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Carotid artery corrected flow time measurement via bedside ultrasonography in monitoring volume status

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ABSTRACT

Purpose: The purpose of this study is to investigate the possible correlation between corrected flow time (FTc) in carotid artery and changes in volume status.
Materials and methods: Ninety-three patients with end-stage renal failure who underwent fluid removal via hemodialysis were enrolled prospectively. The volume of fluid removed as well as prehemodialysis and posthemodialysis measures of FTc in the carotid artery, heart rate, and mean arterial pressure was evaluated. All imaging measurements were performed with patients at supine position, 15 minutes before and after the hemodialysis session, by evaluating the right common carotid artery at the level of the lower border of thyroid cartilage.
Results: The mean FTc before fluid removal was 345.07 ± 37.19 milliseconds. This measure decreased significantly after the volume removal with a posthemodialysis mean of 307.77 ± 31.76 milliseconds ($P < .0001$). There was a statistically significant and negative association between the volume of fluid removed by hemodialysis and the changes in FTc (Pearson correlation, −0.39; $P < .0001$).
Conclusion: The assessment of changes in FTc of carotid artery via Doppler waveform analysis may predict the changes in intravascular volume. The use of this diagnostic modality may be an accurate and noninvasive alternative to currently available methods.

1. Introduction

Administration of intravenous fluid plays a vital role in the effective resuscitation of critically ill patients, particularly in the emergency setting. Decision making on the adequacy of fluid resuscitation depends highly on an accurate estimation of intravascular volume [1]. Not only does volume depletion impose a life-threatening condition, but also volume overload is known to be associated with increased morbidity and mortality [2]. The measurement of central venous pressure by means of pulmonary artery catheterization has been used widely to determine volume responsiveness at daily clinical settings, particularly at emergency departments and intensive care units for almost half of a century [3,4]. In addition to the invasive nature of this procedure, the results of 2 meta-analyses including a recent one published in 2013 did not indicate any evidence in favor of the accuracy of this diagnostic modality [5,6].

During the past few years, bedside ultrasonography has become a popular diagnostic tool in the emergency department due to its numerous advantages, including its completely noninvasive nature, the ease to learn it, availability via portable devices, and providing repeated assessment of the same outcome and real-time information [1]. Several noninvasive or minimally invasive ultrasound modalities have been introduced for the evaluation of volume status. Among these techniques, ultrasound evaluation of inferior vena cava seems to predict volume responsiveness with acceptable accuracy. However, its usage is limited by a diversity of techniques, lack of evidence-based cutoff points, and difficulties encountered while assessing patients with high abdominal fat deposition and excessive intestinal gas [7-9]. Another method is the assessment of descending thoracic aorta blood flow velocity waveform using a nonimaging esophageal Doppler probe. This method enables the calculation of systolic flow time with heart rate correction (corrected flow time [FTc]), which is shown to be directly correlated with intravascular volume [10]. Most recently, Blehar et al suggested a much more feasible and completely noninvasive modality for the assessment of changes in volume status. They have shown that FTc of the carotid artery increases in dehydrated patients after receiving intravenous fluid bolus [11]. However, as the authors themselves have mentioned, their findings were limited by the fact that there is no criterion standard method to determine if the patient is dehydrated.

Hemodialysis is widely used in the routine management of patients with renal insufficiency. In addition to the clearance of metabolic wastes, it is deployed in the management of volume overload [12].

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Given the provided information on the exact amount of volume removed from a patient in a certain hemodialysis session [13], it should provide a valid model for the assessment of volume changes in human body. Hence, based on the current body of evidence, we hypothesized that volume removal in patients with renal insufficiency and its subsequent volume overload will be accompanied by a decrease in FTc in the carotid artery. Assessment of volume changes in patients with volume overload by monitoring FTc changes would provide further insights into the probability of developing new techniques to determine volume status and volume responsiveness in critically ill patients.

2. Materials and methods

2.1. Study design and setting

The current prospective study was performed between September 2014 and December 2014 at the department of nephrology and dialysis of Imam Khomeini Hospital Complex affiliated with Tehran University of Medical Sciences, Tehran, Iran. The Ethics Committee of Tehran University of Medical Sciences reviewed and approved the process of this study. Moreover, the purpose and the process of the study were explained to all participants, and signed informed consents were obtained from them before their enrollment.

2.2. Selection of participants

Using consecutive sampling, all patients with a documented diagnosis of end-stage renal disease (ESRD) who had received maintenance hemodialysis for at least 3 continuous months before the initiation of the current study were screened for eligibility. Vascular access was previously obtained for all investigated patients via arteriovenous graft surgery. Bicarbonate was used as the buffer in dialysis solution due to concerns regarding the risk of hypotension and cardiovascular instability in patients receiving acetate [14]. No other agent potentially affecting the blood pressure was used during hemodialysis. Inclusion criteria were a minimum age of 18 years and fluid removal of at least 1000 mL in 1 session of hemodialysis. Patients with concurrent infection; inflammatory disorders; diabetic foot; clinically significant cardiovascular comorbidities, including valvular heart diseases, heart failure, and bundle-branch block; cardiovascular events, including myocardial infarction and clinically significant arrhythmia; blood transfusion in the past 3 months; or recent administration of vasopressor agents and those who refused to participate were excluded.

