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Clinical paper

Non-invasive central venous pressure measurement by compression ultrasound—A step into real life☆

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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_{ni}) was performed by four investigators in 50 patients of an intensive care unit and compared with invasive CVP measurement (CVP_i).

Results: Feasibility was between 88 and 92% in the different investigator groups. CVP_{ni} measurement showed a significant linear correlation ($r = 0.58–0.68$; $p < 0.001$) with CVP_i in all groups. Mean difference between CVP_i and CVP_{ni} was 2.4 ± 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.

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.[1] Current standard technique for CVP assessment is invasive, requiring insertion of a catheter into a subclavian, internal jugular or peripheral vein, with potential complications.[2,3] 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.[4–18] 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.[4,5,19] Measurements of the inferior vena cava (IVC) diameter using ultrasound is frequently used to assess volume status of critically ill patients,[20,21] 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_i, central venous pressure, invasive assessment; CVP_{ni}, 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.[20] 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.[20] 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 postphlebitic 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 intravasal 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_i) 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_{ni}) was measured on the contralateral side of subclavian catheters to avoid falsely elevated values caused by obstruction of the vein by the catheter. CVP_{ni} 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_i 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_{ni} value was recorded as described above, the upper CVP_{ni} value was recorded just when a persistent collapse of the vein through a whole respiratory cycle was monitored. CVP_i 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