

A Pilot Study Examining the Use of Ultrasound to Measure Intravascular Volume Status in Agricultural Workers in a Field-Based Research Setting

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Objective: The aim of this pilot study was to explore if internal jugular vein (IJV) ultrasound studies on agricultural workers in a field-based research setting could assess volume status during a hydration intervention. **Methods:** We performed pre- and post-work shift IJV ultrasound images on 30 agricultural workers. The IJV collapsibility index values were $<39\%$ (euvoletic) or $\geq 39\%$ (hypovolemic). **Results:** Of the water group, 13% (2/15) had an IJV collapsibility index $\geq 39\%$, and this increased to 19% (3/16) by the end of the work shifts. The electrolyte group did not have any workers start the work shift with an IJV collapsibility index $\geq 39\%$; however, at the postshift assessment, 15% (2/13) were hypovolemic. **Conclusion:** Internal jugular vein ultrasounds may have the potential to be a useful tool to determine volume status in field-based research settings. Further investigation is needed to confirm these findings.

Keywords: ultrasound, volume depletion, environmental heat, agricultural workers

Heat waves, a phenomenon exacerbated by climate change, pose an emergent global health risk, and kidney disease is already recognized as a worldwide public health crisis.¹ Agricultural workers are at higher risk than other occupational groups for heat-related fatalities,² heat-related illness,³ and dehydration.^{4,5} More recently, agricultural workers have also been shown to be at risk of acute kidney injury (AKI) and chronic kidney disease of unknown etiology (CKDu) that is associated with environmental heat exposure, dehydration, volume depletion, and intense physical activity.⁴⁻⁸ A meta-analysis on heat strain

that included diverse populations, exposures, and occupations found a 15% incidence of AKI or kidney diseases among those who worked in high ambient temperatures (Wet Bulb Globe Temperature $>22^{\circ}\text{C}$ [72°F] for very intense work; Wet Bulb Globe Temperature $>25^{\circ}\text{C}$ [77°F] for most occupations) for a minimum of 6 hours per day, 5 days per week, for 2 months of the year.⁹ Thus, risk arises from the work itself for agricultural workers who are at the center of two global public health challenges.

A combination of water (dehydration) and salt (volume) depletion due to laboring in hot and humid conditions has been hypothesized as a potential cause or mediator of AKI that may lead to CKDu among agricultural workers.^{4,5,10-12} A recent study with construction workers, in the hot desert climate of Saudi Arabia, found that exposure to this climate may also lead to kidney injury.¹³ These studies have shown cross-shift changes in hydration biomarkers (urine specific gravity [USG], serum sodium and potassium, and hematocrit), changes in volume (blood pressure), and increases in kidney-related biomarkers (serum creatinine and blood urea nitrogen [BUN]).^{4,5,10-12} Field-based studies with agricultural workers have assessed volume depletion by comparing body weight taken at pre- and postshift, with weight loss suggesting volume depletion.^{5,11,12} This method is noninvasive and feasible in the field; however, it is also imprecise and fails to account for factors such as bowel movements and food and fluid consumption that impact body weight.¹⁴ Furthermore, in a study with agricultural workers in Florida, weighing participants pre- and post-work shift was cumbersome because of layers of clothing and participant discomfort with disrobing for weight measurements.¹⁵

Assessment of volume status is a major challenge in clinical medicine. Various noninvasive methods are used to obtain indirect information about intravascular volume, including physical examination (vital signs, orthostatic changes in blood pressure/pulse) and clinical history (light-headedness, dizziness, more pronounced when standing). Decreased skin turgor, dry mouth, and thirst are used as indicators of dehydration (water loss). Most studies that assess volume depletion are in the hospital setting during acute illness in the emergency room or intensive care unit rather than in an occupational setting, and many of these studies also discuss how physical examinations are not fully reliable in assessment of volume status.¹⁶⁻¹⁸ Ultrasound has emerged as a valuable noninvasive tool in measurement in volume status. There are many targets that can be evaluated using ultrasound, including the internal jugular vein (IJV), inferior vena cava, and echocardiographic measures. The IJV has gained popularity as a target site given the ease of measurement and value in assessing fluid responsiveness.

The aim of this pilot study was to explore if IJV ultrasound studies on agricultural workers in a nonclinical, field-based research setting can assess intravascular volume status.

METHODS

After institutional review board (IRB00112681) approval, in July 2021, the community health workers from the Farmworker Association of Florida recruited a convenience sample of 30 agricultural

LEARNING OUTCOMES

- Understand current practices and barriers of assessing volume depletion in field-based studies with agricultural workers.
- Gain insight on the potential use of ultrasound to assess internal jugular vein collapsibility to determine volume status by researchers studying renal dysfunction, AKI, and CKDu in agricultural workers in field-based research settings.

