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Peripheral i.v. analysis (PIVA) of venous waveforms for volume assessment in patients undergoing haemodialysis

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Abstract

Background: The assessment of intravascular volume status remains a challenge for clinicians. Peripheral i.v. analysis (PIVA) is a method for analysing the peripheral venous waveform that has been used to monitor volume status. We present a proof-of-concept study for evaluating the efficacy of PIVA in detecting changes in fluid volume.
Methods: We enrolled 37 hospitalized patients undergoing haemodialysis (HD) as a controlled model for intravascular volume loss. Respiratory rate (F_0) and pulse rate (F_1) frequencies were measured. PIVA signal was obtained by fast Fourier analysis of the venous waveform followed by weighing the magnitude of the amplitude of the pulse rate frequency. PIVA was compared with peripheral venous pressure and standard monitoring of vital signs.
Results: Regression analysis showed a linear correlation between volume loss and change in the PIVA signal (R^2=0.77). Receiver operator curves demonstrated that the PIVA signal showed an area under the curve of 0.89 for detection of 20 ml kg^{-1} change in volume. There was no correlation between volume loss and peripheral venous pressure, blood pressure or pulse rate. PIVA-derived pulse rate and respiratory rate were consistent with similar numbers derived from the bio-impedance and electrical signals from the electrocardiogram.
Conclusions: PIVA is a minimally invasive, novel modality for detecting changes in fluid volume status, respiratory rate and pulse rate in spontaneously breathing patients with peripheral i.v. cannulas.

Key words: blood plasma volume; catheterization, peripheral; veins

Assessment of fluid volume status remains an elusive problem in clinical medicine. Clinical and laboratory values such as blood pressure, urinary output and physical examination have significant limitations.[1] Dynamic monitors that measure pulse pressure variation are limited to mechanically ventilated patients with tidal volumes that exceed lung volume protection strategies.[2] Despite its limitations, central venous pressure (CVP) continues to be used in intensive care units to estimate intravascular volume status.[3] Peripheral venous pressure (PVP), a surrogate for CVP, has been used increasingly for estimating volume status.[4–7] However, like CVP, PVP is a poor determinant of left ventricular preload or fluid responsiveness.[3 8 9]

More recently, peripheral i.v. analysis (PIVA), a method for analysing the peripheral venous waveform, instead of venous

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Editor's key points

- Peripheral i.v. analysis (PIVA) is a new method of monitoring body fluid volume by analysis of the peripheral venous waveform.
- In this preliminary study, there was good correlation between fluid volumes removed during haemodialysis and volumes determined by PIVA but poor correlation with peripheral venous pressure, pulse or respiratory rate.
- Fluid removal during haemodialysis does not represent blood loss and further data are required to whether PIVA correlates with existing measures of blood volume status or cardiac output.
- Unlike some other modalities, PIVA appears useful in patients breathing spontaneously.

pressure, has been effectively utilized in monitoring overall fluid volume status.[10 11] PIVA has been shown to detect as little as 6% blood volume loss in human model of haemorrhage model.[11] Further, PIVA has been shown to reflect blood volume changes more sensitively than standard vital sign monitoring during haemorrhage, resuscitation and iatrogenic volume overload in a porcine species.[10]

In this study, using haemodialysis (HD) as a model for controlled, quantifiable fluid loss, we compared PIVA, PVP and standard vital signs during HD. We also aimed to demonstrate proof-of-concept for PIVA as volume monitoring in spontaneously breathing individuals.

Methods

The study was performed in accordance with the Vanderbilt Medical Center Institutional Review Board. Thirty-seven adult inpatients receiving intermittent HD (Fresenius 2008 Series Dialysis Machines, Waltham, MA, USA) three times a week were enrolled and informed consent obtained. The nephrologist as per clinical assessment determined the dialysate content, ultrafiltration rate and goal for volume removal.

