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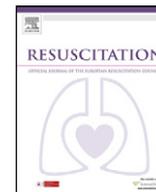
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## Clinical paper

Non-invasive central venous pressure measurement by compression ultrasound—A step into real life<sup>☆</sup>Christoph Thalhammer<sup>a,\*</sup>, Martin Siegemund<sup>b</sup>, Markus Aschwanden<sup>c</sup>, Mirjam Gassmann<sup>c</sup>, Ulrich A. Baumann<sup>d</sup>, Kurt A. Jaeger<sup>c</sup>, Stephan Imfeld<sup>c</sup><sup>a</sup> Department of Angiology, University Hospital, Zurich, Switzerland<sup>b</sup> Department of Anesthesia and Intensive Care, University Hospital, Basel, Switzerland<sup>c</sup> Department of Angiology, University Hospital, Basel, Switzerland<sup>d</sup> Regional Hospital Center RSZ, Muensingen, Switzerland

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## ABSTRACT

**Aim of the study:** Information on central venous pressure (CVP) is helpful in clinical situations like cardiac failure and sepsis. Compression ultrasound (CU) of a forearm vein has been shown to be a reliable method for CVP measurement when assessed by experienced personal under study conditions.

To test the hypothesis, that CU can be reliably used for CVP measurement after a training program and using a portable ultrasound system, we investigated feasibility and accuracy of CU, comparing the results of vascular experts vs. trainees as well as high-end vs. a portable ultrasound system.

**Methods:** CU with non-invasive CVP measurement (CVP<sub>ni</sub>) was performed by four investigators in 50 patients of an intensive care unit and compared with invasive CVP measurement (CVP<sub>i</sub>).

**Results:** Feasibility was between 88 and 92% in the different investigator groups. CVP<sub>ni</sub> measurement showed a significant linear correlation ( $r=0.58-0.68$ ;  $p<0.001$ ) with CVP<sub>i</sub> in all groups. Mean difference between CVP<sub>i</sub> and CVP<sub>ni</sub> was  $2.4 \pm 3.1$  mmHg and similar between the investigators. No differences were observed between measurements done by vascular experts and trainees, as well as between high-end and portable ultrasound systems. Further we demonstrated, that CU is able to detect changes in CVP during the respiratory cycle.

**Conclusions:** After a training program CU can be used by non-vascular clinician for reliable CVP measurement with good quality portable systems. Furthermore, respiratory changes in CVP are detectable by CU. These data suggest CU to be an efficient method for measuring CVP under real life conditions.

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## 1. Introduction

Measurement of central venous pressure (CVP) is often essential for monitoring hemodynamic changes in critically ill patients and during major surgery to estimate cardiac preload, but also in an emergency unit to facilitate and improve further patient management. Clinical estimation of CVP has proven unreliable compared to measurement using a catheter.<sup>1</sup> Current standard technique for CVP assessment is invasive, requiring insertion of a catheter into

a subclavian, internal jugular or peripheral vein, with potential complications.<sup>2,3</sup> Moreover, routine placement of a central venous catheter just for CVP measurement, especially in an outpatient setting, is impractical and not justifiable.

A quick and reliable tool to measure CVP without central venous access would be helpful in cases of hemodynamic emergencies. Several studies employing invasive and non-invasive techniques showed a good correlation between peripheral venous pressure and CVP under a variety of study conditions in the operating room and the intensive care unit.<sup>4-18</sup> Basis for these studies is the fact, that in supine position pressure values within the cephalic, basilic and brachial veins are nearly identical to those of the superior vena cava.<sup>4,5,19</sup> Measurements of the inferior vena cava (IVC) diameter using ultrasound is frequently used to assess volume status of critically ill patients,<sup>20,21</sup> primarily distinguishing hypo- from iso- and hypervolemic conditions. Recently promising results were published correlating IVC diameter with CVP in a highly selected population of stabilized intubated cardiac surgery patients using transesophageal ultrasound. The usability in a more

**Abbreviations:** CVP, central venous pressure; CVP<sub>i</sub>, central venous pressure, invasive assessment; CVP<sub>ni</sub>, central venous pressure, non-invasive assessment; CU, compression ultrasound; PVP, peripheral venous pressure.

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general context of non-intubated emergency setting needs to be awaited.

A novel method using compression ultrasound (CU) showed excellent results in defining CVP by measuring peripheral venous pressure at the forearm.<sup>20</sup> This study, however, was performed by experts in vascular medicine using a high-end ultrasound machine. These two preconditions may not be rapidly available in a hemodynamic unstable situation, in emergency units, as well as in primary and secondary care institutions, so we sought to investigate the influence of lower ultrasound quality and lesser vascular ultrasound experience on the results of non-invasive CVP measurements.