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The Institutional Review Board at Emory University provided approval (IRB00112681) for the study, and all participants provided informed consent.

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workers in Central Florida. Workers were scheduled for a hydration intervention on a workday and assessed pre- and post-work shift. Each participant received a US \$70 gift card.

Detailed methods have been described previously.¹⁹ Briefly, workers were randomized to one of two hydration workday interventions: 5 L (169 oz) of plain water or 5 L of water with an electrolyte solution based on the World Health Organization–recommended oral rehydration formula (glucose, 13.5 g; trisodium citrate dihydrate, 2.9 g; sodium chloride, 2.6 g; potassium chloride, 1.5 g per 1 L).²⁰ Systolic and diastolic blood pressure was measured using a digital system (Omron BP760N; Omron Healthcare Inc, Bannockburn, IL) pre- and postshift after the worker had been seated for a minimum of 5 minutes. We collected urine and blood samples pre- and postshift from the workers. A digital refractometer (Atago PAL-10S digital refractometer; ATAGO USA, Bellevue, WA) was used to measure USG. Urine specific gravity values were categorized as follows: ≥ 1.020 (dehydrated) or < 1.020 (euhydrated). We used the point-of-care iSTAT Blood Analyzer with CHEM 8+ cartridges (Abbott Point of Care, Inc, East Windsor, NJ) to measure hematocrit, creatinine, and BUN in finger-stick blood samples, from which we estimated glomerular filtration rate and calculated serum osmolality. The estimated glomerular filtration rate was calculated with the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation.²¹ Serum osmolality was calculated using the Martin-Calderon equation: $1.86(\text{Na} + \text{K}) + 1.15(\text{Glu}/18) + (\text{Urea}/6) + 14$.²² Inclusion criteria included being between 18 and 49 years of age and working in the agricultural sector for at least the last 4 weeks at the time of enrollment. Workers were excluded if they reported being pregnant, had type 1 or 2 diabetes mellitus, were under treatment for hypertension, or reported a history of glomerulonephritis, pyelonephritis, renal calculi, or a snake bite.

Ultrasound Technique

Internal jugular vein ultrasound studies were performed at the Farmworker Association of Florida's office with a portable Butterfly IQ™ (Butterfly Network, Guilford, CT) pre- and postshift to assess intravascular volume status. All measurements were performed by a single nurse researcher that was blinded to the allocation of randomization. The nurse researcher received training to perform the ultrasounds by a nephrologist who is trained and performs IJV ultrasounds to assess hydration status. Workers sat in a chair with their head at a 45° angle, and their head was rotated slightly $< 30^\circ$ to expose the right IJV. A small amount of water-based gel was placed on the probe. Pressure was applied to the probe once on the neck to locate the IJV and obtain ultrasound images, which were then digitally stored. The diameter of the IJV was measured during maximum and minimum distention during a respiratory cycle (Fig. 1). Internal jugular vein collapsibility index was calculated with the following equation: $[(\text{max diameter} - \text{Min diameter})/(\text{max diameter})] \times 100\%$. The IJV collapsibility index was categorized as follows: $\geq 39\%$ (hypovolemic)

or $< 39\%$ (euvoletic).²³ A nephrologist reviewed and interpreted the images and was blinded to the allocation of randomization.

Statistical Analysis

Descriptive statistics were reported as mean and standard deviation, median and quartiles, and percentage and sample size. No power analysis was completed since this was a pilot study. Analyses were performed using SAS® 9.4 software (SAS Institute Inc, Cary, NC).

RESULTS

A total of 30 agricultural workers were evaluated pre- and postshift to assess intravascular volume status, except for one worker who missed the postshift ultrasound. Therefore, 59 ultrasound studies were performed by the same nurse researcher. All participants agreed to have the ultrasound. The ultrasound process took 5 minutes to complete, and no adverse events occurred. Demographic and work characteristics are detailed elsewhere.¹⁹

In the water group, 13% (2/15) were hypovolemic before they started their work shift; this increased to 3 out of 16 (19%) after their work shift (Table 1). In comparison, the electrolyte group did not have any workers who started the work shift with hypovolemia, increasing to 2 (15%) postshifts. Figure 2 shows changes in IJV collapsibility indices for each participant, with the electrolyte group predominantly increasing over the course of the day while the water group predominantly decreased. Preshift, 50% of the workers in the water group were dehydrated according to USG, falling to 6% postshift. In the electrolyte group, 57% were dehydrated preshift and 50% postshift. There were no significant changes in blood pressure or difference based on sex/gender.

