

Comparison of the central venous pressure from internal jugular vein and the pressure measured from the peripherally inserted antecubital central catheter (PICCP) in liver transplantation recipients

Jung-Yeon Yun¹, So-Hee Park², Dae-Soon Cho¹, Hae-Jeung Jeung¹, Soon-Ae Lee¹, and So Jin Seo³

Departments of ¹Anesthesiology and Pain Medicine, ²Cancer Registration and Biostatistics Branch, Research Institute and Hospital, National Cancer Center, Goyang, ³Department of Anesthesiology and Pain Medicine, Seoul National University Hospital, Seoul, Korea

Background: Unlike its use during stable conditions, central venous pressure (CVP) monitoring from a peripherally inserted central venous catheter (PICC) has not often been used in surgeries with significant hemodynamic alterations. The aim of this study was to evaluate the feasibility of measuring PICC pressure (PICCP) as an alternative to measuring centrally inserted central catheter pressure (CICCP) in adult liver transplantation (LT) patients.

Methods: We measured PICCP and CICCP simultaneously during each main surgical period in adult LT. Statistical analysis was performed using simple linear regression analysis to observe whether changes in PICCP paralleled by simultaneous changes in CICCP. Correlation analysis and Bland-Altman analysis were used to determine the degree of agreement between the two devices. Differences were considered statistically significant when P values were less than 0.05.

Results: A total of 1342 data pairs were collected from 35 patients. The PICCPs and CICCPs were highly correlated overall ($r = 0.970$, $P < 0.001$) as well as at each period measured. The differences among each period were not clinically significant (0.33 mmHg for pre-anhepatic, 0.32 mmHg for anhepatic, -0.15 mmHg for reperfusion, and -0.10 mmHg for neohepatic periods). The overall mean difference was 0.14 mmHg (95% confidence interval: 0.09–0.19) and PICCP tended to give a higher reading by between 0.09 and 0.19 mmHg overall. The limit of agreement was -1.74 to 2.02 overall.

Conclusions: These findings suggest that PICCP can be a reasonable alternative to CICCP in situations of dynamic systemic compliance and preload, as well as under stable hemodynamic conditions. (Korean J Anesthesiol 2011; 61: 281-287)

Key Words: CVP, Liver transplantation, Peripherally inserted central catheter pressure.

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Corresponding author: Jung-Yeon Yun, M.D., Department of Anesthesiology and Pain Medicine, Research Institute and Hospital, National Cancer Center, 323, Ilsan-ro, Ilsandong-gu, Goyang 410-769, Korea. Tel: 82-31-920-1466, Fax: 82-31-920-1463, E-mail: yaepun@korea.com

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Introduction

Trends in central venous pressure (CVP) may be a reasonable surrogate for changes in central volume [1] and valuable information is obtained by examining the waveforms of the CVP tracing [2]. However, the cannulation for a central venous catheter (CVC) can place patients at risk, with fatal complications such as arrhythmia [3], pneumothorax [4], inadvertent arterial puncture [5], hemothorax [6] or cardiac tamponade [7,8].

Because the peripherally inserted central venous catheter (PICC) can be placed without the acute risks associated with direct catheterization of a CVC into the central vessels, it is an attractive alternative to the conventional CVC, or a centrally inserted central catheter (CICC) [9] thus avoiding possible complications associated with direct central vein catheterization.

Although the tip of the PICC is located in the central vascular structure, the monitoring of PICC pressure (PICCP) has not often been used for CVP measurement, owing to the perception that PICCP might be significantly different than CVP measured from a CICC due to its longer length and the resulting higher resistance. Based on laboratory studies with the PICC connected to a constant infusion device [10], PICCP is expected to be higher than CICC by 3 to 4 mmHg. But, when it was measured in 12 patients in the intensive care unit [10], PICCP was only about 1 mmHg higher than CICC with a pressure infusion device to overcome the natural resistance of the PICC. However, this study was performed in non-surgical patients. There has been only one study which compared CICC with PICCP in patients undergoing surgeries with large hemodynamic alterations [11]. To reliably use PICCP as an alternative to CICC during surgeries, it is necessary to study the relationship of PICCP and CICC in operations with hemodynamic instability.