Therefore this study was designed for the following purposes:

- (1) to investigate the feasibility and accuracy of CVP measurements performed by physicians, as yet not familiar with vascular ultrasound examination, using CU after a short training phase and
- (2) to investigate the feasibility and accuracy of CVP measurements using a simple portable ultrasound system, compared to a high-end duplex ultrasound system of the newest generation, and
- (3) to investigate the potential of the method to detect and quantify respiratory changes in CVP.

## 2. Methods

### 2.1. Study design

The study was approved by the local ethics committee. Aware intensive care patients provided oral informed consent. Surrogates provided informed consent for intubated, sedated intensive care patients. In all patients, the central venous catheter was clinically indicated and the physician in charge (MS) attested for the safety of the investigation for the patient.

A pressure manometer (PPM0310, Dr. Baumann, Muensingen, Switzerland) was attached to the ultrasound transducer. The manometer, which is easily attachable to the probe, consists of a translucent silicon membrane (MVQ, Angst and Pfister AG, Zurich, Switzerland) connected to a commercially available pressure meter (Bourdon Haenni AG, Jegenstorf, Switzerland) with a flexible pressure tubing. The system is described in detail elsewhere.<sup>20</sup> A superficial vein at the forearm (preferentially the distal cephalic vein), clearly visible on ultrasound through the translucent manometer membrane was selected. The vein had to be easily compressible, without postphlebotic changes locally and no overt clinical signs of proximal venous obstruction had to be present. More proximal veins are less suitable for this technique as superficial veins with underlying supporting bones are required to minimize falsely elevated values. After applying ultrasound transmission gel the transducer with the pressure meter was placed on the skin with minimal pressure. Following zero adjustment slowly increasing pressure was applied by the transducer until first complete compression of the vein. The pressure at this collapse point indicated the intravascular venous pressure.

A standardized training program for teaching a medical student (MG) and an intensive care specialist (MS) consisted of three 1-h sessions. After explaining the system in detail, volunteers were placed in a comfortable supine position and 30 measurements were done at randomly selected levels of peripheral venous pressure induced by inflating a sphygmomanometer at the upper arm. These values were compared to the ones obtained by the experts (MA, CT) with more than 10 years experience in vascular ultrasound and compression technique was adjusted until adequate results were achieved. The results of the training program were not further analyzed.

Patients of the surgical intensive care unit were consecutively included. Investigators were blinded for CVP, clinical diagnosis,

therapy and volume status of the patients, except MS, who was just blinded for current CVP values. Invasive CVP (CVP<sub>i</sub>) was measured electronically by a custom monitoring kit (Hospira Inc., Lake Forest, IL, USA) including a Transpac IT transducer via a 18G central venous catheter. The measurements were displayed as mean values over time [mmHg] by a Ultraview SL command module (91496-C, Spacelabs Healthcare, Issaquah, WA, US).

To test the three hypotheses, the study was divided in two parts. The *TeachPort Study* tested feasibility and accuracy of CVP measurement after the training phases (*Teach*) using a portable ultrasound system (*Port*) in unselected critically ill patients within a defined examination time. The *influence of respiratory cycle on CVP measurement* was tested in an additional group of intubated patients with continuous registration of ventilation parameters. In contrast to the *TeachPort Study*, which tested the method within time, in this series the examination time was not limited.

### 2.2. TeachPort study

Each patient was examined by all four investigators using two different ultrasound systems:

- Investigator 1: vascular expert with high-end ultrasound system (CT).
- Investigator 2: medical student with high-end ultrasound system (MG).
- Investigator 3: vascular expert with portable ultrasound system (MA).
- Investigator 4: intensive care specialist with portable ultrasound system (MS).

The high-end ultrasound system used was an iU22 duplex scanner (Philips, Best, Netherlands) with a 17.5 MHz linear array transducer. The portable ultrasound system was a SonoSite® TITAN (Bothell, Washington, USA) with a 10.5 MHz linear array transducer.

Non-invasive CVP (CVP<sub>ni</sub>) was measured on the contralateral side of subclavian catheters to avoid falsely elevated values caused by obstruction of the vein by the catheter. CVP<sub>ni</sub> was measured at the site of a clearly visible superficial vein at the forearm with the point of measurement usually below the level of the right atrium. The difference between the level of the ultrasound measurement and the position of the CVP<sub>i</sub> pressure transducer was documented and subtracted from the crude pressure value. Internal diameter of the vein was measured once with the high-end system. The time for complete examination was documented for each investigator. To determine feasibility, a time limit for the maximum investigation time was arbitrarily set at 8 min.