DISCUSSION

Using ultrasound to assess IJV collapsibility may have the potential to be a useful tool in determining volume status by researchers studying renal dysfunction, AKI, and CKDu in agricultural workers in the field.

This study evaluated patients in the morning and then the afternoon to assess if the workers were volume depleted after working a shift primarily in plant nurseries or ferneries during a hydration intervention pilot study. The results showed that three workers in the water group (6% of the total) and two workers in the electrolyte group (14% of the total) showed indications of volume depletion by the IJV collapsibility index postshift compared with preshift. Of note, when evaluating USG, the workers in the water group had improvement in USG compared with the electrolyte group. In the water group, IJV values predominantly declined over the day, which is reflected in the reduction in dehydration as measured by USG. Similarly, in the electrolyte group, IJV values generally increased over the day, and USG remained high. However, the water group did show a mild

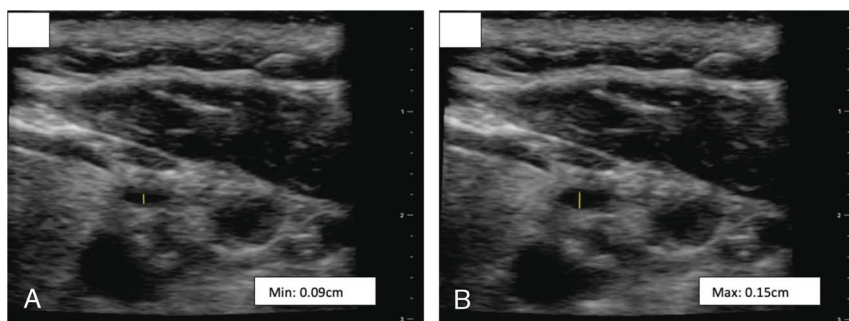


FIGURE 1. Ultrasound images of the IJV. A, IJV minimum anterior–posterior (AP) diameter measurement during respiratory cycle. B, IJV maximum AP diameter measurement during respiratory cycle.

TABLE 1. Cross-Shift Changes in Hydration and Renal Biomarkers in 30 Agricultural Workers in Florida

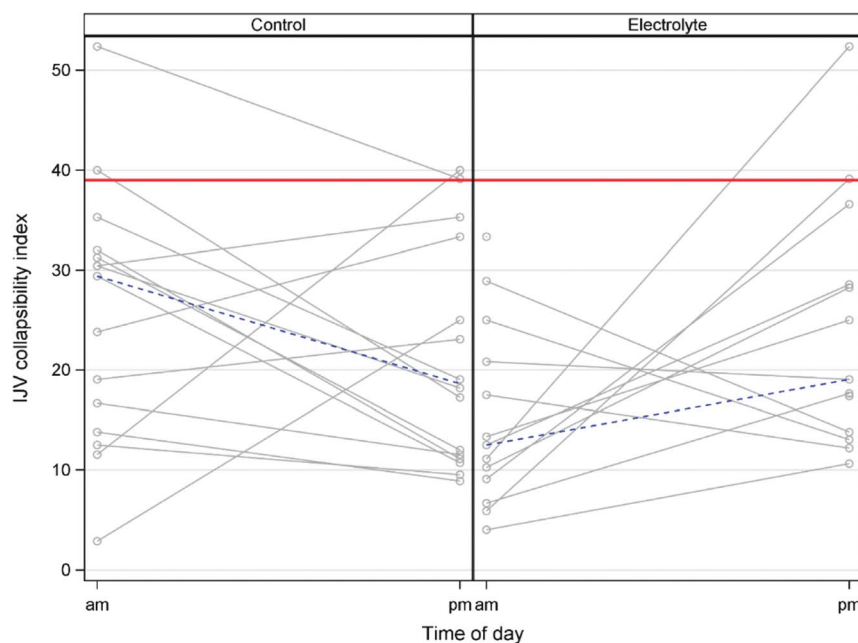
	Time of Day	Intervention			
		Water (n = 16)		Electrolyte (n = 14)	
		n	% or median (q1, q3)	n	% or median (q1, q3)
Hypovolemia, IJV collapsibility index $\geq 39\%$	AM	2/15*	13%	0/13*	0%
	PM	3/16	19%	2/13	15%
Hypovolemia, IJV collapsibility index, %	AM	15	29 (14, 32)	13	13 (9, 21)
	PM	16	19 (11, 34)	13	19 (14, 29)
USG ≥ 1.020 (dehydrated)	AM	8/16	50%	8/14	57%
	PM	1/16	6%	7/14	50%
Blood pressure—systolic	AM	16	109 (100, 122)	14	121 (116, 129)
	PM	16	118 (108, 125)	11	117 (110, 129)
Blood pressure—diastolic	AM	16	72 (69, 82)	14	76 (73, 82)
	PM	16	76 (70, 84)	11	77 (71, 82)
Serum creatinine, mg/dL	AM	16	0.6 (0.5, 0.7)	14	0.6 (0.4, 0.6)
	PM	13	0.7 (0.6, 1.0)	11	0.6 (0.4, 0.7)
Hematocrit	AM	16	39.0 (36.8, 42.3)	14	39.0 (37.3, 42.5)
	PM	13	39.0 (36.0, 43.0)	11	39.0 (33.5, 40.5)
Serum osmolality, mmol/kg	AM	16	282 (279, 285)	14	283 (280, 284)
	PM	13	280 (278, 282)	11	283 (281, 285)
BUN, mg/dL	AM	16	12 (10, 15)	14	12 (9, 18)
	PM	13	13 (10, 14)	11	12 (9, 14)
Serum sodium, mmol/L	AM	16	141.0 (139.8, 143.0)	14	141.0 (140.0, 142.0)
	PM	13	140.0 (138.0, 142.0)	11	142.0 (142.0, 143.0)
Serum potassium, mmol/L	AM	16	4.2 (4.0, 4.3)	14	4.2 (4.0, 4.3)
	PM	13	4.0 (3.7, 4.2)	11	4.0 (3.9, 4.2)
Serum glucose, mg/dL	AM	16	110 (99, 130)	14	110 (102, 114)
	PM	13	101 (97, 114)	11	102 (92, 126)