Liver transplantation (LT) patients undergo extreme hemodynamic fluctuations due to manipulation of the major vascular structures, resulting in large swings in blood volume, systemic vascular resistance and cardiac output [12]. Therefore, we hypothesized that if PICCP can reliably reflect CICC during each main surgical period of LT (i.e. the preanhepatic, anhepatic, reperfusion and neohepatic periods), PICC can be readily used instead of CICC for CICC measurements during hemodynamically variable surgeries like LT.

The objective of this study was to determine the degree of agreement between PICCP and CICC, and whether there are changes in CVP profiles with regard to the different time periods during LT.

Materials and Methods

The study subjects were adults that had been scheduled for elective liver transplant surgery in our hospital. Informed consent was obtained from all patients in advance and the protocol of the present study was approved by the Institutional Review Board at our institution.

Patients did not receive premedication. General anesthesia was induced with thiopental (5 mg/kg) and fentanyl (1.5 µg/kg). Vecuronium (0.1 mg/kg) was given to facilitate orotracheal intubation with a cuffed tube. Anesthesia was maintained with 1.5–3.0% sevoflurane or 1–2% isoflurane in 50% oxygen-medical air balance, with positive pressure ventilation. Advanced venous access High Flow (AVA-HF, 9-French, 10-cm-long poly-urethane catheter, Edwards Lifesciences, Irvine, CA, USA) and pulmonary artery catheter (PAC, 7-French, 110-cm-long Swan-Ganz poly-urethane catheter, Edward Lifesciences, Irvine, CA, USA) were inserted. A double-lumen, open-ended PICC (16-gauge, 55-cm-long poly-urethane catheter, Arrow International, Reading, PA, USA) was placed through the largest vein around the antecubital area.

After all cannulations and insertions, anterior-posterior chest radiography was checked to confirm the appropriate locations of all catheters. The CVP port of PAC and the PICC tip was confirmed to be located in the lower SVC or slightly into the right atrium. The patient was in the supine position with the arms in 90° abduction on an arm board during the PICC insertion and throughout the operation.

CICC and PICCP measurements were taken from the CICC and PICC simultaneously every 10 minutes. In the reperfusion phase, each pressure was measured every minute due to the rapid hemodynamic changes that can occur during this period. At least 6 pairs of data were collected at each main surgical period (i.e. preanhepatic, anhepatic, reperfusion and neohepatic periods). Measurements were recorded at the end of expiration during positive pressure ventilation. Transducers, which use a continuous infusion device with non-heparinized saline at 2 ml/hr, were leveled to the height of the right atrium at the patient's midaxillary line and zeroed to atmospheric pressure. A 16-gauge pressure tubing (Baxter Healthcare, Deerfield, IL, USA) was connected to the CICC, the PICC, and the pressure transducer with a three-way stopcock. The three-way stopcock was turned to place the PICC or CICC in line with the transducer for each measurement. Measurements were taken in rapid succession, with each measurement was taken after the catheter was briefly flushed each time with saline and after the waveform had equilibrated. All pressure measurements were recorded as the digital mean using the Hewlett Packard M1097A monitor (Phillips Medical Systems, Boeblingen, Germany).