### 2.3. Influence of respiratory cycle on CVP measurement

Compressibility of the vein depends on the respiratory cycle, especially in ventilated patients. Thus the hypothesis, that the established ultrasound method is precise enough to measure the changes of CVP during mechanical ventilation was tested. The high-end ultrasound system with a 17.5 MHz transducer was used by one experienced investigator (MA). The lower CVP<sub>ni</sub> value was recorded as described above, the upper CVP<sub>ni</sub> value was recorded just when a persistent collapse of the vein through a whole respiratory cycle was monitored. CVP<sub>i</sub> was determined by measuring CVP online over two to three respiratory cycles and reading minimal and maximal pressure values.

### 2.4. Statistical analysis

Data analysis was performed using the software SPSS 12.0 for Windows (Apache Software Foundation, Forest Hill, USA). The

**Table 1**  
Patient characteristics—TeachPort study.

Parameter	Value
Male/female	34 (68%)/16 (32%)
Age (years)	66.9 ± 14.5
Clinical diagnosis	
Coronary surgery	13 (26%)
Sepsis	11 (22%)
Mitral valve replacement	5 (10%)
Abdominal surgery	5 (10%)
Abdominal aneurysm	4 (8%)
Multiple trauma	4 (8%)
Aortic valve replacement	3 (6%)
Others	5 (10%)
	50 (100%)
Ventilated patients	27 (54%)

Data are expressed as absolute values (%), age as mean ± SD.

**Table 3**  
Patient characteristics—respiratory changes.

Parameter	Value
Male/female	13/7
Age (years)	65.5 (19–83)
Clinical diagnosis	
Aortic valve replacement	5
Polytrauma	5
Coronary surgery	3
Mitral valve replacement	2
Sepsis	1
Abdominal surgery	1
Abdominal aneurysm	1
Others	2
Mechanically ventilated patients	20 (100%)
Mean blood pressure	74 mmHg (45–101)
Systolic blood pressure	111 mmHg (70–167)
Diasystolic blood pressure	59 mmHg (37–84)
Heart rate	79/min (48–128)
Positive end-expiratory pressure	6.8 mmHg (5–15)
Mean airway pressure	11.6 mmHg (7–21)
Peak airway pressure	22.9 mmHg (11–42)
Respiratory rate	15.4/min (9–32)
Tidal volume	611 ml (500–800)

Data are expressed as absolute values, age as median (range), and circulation and ventilation parameters as mean (range).

unit of CVP<sub>i</sub> was mmHg, that of CVP<sub>ni</sub> was mbar. Mbar was transformed into mmHg after complete collection of the data set (1 mbar = 0.75 mmHg). Descriptive data were expressed as mean ± standard deviation (SD) and range. Correlation between invasive and non-invasive pressure was analyzed using Spearman correlation coefficient. Bland–Altman plots were used to show the agreement between CVP<sub>i</sub> and CVP<sub>ni</sub>, plotting the difference against the mean.<sup>24</sup> Group comparisons were performed using Mann–Whitney *U* and Friedmann-tests.

### 3. Results

#### 3.1. TeachPort study

A total of 50 consecutive patients were included. Their characteristics are presented in Table 1. The mean internal diameter of the vein used for measurement was 2.4 ± 0.9 mm (1.1–4.9). Mean investigation time for the different investigators (1, 2, 3, 4) were 3.2 ± 1.4 (1.0–6.5), 4.2 ± 1.9 (1.0–7.5), 2.9 ± 1.6 (1.0–6.5) and 3.7 ± 1.9 (0.5–7.9) min and feasibility was 92, 90, 88 and 88%, respectively. Differences in duration and feasibility were statistically not significant.

The mean ultrasound calibration point was 6.6 cm below the CVP<sub>i</sub> pressure transducer (–3 to 15 cm). Mean CVP<sub>i</sub> of all measurements was 12.3 ± 4.8 mmHg (3–25) and mean CVP<sub>ni</sub> was 9.8 ± 4.5 mmHg (1–26). Table 2 compares CVP<sub>i</sub> vs. CVP<sub>ni</sub> values over all, as well as for single investigators, investigator groups and different ultrasound systems. CVP<sub>ni</sub> was on average 2.5 ± 4.0 mmHg (range: –9.5 to 13.8) lower than CVP<sub>i</sub>. The difference was statistically significant (*p* < 0.005) for all groups. However, no systematic differences between different investigators, ultrasound systems or expertise were found (*p* = 0.91, *p* = 0.79, *p* = 0.36, respectively, Table 2). Linear regression analysis revealed a significant cor-

relation between CVP<sub>i</sub> and CVP<sub>ni</sub> (*r* = 0.72; *p* < 0.001) for mean values of all examinations. The correlation remained significant for each investigator separately (Fig. 1), however, with lower correlation coefficients (*r* = 0.58–0.68; *p* < 0.001). Bland–Altman plots presented for the different investigators show the differences between CVP<sub>i</sub> and CVP<sub>ni</sub>, plotted against their mean (Fig. 2), revealing no tendency for a systematic bias.