*Two morning readings early in the study were performed incorrectly and were not included (one in each group).

increase in serum creatinine, although not statistically significant. The increase in serum creatinine in the water group is interesting as it has been hypothesized that prolonged physical exertion in the heat and dehydration have been shown to increase indicators of kidney injury and dysfunction.^{4,11,12,24,25} Thus, further investigations are needed to study the relationship of hydration and prolonged physical

exertion in the heat and additional factors that contribute to renal dysfunction along with hydration interventions.

Furthermore, the water group showed a decrease in dehydration in the afternoon but still showed an increase in volume depletion, presumably since these subjects only replaced their water losses and not their sodium losses. Because the electrolyte group received both salt

**FIGURE 2.** Changes in IJV collapsibility index by type of beverage and time of day. The blue line connects median values, the red line is the hypovolemic limit, and the grey lines connect the individual's readings.

and water replacement, the group had less volume depletion. Serum osmolality was relatively unchanged, indicating that antidiuretic hormone (ADH) was still under osmotic control—if the degree of volume depletion had exceeded 5%, then ADH comes under nonosmotic release. Thus, the portable ultrasound measurements detected volume depletion and not just dehydration. Volume depletion is more important because it can reduce blood pressure when it is severe and poses a risk for AKI and potentially CKDu.

Our findings highlight the difference between dehydration and intravascular volume status, although these terms are sometimes used interchangeably. Dehydration refers to loss of water and does not always lead to volume depletion. Volume depletion is loss of salt and water that can potentially lead to lower blood pressure and renal perfusion. Most of the time, the kidney can compensate for volume depletion using other hormones such as ADH and activation of the renin-angiotensin-aldosterone system by increasing salt and water reabsorption. However, if volume depletion is severe enough, the compensatory mechanisms are unable to prevent volume depletion, and this could lead to AKI. This is important as repeated episodes of AKI can lead to chronic kidney disease, and this has been proposed to be a possible mechanism related to CKDu.

There are several limitations to this study. First, it is a small-sized pilot study that was performed at one location, and thus, findings are not statistically significant. Second, although IJV collapsibility index is a useful tool for assessing volume status, a single method has not been identified as the criterion standard in volume status assessment, and a multifactorial approach is best taken. Furthermore, we used an IJV collapsibility index >39% to define volume depletion based on a small study involving patients in the intensive care unit, and it is unclear if this translates directly to our study population. Several strengths of this pilot study include the ability to compare the effects of drinking plain water to those of drinking an electrolyte solution, and the inclusion of multiple indicators of hydration in an occupational setting.

CONCLUSION

Internal jugular vein ultrasounds in a field-based research settings may have the potential to be a useful tool to determine volume status for the study of renal dysfunction among agricultural workers. The IJV collapsibility index is an easy and reproducible measure that may be used in the field-based research settings to assess volume status. However, larger studies are needed to evaluate the accuracy of the IJV collapsibility index as an indicator of volume status among people outside the hospital setting.

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