This study was designed to have at least 30 patients based on a sample size calculation to detect the mean difference of 1 mmHg and standard deviation of 1.6 mmHg (equivalent to having an effect size of 0.625) at the 5% significance level and with 90% statistical power. Data are presented as means ± standard deviation. Statistical analysis was performed using a simple linear regression model in all patients and for each period of surgery to determine whether changes in PICCP paralleled changes in CICC. To determine the degree of agreement between the two devices, the difference between the PICCP and the CICC measurements was plotted against the averages of the two devices (Bland-Altman analysis) [13]. Bias was calculated as the mean of the difference between the simultaneous PICCP and CICC measurements. The limits of agreement of the bias were defined as the bias ± (1.96 × standard deviation). To assess the precision of the estimated limit of agreement, 95% confidence intervals for the bias were calculated.

A clinical limit of agreement was defined as ± 2 mmHg

Table 1. Demographic and Clinical Characteristics of Patients

Variable	Mean ± SD or frequency (%)	Range
Age (yr)	53.7 ± 6.7	36–66
Gender		
Male	26 (74%)	
Female	9 (26%)	
Height (cm)	165.0 ± 7.9	150–180
Weight (kg)	66.3 ± 11.0	40–93
Operation time (min)	405.8 ± 77.5	295–595
Anesthesia time (min)	493.0 ± 77.7	350–685
Location		
Right	27 (77%)	
Left	8 (23%)	
Crystalloids (ml)	4,557.4 ± 1,696.5	2,400–9,900
Colloids (ml)	1,291.2 ± 641.4	100–2,300
Whole blood, autologous (ml)	574.6 ± 300.3	0–1,184
Packed red blood cell (unit)	3.3 ± 2.1	0–9
Fresh frozen plasma (unit)	5.2 ± 2.7	0–10
Platelet concentrate (unit)	5.5 ± 3.0	0–12
Urine output (ml)	753.3 ± 588.7	150–2,670
Estimated blood loss (ml)	2,013.2 ± 1,328.4	500–6,000

for PICCP when compared with CICC. Repeated Measures Analysis of Variance (ANOVA) was performed to study whether there were significant differences between PICCP and CICC using a mixed effects model while accounting for the within-subject variation. Differences were regarded as being statistically significant when P values were less than 0.05. All statistical analyses were performed by SAS, version 9.1.3 (Cary, NC, USA) and graphical presentations were performed using Stata, version 11.0 (StataCorp, College Station, Texas, USA).

Results

Demographic and clinical characteristics of the study patients are presented in Table 1. A total of 1342 PICCP/CICC data pairs were collected from 35 patients and statistically analyzed. For each patient, paired PICCP/CICC measurements were taken at different time points (31–55 time points). Data on one patient (40 data pairs) were discarded before data analysis due to an inadequate positioning of the PICC tip in the right internal jugular vein.

Table 2 presents the means and standard deviations of PICCP and CICC at the main surgical periods, along with the estimated bias and 95% CI of bias. Overall, the measured PICCP was slightly higher than CICC by 0.14 mmHg, but these differences were not statistically different (mean ± standard deviation for CICC and PICCP were 7.98 ± 3.90 mmHg and 8.12 ± 3.93 mmHg, respectively, P = 0.1435) and bias was well within the limit of agreement. When examining each surgical period, PICCPs were significantly higher than CICPs during preanhepatic and anhepatic period, but similar during the reperfusion and neohepatic periods. These differences were well within the limit of agreement (Table 2).

Furthermore, Pearson’s correlation analysis revealed that PICCP and CICC were very highly correlated overall (r = 0.970, P < 0.001) (Fig. 1). Similarly, a significantly high correlation was observed for data pairs of PICCP and CICC in patients during each surgical period: preanhepatic (Pearson’s correlation coefficient, r = 0.963, P < 0.001), anhepatic (r = 0.959, P < 0.001),