#### 3.2. Respiratory changes in CVP

A total of 20 consecutive, ventilated patients were studied. Their characteristics and ventilation parameters are presented in Table 3. The mean internal diameter of the vein used for measurement was 2.0 ± 1.2 mm (range 0.5–4.5). The mean minimal CVP<sub>i</sub> was 12.2 ± 3.9 mmHg (5.3–21.3), the mean maximal CVP<sub>i</sub> was 17.7 ± 5.2 mmHg (12.0–29.3), resulting in a mean respiratory change of 5.5 mmHg. The mean minimal CVP<sub>ni</sub> was 13.8 ± 3.9 mmHg (8.5–22.0), the mean maximal CVP<sub>ni</sub> was 18.6 ± 4.0 mmHg (12.5–26.0), resulting in a mean respiratory change of 4.8 mmHg. Linear regression analysis revealed a significant positive correlation between minimal CVP<sub>i</sub> and CVP<sub>ni</sub> (*r* = 0.66; *p* < 0.01) and maximal CVP<sub>i</sub> and CVP<sub>ni</sub> (*r* = 0.71; *p* < 0.001; Fig. 3). CVP<sub>ni</sub> measurements overestimated CVP<sub>i</sub> with a mean difference of 1.6 mmHg for minimal values and 0.8 mmHg for maximal values.

**Table 2**  
Central venous pressure measurements.

Group	CVP <sub>i</sub>	CVP <sub>ni</sub>	Mean difference
All investigators	12.3 ± 4.8 (3–25)	9.8 ± 4.5 (1–26)	+2.5 ± 4.0 (–13.8 to 9.5)
Investigator 1	12.4 ± 4.8 (5–24)	9.3 ± 4.8 (1–26)	+3.1 ± 4.4 (–13.7 to 6.5)
Investigator 2	12.3 ± 5.0 (5–25)	9.9 ± 4.0 (2–22)	+2.4 ± 3.8 (–13.0 to 3.0)
Investigator 3	12.4 ± 4.8 (3–24)	10.0 ± 4.4 (2–26)	+2.4 ± 3.7 (–11.2 to 8.5)
Investigator 4	12.2 ± 4.8 (3–22)	9.9 ± 4.8 (2–24)	+2.2 ± 4.1 (–10.0 to 9.5)
High-end US	12.3 ± 4.8 (5–25)	9.6 ± 4.4 (1–22)	+2.8 ± 4.1 (–13.7 to 6.5)
Portable US	12.3 ± 4.8 (3–24)	10.0 ± 4.6 (2–26)	+2.3 ± 3.9 (–11.25 to 9.5)
Vascular experts	12.4 ± 4.8 (3–24)	9.6 ± 4.6 (1–26)	+2.8 ± 4.1 (–13.8 to 8.5)
Trainees	12.2 ± 4.8 (3–25)	9.9 ± 4.4 (2–24)	+2.3 ± 4.0 (–13.0 to 9.5)

Data are expressed as mean ± SD (range).