Patients with decompensated moderate–severe congestive heart failure, patients presenting with hypotension [mean arterial pressure (MAP) <55mmHg] and patients receiving mechanical ventilation were excluded from the study. All patients had a peripheral i.v. cannula (Smiths Medical, Mundelein, IL, USA) ranging from 22G to 18G placed in the upper extremity before HD, per routine. All cannulae were in the arm opposite an arteriovenous fistula or central venous dialysis catheter. IV cannulae were dedicated to monitoring *via* a pressure transducer (Edwards Lifesciences, Irvine, CA, USA) connected to a portable data acquisition device. Each cannula was flushed hourly and the site inspected to ensure proper position and patency.

Peripheral venous waveform data were obtained and recorded continuously 15 min before, throughout and up to 15 min after HD. Times were noted when the dialysis machine was paused or turned off. The PIVA signal was only analysed during periods when the HD pump was paused (between 5 and 15 min) or turned off. Standard vital signs including pulse rate, noninvasive cuff arterial blood pressure, respiratory rate and oxygen saturation were measured using an IntelliVue bedside monitoring system (Philips North America Corp, Andover, MA, USA). Blood pressure measurements were obtained every 15 min per standard HD protocol.

PIVA and PVP data were sampled at a rate of 500 Hz and downloaded and analysed *via* LabChart 7 (ADInstruments, Colorado Springs, CO, USA). Fast Fourier transformation of the peripheral venous signal was measured at baseline and throughout HD. The magnitude of the amplitude of the frequencies F_0, corresponding to respiration rate and F_1, corresponding to pulse rate, was calculated. Amplitude magnitudes were averaged over 16 s to create 8 K windows with window overlapping of 50% with Hann (cosine-bell).

Statistical analysis was performed with JMP Pro 11 (Cary, NC, USA) and GraphPad Prism (La Jolla, CA, USA). To create receiver operator curves (ROCs), data were inputted into a nominal logistic regression model.

Results

Clinical demographics

Thirty-seven patients were enrolled. Three patients were excluded for peripheral i.v. infiltration during the HD study. IV infiltration was identified by loss of venous waveform signal. In all three subjects, there was visual evidence of i.v. infiltration when flushed with <5 ml of normal saline during the hourly i.v. assessment. Five additional patients were excluded from the PIVA signal linear regression analysis because of intradialytic hypotension, defined by a MAP <55 mm Hg.

All subjects were patients admitted to the hospital undergoing HD (Table 1). The mean age was 62 yr (SD=12 yr), with 24 (65%) men and 13 (35%) females. Average BMI was 30 (SD=7). Significant medical conditions included: 20 patients with a diagnosis of diabetes (54%), 35 patients with a diagnosis of hypertension (95%), 10 patients with a diagnosis of left heart failure (27%) and six patients with a diagnosis of right heart failure (16%).

Peripheral venous waveform signal analysis

The peripheral venous waveform was obtained when the HD pump was paused or discontinued, as the dialysis pump resulted in dampening of the peripheral venous waveform signal (Fig. 1A and C). Fast Fourier transform analysis revealed peaks at frequencies corresponding to respiratory rate (F_0) and pulse rate (F_1) (Fig. 1B and D). The F_1 amplitude magnitude was noted to significantly decrease as volume was removed during HD (Fig. 1B and D). There was excellent correlation between the F_0 frequency and the monitored respiratory rate (Fig. 2). Similarly, the F_1 frequency correlated with pulse rate obtained by a 5-lead electrocardiogram (Fig. 2).

Peripheral venous waveform signal and volume

Comparisons were made between the percentage change in PIVA signal and PVP with the amount of volume removed *via* ultrafiltration. Regression analysis revealed a linear correlation between the amount of volume removed and the percentage change in PIVA signal (R^2=0.77) (Fig. 3A). However, there was no significant correlation between the PVP, MAP or pulse rate with volume removed during ultrafiltration (Fig. 3B–D, respectively). ROCs demonstrated that the PIVA signal showed an area under the curve (AUC) for detection of 20 ml kg^{-1} of 0.890, whereas the AUC for PVP was 0.482 (Fig. 4).

Eight patients were excluded from analysis. Five patients developed intradialytic hypotension (systolic blood pressure <90 mm Hg, MAP <50 mm Hg). Of note, in these five patients, there were changes in the PIVA signal before hypotension, including low F_1 amplitude magnitudes. Three patients were excluded for dislodgement or infiltration of the i.v. cannula