Table 2. PICCP and CICC during Liver Transplant Surgery

Period of LT	PICCP (mmHg)	CICC (mmHg)	Bias (mmHg)	P value	95% CI of bias (mmHg)	Limit of agreement (mmHg)
Total (n=1342)	8.12 ± 3.93	7.98 ± 3.90	0.14 ± 0.96	0.1435	0.09 to 0.19	–1.74 to 2.02
Preanhepatic (n=403)	7.88 ± 4.03	7.55 ± 3.86	0.33 ± 1.08	0.0081	0.22 to 0.43	–1.80 to 2.45
Anhepatic (n=371)	6.71 ± 3.25	6.38 ± 3.22	0.32 ± 0.93	<0.0001	0.23 to 0.42	–1.50 to 2.14
Reperfusion (n=184)	9.80 ± 3.34	9.95 ± 3.44	–0.15 ± 0.82	0.1459	–0.27 to –0.03	–1.75 to 1.46
Neohepatic (n=384)	8.94 ± 4.18	9.03 ± 4.04	–0.10 ± 0.81	0.3168	–0.18 to –0.02	–1.69 to 1.50

Values are expressed as means ± SD or ranges. CICC: centrally inserted central catheter pressure, PICCP: peripherally inserted central catheter pressure, LT: liver transplantation, Bias: mean difference (PICCP-CICC), P value: obtained from a mixed effects model for repeated measures analysis by accounting for within-subject variability, 95% CI (confidence interval): bias ± 1.96 × standard error (SE), Limit of agreement: bias ± 1.96 × standard deviation (SD).

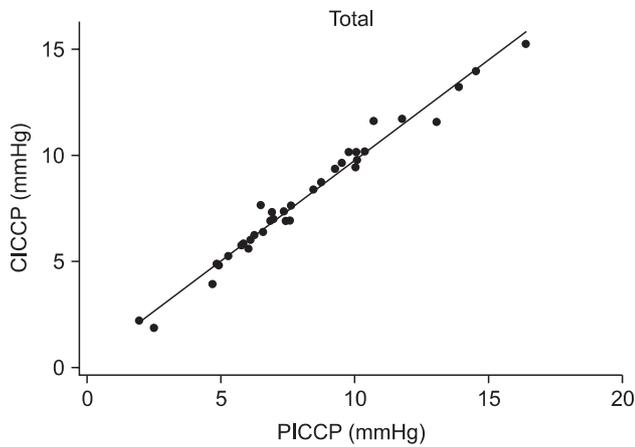


Fig. 1. Linear regression analysis plot of PICCP and CICCp for all data pairs with Pearson's correlation coefficient ($r = 0.970$, $P < 0.001$). CICCp: centrally inserted central catheter pressure, PICCP: peripherally inserted central catheter pressure.

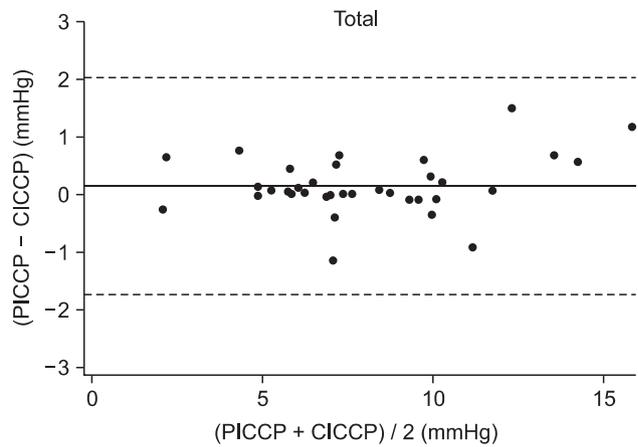


Fig. 2. Bland-Altman plot for all data pairs with calculation of bias and precision. The solid horizontal line represents the mean bias between the two devices. The two dashed horizontal lines represent the mean bias ± 1.96 times the standard deviation of the differences. CICCp: centrally inserted central catheter pressure, PICCP: peripherally inserted central catheter pressure.