2.3. Ultrasonography modality

All imaging measurements were performed with patients in supine position, 15 minutes before or after hemodialysis session, by evaluating the right common carotid artery at the level of the lower border of thyroid cartilage. Ultrasound evaluation of FTc in the carotid artery was performed as previously described by Blehar et al [11] in all cases by the same sonographer who was an attending emergency medicine physician in a real-time fashion. All measurements were also repeated later by another sonographer in a blinded fashion. This was performed by a linear array ultrasound transducer, model L743, with a frequency range of 5 to 10 MHz, which was deployed on a portable device (SonoScape S6; SonoScape, Shenzhen, China) with an angle of insonation between 60° and 72°. Long-axis B-mode imaging of the vessels was followed by their digital recording supplemented by spectral Doppler waveform tracing with angle correction. We did not encounter any difficulties in performing these measurements, and no significant calcification was observed in the arteries. The images were then evaluated by the same reviewer in all cases to determine if the measurement of flow time and cycle time by means of electronic calipers was correct (Fig. 1). *Corrected flow time* was defined as flow time/√cycle time [11,15].

2.4. Outcomes

Corrected flow time was defined as the primary outcome measured while heart rate (HR) and mean arterial blood pressure (MAP) were also measured before and after hemodialysis. The volume of fluid removed was recorded by reviewing the digital output of Fresenius 4008 Hemodialysis Unit (Fresenius SE & Co. KGaA, Bad Homburg vor der Höhe, Germany).

2.5. Statistical analysis

A minimum sample size of 56 cases was calculated with an α of .05 and a power of 0.8 to distinguish a change of at least 10% in pre–volume removal and post–volume removal FTc. All data were analyzed using SPSS for Windows, version 17.0 (SPSS, Inc, Chicago, IL). Normal Q-Q plots and Shapiro-Wilk test of normality were used to evaluate the normality of data distribution. Quantitative variables are presented as mean ± SD plus 95% confidence interval (95% CI) and categorical variables as frequency (percentage). Paired t test was performed to assess the statistical significances observed in FTc, HR, and MAP before and after volume removal. Independent t test was used to assess the statistical significance of differences observed between groups of patients with different amounts of fluid removal. $P < .05$ was considered statistically significant.

3. Results

3.1. Patients' characteristics

At last, a total number of 93 patients with a mean age of 59.00 ± 13.2 years (95% CI, 56.35-61.68 years) were enrolled in the current study. Of these, 58 cases (62.4%) were male, and the remaining 35 (37.6%) were female. The mean volume of fluid removed via hemodialysis was 2409 ± 787 mL (95% CI, 2242.47-2563.37 mL). Eighty-six patients (92.5%) had a comorbid condition in addition to renal insufficiency. Sixty-three patients (67.7%) had a drug history with some kind of agents that could probably result in the reduction of blood pressure or intravascular volume. Table 1 demonstrates patients' demographic data. Table 2 summarizes the number of patients who had a drug history of antihypertensive agents.

3.2. Corrected flow time

The mean FTc before fluid removal was 345.07 ± 37.19 milliseconds (95% CI, 338.14-352.53 milliseconds). This measure decreased significantly after volume removal with a posthemodialysis mean of 307.77 ± 31.76 milliseconds (95% CI, 301.10-314.42 milliseconds) ($P <$ .0001). The mean reduction in FTc from baseline to after fluid removal was 37.30 ± 42.04 milliseconds (95% CI, 28.38-45.90 milliseconds) or in other words 10.04% ± 11.82%. Corrected flow time decreased in 83 patients (89.20%) and by at least 10% in 51 patients (54.40%). There was a statistically significant and negative association between the volume of fluid removed by hemodialysis and the changes in FTc (Pearson correlation, −0.39; 95% CI, −0.16 to 0.56; $P < .0001$). Fig. 2 demonstrates the association between FTc and the volume of fluid removed via hemodialysis. We also categorized patients based on the amount of volume removed into 4 groups: less than 2000, 2000 to 2499, 2500 to 2999, and 3000 or higher (Table 3). The mean changes in FTc in the first group was significantly lower than the last group (11.10 ± 36.12, 95% CI 7.97-26.50 milliseconds, vs 57.71 ± 40.94, 95% CI 44.10-74. 42 milliseconds; $P < .0001$). The mean HR before and after fluid removal was 76.83 ± 12.07 beats per minute (95% CI, 74.37-79.23 beats per minute) and 78.48 ± 12.25 beats per minute (95% CI, 76.02-80.90 beats per minute), respectively. There was no significant difference between prehemodialysis and posthemodialysis HR (P = .094). The mean MAP before fluid removal was 102.14 ± 18.29 mm Hg