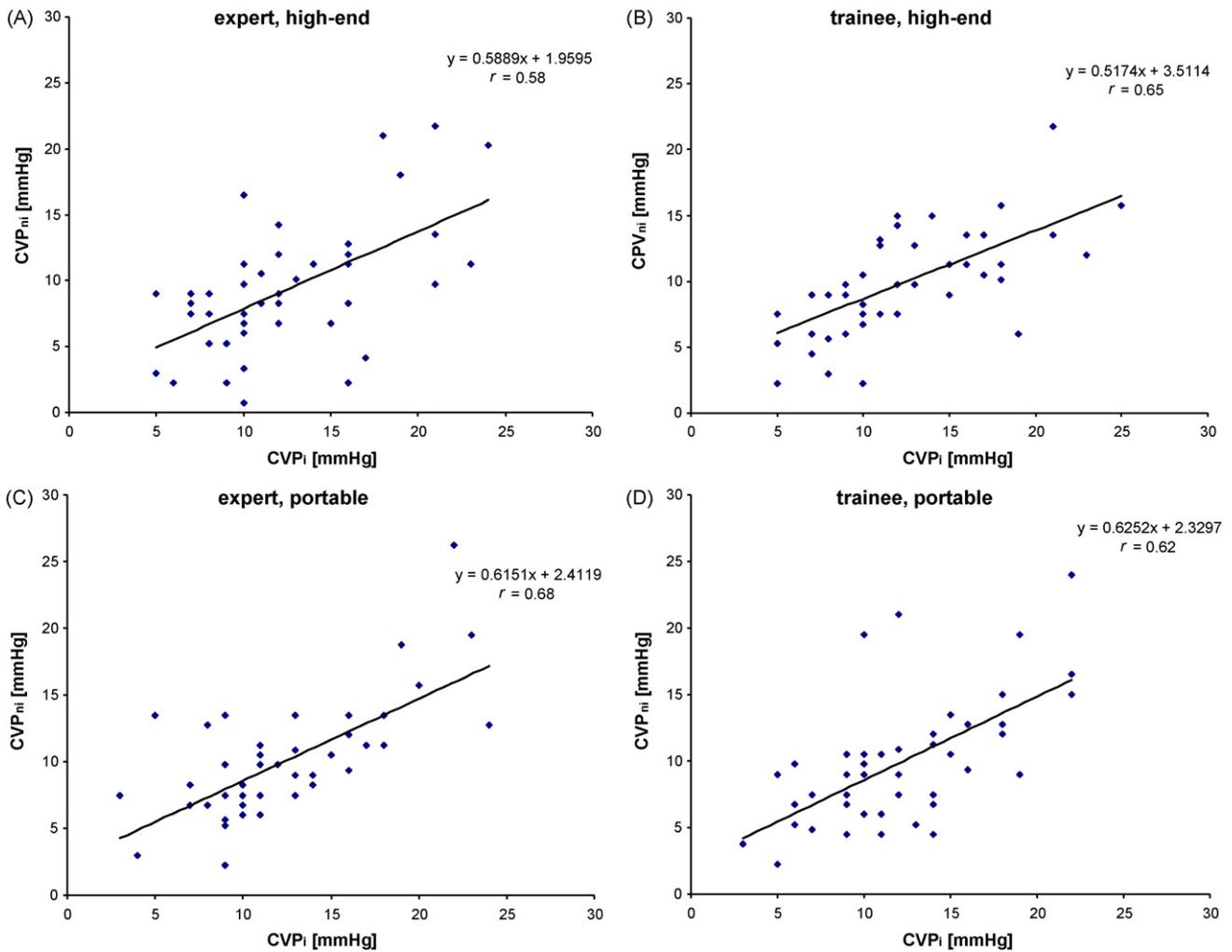


Fig. 1. CVP<sub>i</sub> and CVP<sub>ni</sub> in 50 intensive care patients. Linear regression: positive correlation between CVP<sub>i</sub> and CVP<sub>ni</sub> measured by four different investigators.

#### 4. Discussion

CVP is frequently used in clinical practice to follow patients hemodynamics for diagnostic and treatment purposes. Routine measurement of CVP requires a central venous line, associated with a relevant risk of complications.<sup>2,3</sup> A novel non-invasive method using peripheral compression ultrasound has been proved to measure CVP in a reliable and reproducible manner in a vascular experts setting and therefore bears the potential to be used as a first line measurement of CVP in emergency situations without requiring invasive techniques.<sup>23</sup> Volume status estimation can also be done by visualizing and measuring the inferior vena cava diameter using transthoracic ultrasound, though conflicting results have been published concerning the estimation of absolute CVP values. Arthur et al.<sup>20</sup> was able to show good correlations of transesophageal IVC diameter measurements with CVP in stabilized intubated cardiac surgery patients, whereas Lorsomradee et al.<sup>22</sup> was only able to show good correlations for CVP values below 11 mmHg and poor correlations when CVP was above 11 mmHg. Additionally non-invasive transthoracic ultrasound seems to provide less accurate results.<sup>21</sup>

In this study, feasibility and accuracy of non-invasive CVP measurement by unskilled investigators as well as using a simple portable ultrasound system were investigated. No differences in accuracy or feasibility with respect to both the quality of ultra-

sound system and the ultrasound experience of the investigators were observed, provided the use of an adequate, high transducer frequency and an initial training period. We therefore conclude, that this novel method may be suitable for a “real life” situation, and warrants further evaluation in a larger setting.

