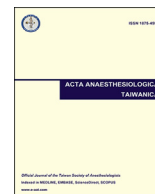




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Research paper

Evaluation of cardiac output by bioreactance technique in patients undergoing liver transplantation



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ABSTRACT

Background: This study compared the cardiac output (CO) obtained from PiCCO with that obtained from the noninvasive NICOM method.**Methods:** Twenty-one cirrhotic patients receiving liver transplantation were enrolled. During the operation, their CO was measured by the PiCCO system via the thermodilution method as the standard and by the NICOM method. Two parameters including cardiac index (CI) and stroke volume index (SVI) were collected simultaneously at three phases during the surgery including the dissection phase (T1), the anhepatic phase (T2), and the reperfusion phase (T3). Correlation, Bland and Altman methods, and linear mixed model were used to evaluate the monitoring ability of both systems.**Results:** Poor correlation was noted between the data measured by NICOM and PiCCO; the correlation coefficients for CI and SVI measured between the two systems were 0.32 and 0.39, respectively. Bland and Altman analysis showed the percentage error of CI as 63.7%, and that of SVI as 66.6% for NICOM compared to PiCCO. Using the linear mixed model, the CI and SVI measured using NICOM were significantly higher than those using PiCCO (estimated regression coefficient 0.92 and 10.77, both $p < 0.001$). Mixed model analysis showed no differences between the trends of CI and SVI measured by the two methods.**Conclusions:** NICOM provided a comparable CI and SVI trend when compared to the gold standard PiCCO, but it raises concerns as an effective CO monitor because of its tendency to overestimate CI and SVI especially during the state of high cardiac output.Copyright © 2016, Taiwan Society of Anesthesiologists. Published by Elsevier Taiwan LLC. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Background

A subset of patients with cirrhosis develops ascites, volume overload, and signs of hyperdynamic circulation including high cardiac output (CO) and low systemic vascular resistance.¹ Intraoperatively, this altered hemodynamics is also further complicated by the relative hypovolemia due to peripheral autonomic neuropathy, surgical manipulation of the major vessels, hemorrhage, and reperfusion.² These patients therefore present a significant management challenge for anesthesiologists during liver transplantation. Thus, accurate cardiovascular monitoring to guide the delicate fluid management and optimize hemodynamic stability during liver transplantation is critical to maintain adequate systemic and graft perfusion.

There are at the present several forms of CO monitoring available, and they can be divided into invasive techniques and

noninvasive techniques.³ The gold standard in CO measurement is the invasive thermodilution technique through the pulmonary artery catheter (PAC). However, the clinical necessity of PACs has been challenged because of its invasiveness and the possibilities of serious complications.^{4,5} Therefore, less invasive techniques such as the PiCCO System (Pulsion Medical Systems AG, Munich, Germany) have emerged commercially in lieu of the more invasive monitor. Many studies had shown that the PiCCO system, which uses transpulmonary thermodilution for the calibration procedure, has a high accuracy and is comparable to that of PAC.^{6–10} This less invasive PiCCO system is currently used routinely on patients undergoing liver transplantation in the National Taiwan University Hospital.

The NICOM system (Cheetah Medical Inc., Portland, OR, USA) uses four electrodes placed over the chest wall, which provide a measure of bioreactance, the analysis of frequency shifting. Compared with the traditional bioimpedance method, NICOM yields a 100-fold greater signal/noise ratio. Recent studies have shown that NICOM also provides a continuous and completely

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noninvasive measurement of CO for patients receiving outpatient hemodialysis therapy.^{11,12} However, the accuracy of NICOM in the surgical setting is not well established.

The aim of this study is to determine the accuracy of CO measurements obtained from the noninvasive NICOM system and to compare the data with the current standard PiCCO monitoring system during liver transplantation surgery.

2. Methods

2.1. Patients and anesthesia

This study was approved by the institutional review board of National Taiwan University Hospital (trial registration: NCT01922557), and written informed consent was obtained from all patients. Cirrhotic patients scheduled for liver transplantation were enrolled from December 2010 to June 2012. Patients with history of aortic regurgitation were excluded. All patients received general anesthesia with endotracheal tube intubation. The anesthesia was induced with intravenous etomidate (18–20 mg) and fentanyl 2–4 ($\mu\text{g}/\text{kg}$). Muscle relaxation was provided by a bolus cisatracurium, followed by 3 $\mu\text{g}/\text{kg}/\text{min}$ infusion. Inhaled desflurane was used as the intraoperative maintenance anesthesia. Tidal volume of the ventilator was set at 8–10 mL/kg using volume control mode with 40–60% of low flow oxygen. End tidal CO_2 was maintained at 35–45 mmHg. Intraoperative analgesia was given with fentanyl boluses, which was titrated according to the patients' reaction.

