Crit Ultrasound J (2010) 2:43–45
DOI 10.1007/s13089-010-0033-4

BRIEF COMMUNICATION

Ultrasound measurements of lower extremity soft tissue and interstitial fluid thickness may be used as an early indicator of dehydration

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Received: 1 May 2010 / Accepted: 26 May 2010 / Published online: 16 June 2010

Abstract
Purpose Several studies have suggested that clinical indicators of a patient's fluid status that are frequently used in practice are highly variable and not useful in the differentiation of these patients. In this study, we examine the potential use of ultrasound measurements of soft tissue and interstitial fluid thickness for the detection of conditions of mild to moderate dehydration.
Materials and methods This study involved healthy subjects in which a mild dehydration was a consequence of tilt bed rest (average loss of plasma volume of $\sim$10%). The soft tissue and interstitial thickness superficial to the calcaneous and immediately below the lateral malleolus were measured in the supine position using high frequency ultrasound both before and after the treatment. Also the echocardiographic measurements of orthostatic induced changes in stroke volume were obtained.
Results In the eight healthy subjects studied, there was an average of a 13% diminution in both the ankle and pretibial soft tissue and interstitial thickness after tilt bed rest ($p = 0.05$) that coincided with mildly decreased orthostatic induced changes in stroke volume.
Conclusions Traditional tilt testing has been a less than satisfactory technique for determining the hydration status of patients. This study looks at the possibility of using ultrasound as a method for the objective measurement of tissue dehydration. The method was able to detect significant changes in tissue interstitial fluid under conditions of mild dehydration. Since the technique obtains measurements in the supine position, it also obviates creating orthostatic symptoms in restrictive clinical environments.

Keywords Ultrasound · Dehydration · Emergency

Introduction

The determination of the fluid status is a critically important aspect in the assessment of the emergent patient. Traditional hallmark findings on clinical examination such as the capillary refill are not always predictive of the patient's state of hydration [1]. Likewise, commonly used techniques that observe changes in heart rate and blood pressure during emergency department (ED) orthostatic testing have been found to be highly variable and lack the sensitivity and specificity to be clinically dependable [2, 3]. Even an optimized tilt test has shown limited utility in detecting mild to moderate intravascular fluid loss (<10%) [4–6]. Invasive measurements of central fluid volume status are impractical for most patient scenarios and might not always detect mild fluid losses. What is needed are simple objective measures that can be obtained with tools readily available in an ED environment and require very little patient manipulation. In this study, we examine the potential use of ultrasound measurements of interstitial

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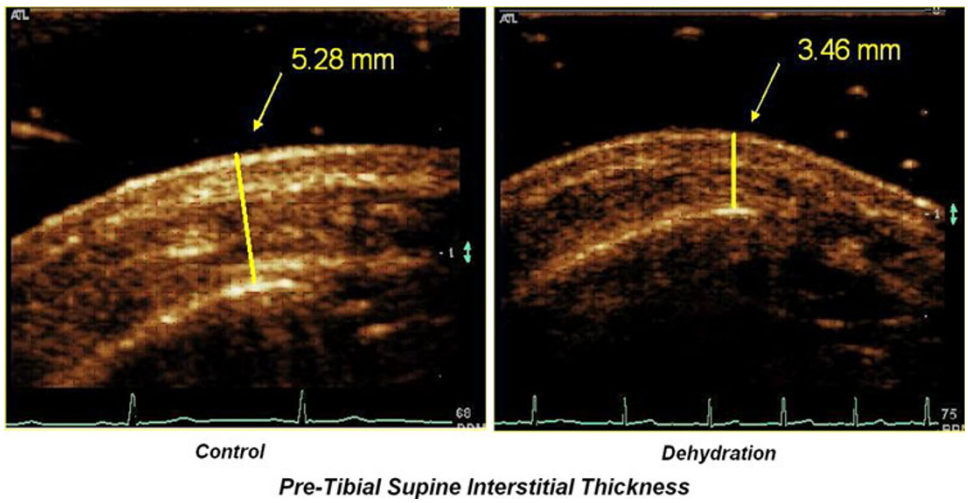

Fig. 1 Ultrasound images of the skin tissue and interstitial thickness superficial to the calcaneous and immediately below the lateral malleolus measured before and after dehydration

fluid and dermal soft tissue thickness for the detection of conditions of mild to moderate dehydration.