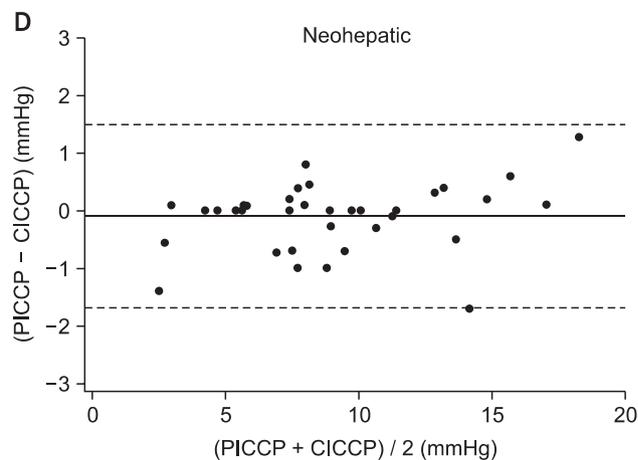
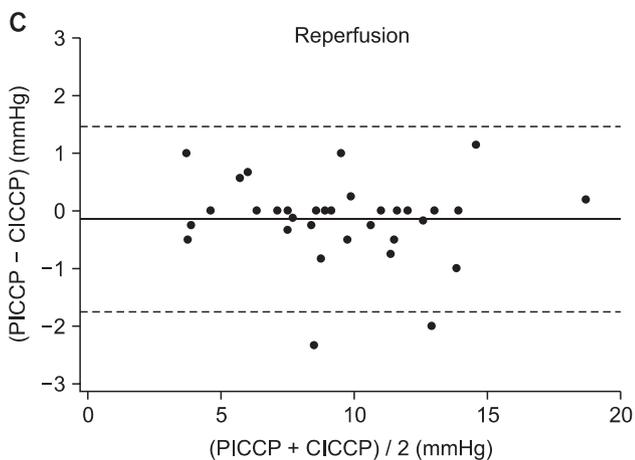
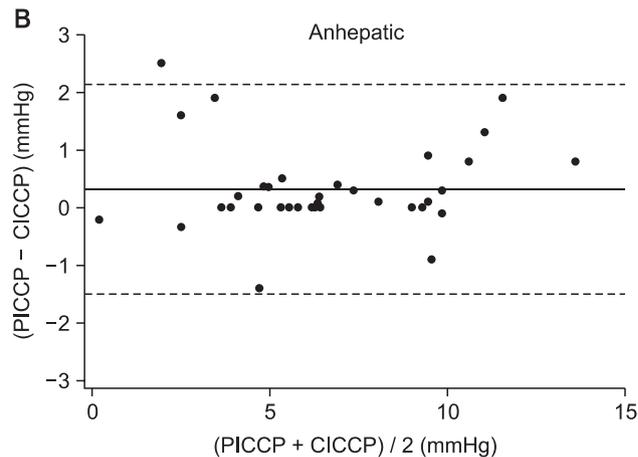
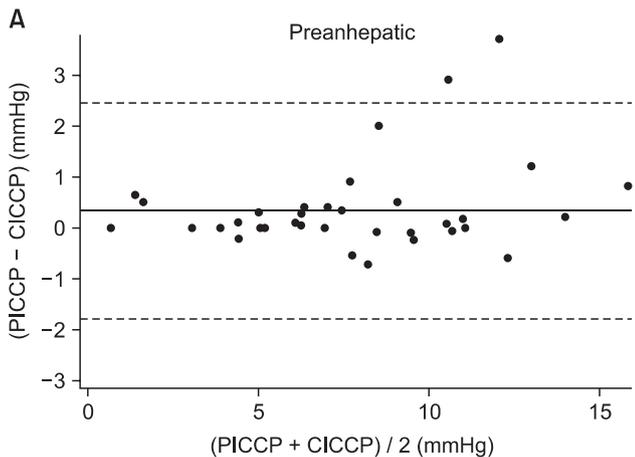