Aside from noninvasive monitors as suggested by the American Society of Anesthesiologists, patients also received invasive radial or brachial artery pressure and central venous pressure measured via the internal jugular vein as standard invasive monitors. All patients had a standard adult PiCCO catheter inserted through the right femoral artery with one end of the catheter connected to the PiCCO System. The CO data measured by PiCCO were acquired via the thermodilution method. The alternative device to measure CO was NICOM. All patients were attached to the NICOM electrodes after the induction of anesthesia. The anesthetic management was guided by routine monitors, and the CO value was measured by PiCCO. The measured CO values and stroke volume values were indexed by each patient's estimated body surface area.

2.2. Data collection

Two primary parameters including cardiac index (CI) and stroke volume index (SVI) were collected simultaneously at three time points including dissection phase (T1), anhepatic phase (T2), and reperfusion phase (T3) with at least two measurements made in each phase. Each of these phases was defined as follows: T1 as 30 minutes after skin incision, T2 as 5 minutes after the recipient's liver being removed, and T3 as 30 minutes after reperfusion. CI and SVI were recorded simultaneously from both PiCCO and NICOM systems, with the results abbreviated as PCI (CI of PiCCO), NCI (CI of NICOM), PSVI (SVI of PiCCO), and NSVI (SVI of NICOM). PCI was measured using the transpulmonary thermodilution technique, after injecting 15–20 mL boluses of cold normal saline via a central venous catheter. If the variation among the two readings is more than 10%, one additional measurement was taken for an average reading.

2.3. Statistical analysis

Sample size was calculated with <http://biostat.mc.vanderbilt.edu/twiki/bin/view/Main/PowerSampleSize>, where $\alpha = 0.05$ was set. A power of 80% results in a sample size of 51 pairs of dataset. With three phases of measurement for each patient, a minimum of

17 patients was determined to be necessary. Demographic data were expressed as mean values and standard deviation (SD) for continuous variable or percentage for categorical variable. Pearson's correlation and linear regression of CI and SVI measured by different techniques were assessed. The mean, bias (mean difference), limits of agreement (bias \pm 2SD), and percentage error were all calculated for both CI and SVI. Percentage error was calculated as the ratio of 2SD of the bias to mean CI or SVI of the study. From these results, the degree of agreement was analyzed using Bland–Altman analysis, where the differences between two different values of NICOM and PiCCO are plotted against the average values of these two measurements. The same analysis was repeated for both CI and SVI.

Paired *t* test was used to examine the differences in CI and SVI by PiCCO and NICOM. The trend analysis of PCI and NCI and PSVI and NSVI were performed by linear mixed model for the group \times time interaction effect, the time effect, and the group effect. As time points were not equidistant, time was considered a categorical variable. A *p* value <0.05 was considered to be statistically significant. All statistical analyses were performed with SAS version 9.2 (SAS Institute Inc., Cary, NC, USA).

3. Results

Twenty-one patients were enrolled in the study (9 female and 12 male). The demographic characteristics are summarized in Table 1. The indications for liver transplantation were hepatocellular carcinoma related liver cirrhosis (8), hepatitis B or C related liver cirrhosis (8), hepatitis B exacerbation (2), primary biliary cirrhosis (1), biliary atresia status after Kasai operation (1), and alcoholic related liver cirrhosis (1).

A total of 130 paired observations were collected. Data for CI and SVI were both measured by NICOM system (NCI and NSVI) and PiCCO system (PCI and PSVI). The overall mean (SD) of PCI and NCI was 4.0 L/min/m² (1.0 L/min/m²) and 5.2 L/min/m² (1.6 L/min/m²), respectively (*p* < 0.0001). The overall mean of PSVI was 44.9 mL/m² (12.1 mL/m²) and the overall mean of NSVI was 58.5 mL/m² (18.8 mL/m²) (*p* < 0.0001). The scattered plots and regression line of CI and SVI (Figure 1) showed poor correlation between the data measured by NICOM and PiCCO systems. The correlation coefficients for CI (Figure 1A) and SVI (Figure 1B) were 0.32 and 0.39 (*p* = 0.0004 and *p* < 0.0001), respectively. The slope of the regression line was less than 1, with most of the dots being distributed over the left lower side of Figure 1.

The result of Bland–Altman analysis is shown in Figure 2. Figure 2A illustrates the CIs measured by NICOM and PiCCO. The mean difference (bias) of CI (NCI – PCI) was 1.22 L/min/m² with 95%

Table 1
Summary of the clinical and laboratory features of the study cohort.

Variables	Value (mean \pm SD) (<i>n</i> = 21)
Age (y)	53.8 \pm 11.1
INR	1.3 \pm 0.3
Total bilirubin (mg/dL)	7.1 \pm 9.9
Blood creatinine (mg/dL)	1.2 \pm 0.9
Albumin (g/dL)	3.4 \pm 0.6
Body mass index (kg/m ²)	24.1 \pm 3.3
Sex, <i>n</i> (%)	
Male	12 (57.1)
Female	9 (42.9)
Child Classification, <i>n</i> (%)	
A	6 (28.6)
B	8 (38.1)
C	7 (33.3)

Values presented as mean \pm standard deviation (SD) or *n* (%).
INR = International Normalized Ratio.

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