Many studies comparing peripheral venous pressure with CVP under different conditions (e.g. neurosurgery, liver transplantation, different provocation maneuvers), showed a good correlation between the two measurements. However, most of the studies reported a negative difference (CVP – PVP) of up to 4.4 mmHg, resulting in an overestimation of central venous pressure by using a peripheral line (Table 4). By contrast, in the present study we observed no overestimation, but a consistently slightly lower CVP value in all groups with a mean difference of 2.5 mmHg, a value not of clinical relevance, but for methodological consideration. More detailed analysis of the two systems revealed a theoretical explanation for this observation. Invasive pressure values recorded by the cardiovascular monitor are presented as a time-weighted average of venous pressure, as per manufactures software. The mean value of CVP over time does not reflect the amplitude of changes in central venous pressure during respiration. An underestimation with the presented CU method may therefore be explained by the measuring method where the pressure is determined at the time of first collapse of the vein. This value corresponds to the lower pressure of the respiratory pressure amplitude. From a theoretic-

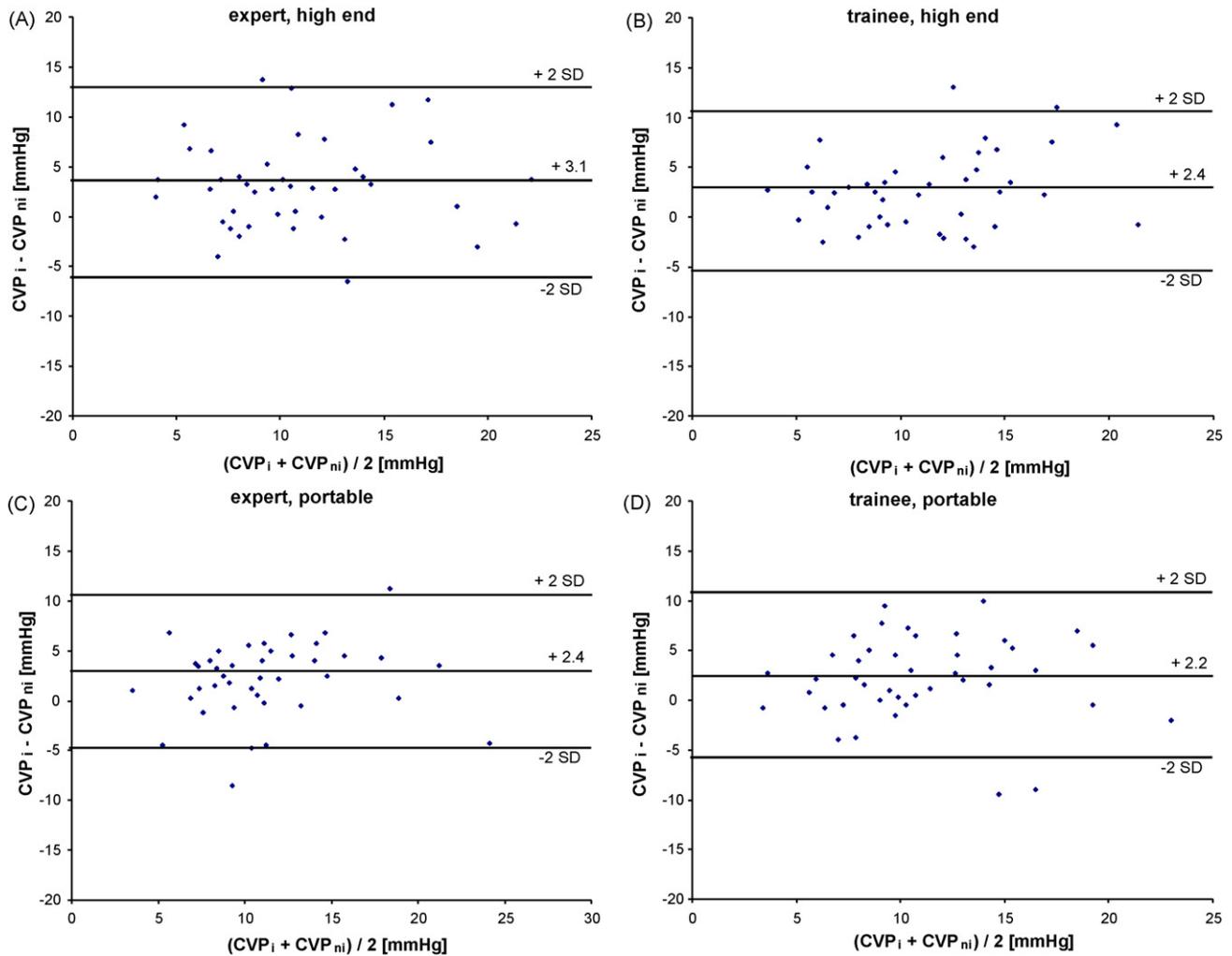


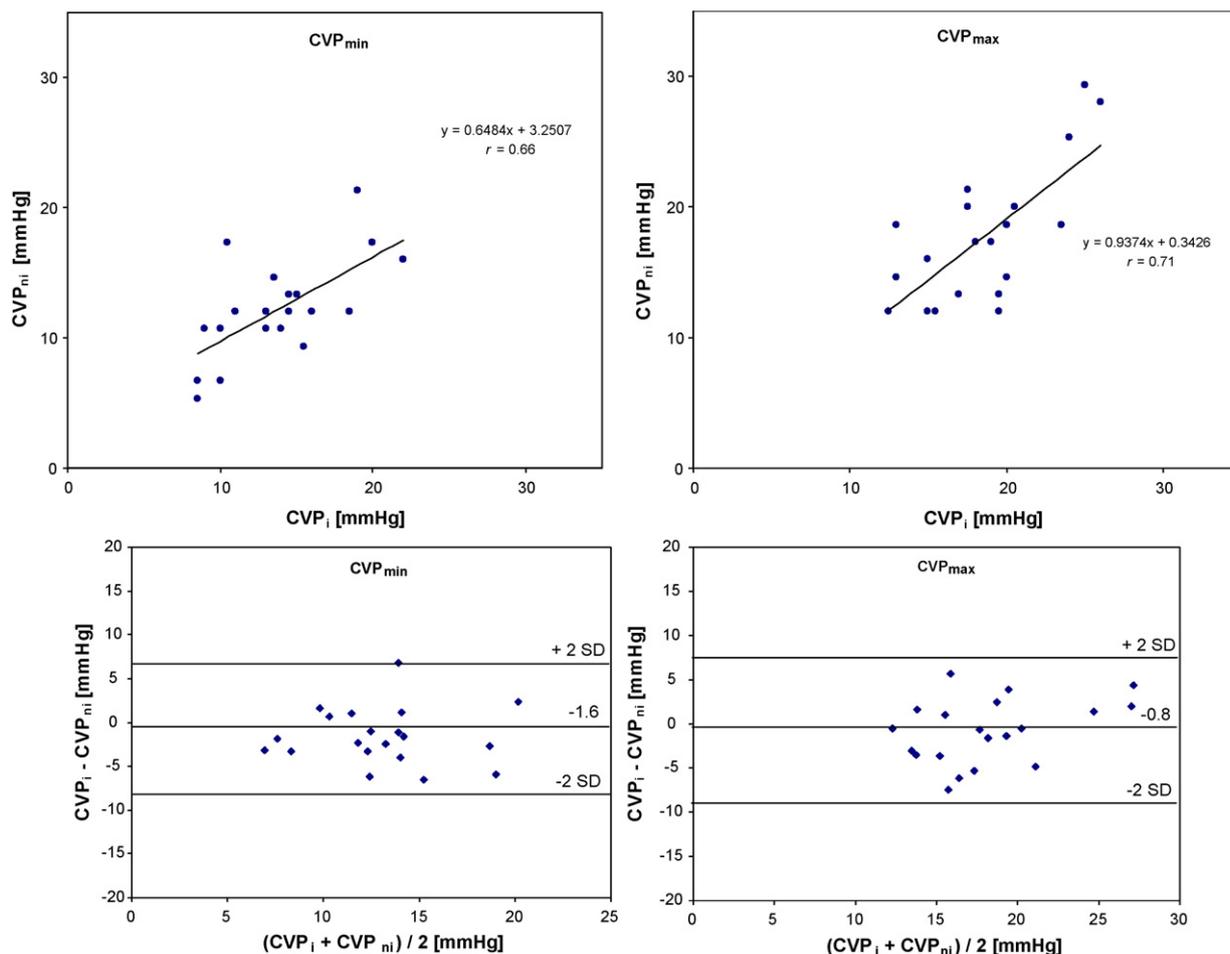
Fig. 2. CVP<sub>i</sub> and CVP<sub>ni</sub> in 50 intensive care patients. Bland–Altman plots: CVP<sub>i</sub> and CVP<sub>ni</sub> plotted against their mean measured by four different investigators.