Fig. 3. Bland-Altman plot for each surgical period with calculation of bias and precision. (A) Bland-Altman plot for data points collected during preanhepatic period. (B) Bland-Altman plot for data points collected during anhepatic period. (C) Bland-Altman plot for data points collected during reperfusion period. (D) Bland-Altman plot for data points collected during neohepatic period. The solid horizontal line represents the mean bias between the two devices. The two dashed horizontal lines represent the mean bias ± 1.96 times the standard deviation of the differences. CICCp: centrally inserted central catheter pressure, PICCP: peripherally inserted central catheter pressure.

reperfusion ($r = 0.971$, $P = 0.016$) and neohepatic ($r = 0.981$, $P = 0.021$). Bland-Altman plots also demonstrated very good agreement between the two measurements (Fig. 2 and 3). A total of 96.2% of all measurements were clinically within the acceptable limits of bias (± 2 mmHg).

Discussion

In this study, PICCP changed in parallel with CICCIP with a strong correlation overall and the correlations also remained strong at each surgical period. The overall differences, or bias, between the two measurement devices in this study was 0.14 mmHg (95% CI of 0.09–0.19 mmHg), suggesting that the PICCP readings tended to be from 0.09 to 0.19 mmHg higher as determined by Bland-Altman analysis. At each surgical period, the bias remained within 0.33 mmHg at its maximum. Therefore, PICCP can readily represent CVP during hemodynamically variable situations like LT.

It is difficult to assess the relationship between PICCP and CICCIP because a PICC and a CICC are seldom inserted concomitantly in one patient. Therefore, there have been few studies in which simultaneous monitoring of PICCP and CICCIP was possible. In our hospital, because a PICC is concomitantly inserted with a CICC at anesthetic induction, both PICCP and CICCIP can be measured in one patient during the operation.

Based on a bench study by Black et al. [10] when a PICC is connected to a constant infusion device, PICCP was higher than CICCIP by 3 to 4 mmHg. However, when performed in patients in the intensive care unit, PICCP was greater than CICCIP by only 1 mmHg after 77 data pairs were analyzed [10]. The authors suggested that that warmer in vivo temperature might play a role in this discrepancy between the laboratory data and the clinical data. According to Poiseuille's law, which states P (pressure drop) = $8\eta lV/(\pi r^4t)$, where η is the viscosity coefficient, l is the length, V/t is the flow, and r is the radius [14], the expanded lumen and lowered viscosity by a higher in vivo temperature can possibly result in a lower pressure drop and small pressure differences. Unlike the previous study in non-surgical patients [10], our study was performed in the surgical patients with widely fluctuating hemodynamic variables due to the manipulation of relatively large vessels. However, our results showed an even smaller difference between CICCIP and PICCP than those in the aforementioned and this was probably due to the acquired stability from a larger number of data pairs.

Recently, some authors reported that the transduction of peripheral venous pressure might replace the measurement of CVP [15-17]. However, there are some limitations monitoring CVP from peripheral venous pressure. CVP can be measured from a peripheral intravenous catheter only when there is continuity with the central venous compartment, demonstrated

by an increase in the CVP from the peripheral intravenous catheter in response to a sustained inspiratory effort and by occlusion of the extremity above the site of the catheter [18]. Moreover, a peripheral venous pressure measurement does not accurately estimate the absolute value of CVP in critically ill patients [19].

