the ICG-CO monitor, the time-period that was used to determine the mean cardiac output measurement was determined by the heart rate, and for each heart beat the most recent mean value was shown. In this current study, the period for calculating the mean was 16 heart beats. Then, the observer recorded the displayed cardiac output value of the two devices every 5 min, so if there had been rapid changes in cardiac output within 10–20 s, there could have been differences in the measured values.

The accuracy of ICG decreases when there is a rapid change in haemodynamic loading[14] and the accuracy of the FloTrac™/Vigileo™ monitor is also reported to decrease when there is a rapid change in the intravascular volume, cardiac contractility, vascular resistance, and vascular compliance.[15] However, even the thermodilution method, which is considered the gold standard, has a certain degree of imprecision.[16]

Impedance cardiography monitors read ECG and thoracic impedance through electrodes in order to calculate the cardiac output, so the cardiac output values cannot be obtained while using electrocautery.

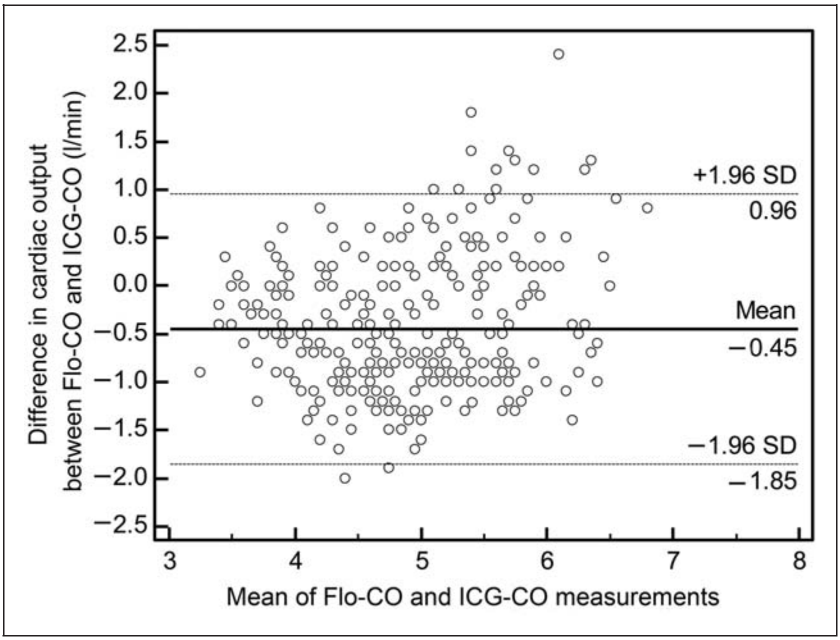

Figure 1. Bland–Altman plot of the difference between the cardiac output (CO) measurements determined using a FloTrac™/Vigileo™ monitor (Flo-CO) and a *niccomo*™ impedance cardiography monitor (ICG-CO) in patients ($n = 11$; 302 pairs of data) undergoing open gastrectomy. Bias = −0.45 l/min (solid line); dashed lines indicate upper and lower limits of agreement (±1.96 × SD); *y*-axis: CO FloTrac™/Vigileo™ – CO ICG; *x*-axis: (CO FloTrac™/Vigileo™ + CO ICG)/2.

Nevertheless, the measured value was updated every heart beat, so the cardiac output was shown as soon as the signal was read after the completion of electrocautery. However, if the cardiac output was expressed beat-to-beat, the variation could be large (due to physiological reasons such as respiration); consequently, it was generally expressed as a mean for a set number of heart beats. Thus, when the use of electrocautery was discontinued, the cardiac output display was delayed until a set number of heart beats before a mean value was determined. Therefore, if the set number of heart beats decreased, the delay time also decreased. For example, if 16 heart beats were set as the number needed to determine the mean value, when the heart rate was 80, the delay would be for ~12 s after stopping electrocautery, in order for the cardiac output to be shown again. However, the *niccomo*™ monitor used in this current study continuously showed cardiac output values when a loss of thoracic impedance was experienced for less time than the set number of heart beats. This was the case as long as the heart rate could be checked by the ECG signal even when thoracic impedance values could not be read due to other external reasons, including the use of electrocautery. If the set number of heart beats was 16, the cardiac output was continuously shown as long as the ECG signal could be checked, even when there was a loss of thoracic impedance signalling for 15 heart beats. In this situation, the accuracy of the cardiac output measurements could decrease.

The signal loss of $14.3 \pm 8.0\%$ in this current study did not relate to the time where the signal could not be read during the entire surgery. As data were updated every 5 min, it meant that if electrocautery was used at that point, the measured values were not shown. In abdominal surgery, electrocautery is mainly used at the start of the surgery, and it is not often required during the surgery. However, in most situations, the measured values could be checked within a maximum of 20–30 s after the discontinuation of electrocautery, so there were no actual difficulties in ICG monitoring due to electrocautery.

This current study had a number of limitations. First, the gold-standard (thermodilution) method was not used for comparison. In major abdominal surgery, inserting a pulmonary tube to monitor cardiac output is too invasive when compared with the obtained benefits, so it is not generally recommended.[2] For this reason, most literature that compares the measurement of cardiac output using the thermodilution method is limited to patients with severe cardiopulmonary disease, or to heart or transplant surgeries.[5,6] Although the thermodilution method measures cardiac output continuously, the data collection time would be longer than for the FloTrac™/Vigileo™ or *niccomo*™ ICG monitors. Hence, the FloTrac™/Vigileo™ monitor was considered to be a more appropriate comparison than the thermodilution method. Secondly, our study compared the entire duration of surgery from induction of anaesthesia to the patient waking up, but it would be more beneficial to evaluate the applicability of ICG monitoring during surgery, if cardiac output values were categorized into each event during the surgical procedure. Further research also needs to be conducted in patients undergoing difference types of surgery.

Impedance cardiography is progressing even to the present day. Suttner et al.[5] explained that the low accuracy of ICG used after cardiopulmonary bypass in haemodynamically unstable patients was due to increased conductivity, as the thoracic fluid content increased after surgery. This issue has been overcome by re-establishing the calculation algorithm and the development of computer technology.[7] The *niccomo*™ monitor used in this current study calculated the SV using the modified formula of Sramek and Bernstein.[17] Recently, the accuracy of ICG devices that use the modified Sramek and Bernstein formula for calculating the SV are being reported,[18–20] therefore further research on using this method for monitoring during surgery is considered necessary.

Although ICG does not show central venous pressure or pulmonary arterial pressure, it does show continuous cardiac output in real time, so circulatory failure can be identified quickly. Furthermore, it is easier to use, economical, less invasive and has an improved safety profile, compared with any other monitoring method that is available.[21] Hence, there are attempts to apply ICG in various areas such as postural stress tests, cardiac rehabilitation, pacemaker optimization and pregnancy monitoring.[22] Even in surgery, although ICG cannot perfectly replace the invasive cardiac output monitor used in current abdominal operations, it could be helpful for patients who are unable to have invasive monitoring.

Declaration of conflicting interest

The authors declare that there are no conflicts of interest.

Funding

This work was supported by a 2012 research grant from Inje University, Goyang, Republic of Korea.

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