**Table 4**  
Central vs. peripheral venous pressure—difference (CVP – PVP) in the literature.

Author	Year	Patients	CVP	PVP	Mean difference	Setting
Ricksten et al. <sup>19</sup>	1986	8	10.5 <sup>a</sup> 5.4 <sup>a</sup>	11.0 <sup>a</sup> 6.1 <sup>a</sup>	-0.45 <sup>a</sup> -0.68 <sup>a</sup>	Abdominal surgery: controlled respiration Abdominal surgery: spontaneous respiration
Munis et al. <sup>6</sup>	2001	15	10.0	13.0	-3.0	Neurosurgical unit
Amar et al. <sup>4</sup>	2001	150	8.0 5.0	9.0 7.0	-1.6 -2.2	Surgical, intraoperative Surgical, postoperative
Charalambous et al. <sup>9</sup>	2003	20	n.a.	n.a.	-4.4	Intensive care unit, different occasions
Tugrul et al. <sup>15</sup>	2004	500	11.0	13.0	-2.0	Different position, catheter sites and diameter
Desjardins et al. <sup>5</sup>	2004	19	10.2	10.9	-0.72 <sup>b</sup>	Various conditions (highest after nitroglycerine)
Anter and Bondok <sup>16</sup>	2004	50	n.a. n.a.	n.a. n.a.	-1.92 -2.45	Pediatric surgery, intraoperative Pediatric surgery, postoperative
Sahin et al. <sup>11</sup>	2005	15	n.a.	n.a.	+0.06	Neurosurgical, effect of body temperature
Sahin et al. <sup>10</sup>	2005	30	n.a.	n.a.	-0.07	General anesthesia, effect of catheter site
Hoftman et al. <sup>12</sup>	2006	9	9.5	11.0	-1.5	Liver transplantation, different surgical events
Hadimioglu et al. <sup>13</sup>	2006	30	11.0	13.5	-2.5	Kidney transplantation
Thalhammer et al. <sup>23</sup>	2007	50	12.4 <sup>a</sup>	12.5 <sup>a</sup>	-0.1 <sup>a</sup>	Medical intensive care unit
Choi et al. <sup>14</sup>	2007	50	5.9	7.0	-1.16	Living donor hepatectomy
Cave and Harvey <sup>18</sup>	2008	34	10.0 12.6	11.0 13.0	-1.0 -0.4	Postoperative intensive care unit After volume expansion
Biancofiore et al. <sup>17</sup>	2008	35	11.3	12.2	-0.9	Major hepatic resection
Current study	2009	50	12.3	9.8	+2.5	Operative intensive care unit

<sup>a</sup> [cmH<sub>2</sub>O].

<sup>b</sup> Maximal difference.



**Fig. 3.** Changes in  $CVP_i$  and  $CVP_{ni}$  during the respiratory cycle. Linear regression: positive correlation between minimal and maximal  $CVP_i$  and  $CVP_{ni}$  values in 20 ventilated patients. Bland–Altman plots: minimal and maximal  $CVP_i$  and  $CVP_{ni}$  plotted against their mean.

cal point of view the two methods, i.e. the “one moment” pressure vs. the mean pressure do not differ in a relevant manner as long as the pressure amplitude is low. With higher CVP amplitudes larger differences from an invasively measured mean value can be expected, as the  $CVP_{ni}$  represents the lowest pressure point during the respiratory cycle. In our substudy we were able to show that the CU method in fact is able to distinguish between higher and lower CVP resulting in a negligible difference. This may finally explain a relevant part of the difference as we examined more than 50% ventilated patients in the first 50 patients. It could therefore be necessary, that especially in patients with spontaneous deep respiration or mechanical ventilation a mean value of the lowest and highest  $CVP_{ni}$  value should be calculated in the same way as with the electronic pressure meter or the classical water column method.

Appraising the study by Rizvi et al. where the effect of airway pressure on interobserver reading agreement in the invasive assessment of CVP was tested, a astonishingly low agreement (limits of 2 mmHg) between 79 and 86%, even in experts was observed,<sup>25</sup> demonstrating some variability in the gold standard possibly caused by changing airway pressure. Considering these facts a certain difference when comparing two methods of measuring CVP should be put into perspective.

In our opinion the presented method is able to concur with invasive CVP measurement and could become a method of choice to rapidly acquire CVP values in acute situations as massive pulmonary embolism, pericardial tamponade or acute right heart insufficiency.

### 5. Conclusion

Our data show that  $CVP_{ni}$  can be adequately obtained within a short time (less than 4 min) and does neither depend on specialized personal nor on a high-end ultrasound systems.

A reliable non-invasive technique for measuring central venous pressure is presented. The technique is easily learnable in a short time and is reliably applicable with a small portable ultrasound system. Measuring central venous pressure without the use of intravenous catheterization in a reliable manner may be an attractive tool especially in selected emergency situations.

### Conflict of interest

There are no relationships with industry and no financial supports.

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