During LT, hemodynamic instability is characteristic due to cross-clamping of the inferior vena cava, sudden massive bleeding and reperfusion of the donor graft during the procedure [12]. One of the major objectives of our study was to observe the influence of the acute hemodynamic changes on the PICCP-CICCIP differences. Overall, a dramatic change in systemic hemodynamic conditions during LT was not associated with significant differences in PICCP and CICCIP in our study. Based on the statistical analysis using the repeated measures ANOVA comparing the bias of the four surgical periods, bias during the neohepatic period (-0.10 mmHg) was not statistically different from the reperfusion period (-0.15 mmHg), but different from those of the preanhepatic (0.33 mmHg) and anhepatic (0.32 mmHg) periods. However, all differences were at most 0.33 mmHg which is likely to be clinically negligible. PICCP-CICCIP differences were statistically significant during the preanhepatic and anhepatic periods by 0.33 mmHg and 0.32 mmHg, respectively and PICCP showed strong correlations with CICCIP during these two periods ($r = 0.963$ and 0.959 , respectively). These findings suggest that during the preanhepatic and anhepatic periods, PICCP was parallel with CICCIP and was consistently higher than the CICCIP by about 0.3 mmHg. During the reperfusion and neohepatic periods, differences between the PICCP and the CICCIP were not statistically and clinically significant (-0.15 mmHg and -0.10 mmHg, respectively) while the correlations remained strong ($r = 0.971$, 0.981 respectively). There is practically no difference between PICCP and CICCIP during the reperfusion and neohepatic periods.

The expected relationship in which the PICCP was a few mmHg higher than CICCIP described in the previous study [10] was actually reversed, with the CICCIP marginally higher than PICCP in the reperfusion and neohepatic periods in our study. According to Poiseuille's law ($P = 8\eta lV/(\pi r^4t)$), the components of the resistance in the PICC are length, diameter of lumen, flow rate and viscosity. The viscosity becomes higher with higher hemoglobin levels and lower temperatures. In our study, CVP was measured from the CVP port on the PAC inserted through the AVA catheter. In the reperfusion period, a large amount of blood products are infused rapidly through the AVA catheter, increasing the viscosity and the flow rate resulting in higher pressure drops according to Poiseuille's law. Therefore, it is suggested that the CVP reading could become higher and consequently the PICCP-CICCIP differences can become

smaller during this period. This is the theoretical explanation with Poiseuille's law and is based on the assumption that the laminar flow exists across the length of a catheter in a closed system and the effects of surface tension are equal throughout the length of the catheter.

Characteristic CVP waveforms (a-, c-, and v-wave excursions) can be helpful in the diagnosis of arrhythmia, tricuspid valve disease, pericardial disease, and right ventricular dysfunction [16]. In one study which compared the waveforms of the CICC and PICCP [20] (although there was some phase delay in the PICC waveform), the peaks, troughs and means of the dynamic pressure waveforms of the 5 Fr and 6 Fr PICC were equal to those of the 7 Fr triple lumen conventional CICC control. Therefore, PICCP waveforms also can be helpful to analyze various cardiovascular conditions, similar to the CICC.

PICCs have been in use primarily to provide long-term venous access necessary for parenteral nutrition and chemotherapy [21]. PICC also can be used instead of the CICC for CVP measurement in the variety of situations where typical approaches with central catheters are not feasible. It would be also advantageous to use CVP information available in patients already with PICCs without performing additional invasive procedures. In consideration of our findings, PICCP would reflect CICC even more reliably if flow rate and viscosity are maintained stable by appropriate infusion methods and temperature management. Our study was performed in PICCs newly cannulated in the operating theatre and the measurement was done with relatively large bore catheters with the arm abducted at 90 degrees. Hands held in parallel to the body (like in maxillofacial/neck surgeries) might cause kinks at the clavicle area. Also, in children, the catheter is much smaller and therefore damping might ensue.

Although PICC can reduce the acute risk of pneumothorax and inadvertent arterial puncture, clinicians should consider the possibility of other complications such as catheter malposition, thrombosis, phlebitis and cardiac tamponade associated with the PICC [22,23]. Therefore, when positioning the PICC tip, it is vital to allow for movement of the catheter that will occur with arm abduction and to check chest radiography to confirm the location of the catheter tip [23].

In conclusion, our study confirmed that the PICCP and the CICC correlate well under conditions associated with LT surgery. A high level of agreement found in this study and the PICCP may therefore represent an attractive alternative to CICC monitoring in other patient populations with similar intraoperative hemodynamic derangements.

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