Non-invasive Venous Waveform Analysis Quantitates Dehydration in Athletes
Monica Polcz, MD\textsuperscript{1,2}, Kyle Hocking\textsuperscript{1}, PhD, Richard Boyer, MD, PhD\textsuperscript{2}, Scott Wardlaw, MD\textsuperscript{1}, Colleen Brophy, MD\textsuperscript{1}, Bret Alvis, MD\textsuperscript{3}
\textsuperscript{1}Vanderbilt University Medical Center Department of Surgery, \textsuperscript{2}Vanderbilt University Department of Biomedical Engineering, \textsuperscript{3}Vanderbilt University Medical Center Department of Anesthesiology

\textbf{Introduction:} Exertional volume loss and dehydration results in decreased athletic performance and metabolic derangements that in severe cases leads to systemic collapse. Measurement of body weight is the only viable current practice to measure exertional volume loss but repeated measurements in this setting are impractical. The highly compliant venous system functions as a volume reservoir and analysis of the peripheral venous waveform has shown promising correlations with volume status. A wristband device (Non-Invasive Venous waveform Analysis, NIVA) that noninvasively captures the peripheral venous waveform was applied to athletes to determine correlation with weight as a surrogate for volume status.

\textbf{Materials and Methods:} 35 athletes performed cardiovascular aerobic exercise for 45-120 min. Peripheral venous waveforms were obtained by applying a piezo electric sensor device to the volar aspect of the wrist 10 minutes prior to the start of exercise and after a 15-minute rest period following exercise. Body weights were concurrently obtained. Waveforms from an additional 7 subjects were obtained standing, sitting, supine and after passive straight leg-raise. For analysis, venous waveform signals were transformed from the time domain to the frequency domain with a fast Fourier Transform. Patterns in the relative powers of the frequency corresponding to pulse rate and harmonics of that frequency, correlating to altered venous volume states, were noted and a weighted algorithm was developed using this patient derived data to create a NIVA score.

\textbf{Results and Discussion:} There was minimal variation in baseline NIVA signal amongst the athletes. The NIVA signal correlated with the body weight change after exertional athletic activity (p<0.05) with an $R^2$ value of 0.893 (n=35). NIVA signals increased from standing to sitting, supine, and supine with legs raised consistent with increases in central blood volume. There was a strong correlation between changes in NIVA signal and changes in body weight after athletic exertion. NIVA represents a novel, noninvasive approach to measure volume losses during exertional exercise.

\textbf{Translational Impact:} This study demonstrates the utility of using actual patient data to validate a model that analyzes changes in the peripheral venous waveform that occur with dehydration. Assessment of volume status in the clinical setting is often difficult, requiring invasive procedures or the use of unreliable clinical signs, however this novel non-invasive technology has potential applications for use beyond athletes, in clinical scenarios in which volume status is clinically challenging (eg. heart and renal failure, perioperative management., hemorrhage, resuscitation)...

\textbf{Figure 1.} Representative image of the time domain (top) and frequency domain (bottom) of a venous waveform obtained prior to exercise.

\textbf{Disclosure Statement:} Kyle Hocking, Susan Eagle, Franz Baudenbacher and Colleen Brophy are inventors of patents associated with the NIVA technology as well as shareholders in VoluMetrix, a company that has licensed the NIVA technology.

\textbf{Acknowledgements:} NSF Phase I SBIR 1549576