Methods

This study involved healthy volunteer subjects who were participating in an extended period of 6° head down tilt bed rest protocol in which a mild dehydration is an established common consequence (average loss of plasma volume of ~10%). Using an ultrasound technique previously described in the literature (17.5 MHz linear array transducer), the skin tissue and interstitial thickness superficial to the calcaneous and immediately below the lateral malleolus were measured both before and after the study period [7–10]. During both the measurements the subjects were in the supine position for which they had been equilibrated. The superficial dermis surface and the bone–tissue interface were used as the measurement boundary landmarks (see Fig. 1). The same point on the external surface of the skin was used in both the measurements (before and after dehydration). Echocardiographic measurements of orthostatic changes in stroke volume were obtained before and after the protocol period using a standard tilt testing methodology. The results were compared used a standard *t* test analysis. The NASA Johnson Space Center Committee for the Protection of Human Subjects (institutional review board) approved the experimental protocol and all subjects gave their written informed consent.

Results

In eight subjects studied, there was an average of a 13% diminution in both the ankle skin tissue and interstitial thickness after the protocol period (average 60 days of head down bed rest) as compared to measurements acquired prior to the bed rest ($p = 0.05$) (see Fig. 2). This general contracture of the soft tissue and interstitial fluid space coincided with a mild increase in the orthostatic induced changes in stroke volume in those patients with echo measurements and significant orthostasis in two other post-protocol subjects.

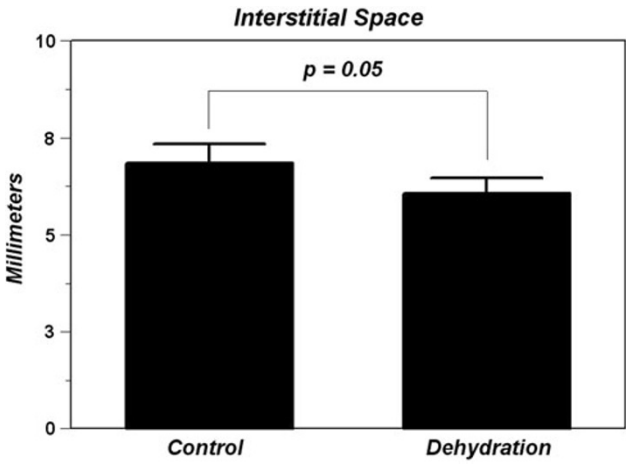

Fig. 2 There was an average of a 13% reduction in both the ankle skin tissue and interstitial thickness after the protocol period ($n = 8$) as compared to measurements acquired prior to the protocol

Conclusions

Traditional ED methods for determining the hydration status of patients have been shown to have significant limitations in specificity and sensitivity [2–4]. Commonly used methods, such as orthostatic tilt testing, are often unable to differentiate conditions of mild dehydration and may be unnecessary or impractical in patients with severe

fluid losses [4]. Likewise, clinical signs and symptoms, such as with the examination of mucous membranes of patients, lack the objectivity required for accurate clinical decision making. Other methods that measure central fluid pressures or plasma volume are invasive, complex and very expensive for routine use. Despite the shortcomings of the currently available approaches, an adequate assessment of fluid status of patients is still an important part of the usual practice of emergency medicine.

The current study looks at the possibility of using high-frequency dermal ultrasound as a method for the objective measurement of tissue dehydration. This technique has been used successfully in anesthesiology for the monitoring of perioperative fluid status [7–9]. In this setting, an increase in the ultrasound measured total tissue thickness at the level of the pretibial ankle has been strongly correlated with intraoperative positive fluid balance ($r = 0.96$), while the changes in central venous pressure did not reflect the amount of fluid application comparably [7–9]. It has also been used to follow changes in general hydration status [10]. Our results suggest that this method may also be useful in detecting significant changes in tissue interstitial fluid under conditions of mild dehydration. This plasma volume loss of $\sim 10\%$ for the patients in this study is comparable to the 450 mL blood loss used in other ED-based studies where orthostatic vital signs were found to be insufficient measures for the detection of fluid losses [2]. Since the technique obtains measurements in the supine position, it also obviates the potential of creating orthostatic symptoms in the ED environment.

While there is evidence supporting a great potential for this new methodology, this current study in healthy individuals has limitations in determining the adequacy of ultrasound-based measurements to differentiate the hydration status of patients in the ED. Further study is required to determine the specificity and sensitivity of the technique in this environment under varied states of patient hydration. The specific meaning of changes in tissue thickness also should be correlated with objective clinical parameters and physiologic endpoints.

Many forms of ultrasound equipment are becoming readily available to emergency physicians. These technologies are now commonly used in the non-invasive evaluation of a spectrum of ED patients, including those with severe trauma or potential obstetrical emergencies [11]. The potential use of these tools for the assessment of patient fluid status represents a new function that might have an even more widespread applicability.

Conflict of interest None.

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