Hydration Status, Kidney Function, and Kidney Injury in Florida Agricultural Workers

Jacqueline Mix, PhD, MPH, Lisa Elon, MS, MPH, Valerie Vi Thien Mac, PhD, RN, Joan Flocks, JD, Eugenia Economos, Antonio J. Tovar-Aguilar, PhD, Vicki Stover Hertzberg, PhD, FASA, and Linda A. McCauley, PhD, RN

Objective: Recent findings suggest that laboring in hot occupational environments is related to kidney damage in agricultural workers. We examined hydration status and kidney function in 192 Florida agricultural workers. **Methods:** Blood and urine samples were collected over 555 workdays during the summers of 2015 and 2016. Urine-specific gravity (USG), serum creatinine, and other kidney function markers were examined pre- and post-shift on each workday. Multivariable mixed modeling was used to examine the association of risk factors with hydration status and acute kidney injury (AKI). **Results:** Approximately 53% of workers were dehydrated (USG $\geq$1.020) pre-shift and 81% post-shift; 33% of participants had AKI on at least one workday. The odds of AKI increased 47% for each 5-degree (°F) increase in heat index. **Conclusion:** A strikingly high prevalence of dehydration and AKI exists in Florida agricultural workers.

Keywords: agricultural workers, climate change, dehydration, heat exposure, kidney injury

BACKGROUND

Agricultural workers routinely perform intense work activities in hot and humid conditions and are at a high risk of adverse health outcomes as a result of the environments in which they work. Average annual heat-related mortality in agricultural workers is nearly 20 times greater than that of the overall U.S. workforce[1,2] and heat-related morbidity has been reported to be more than four times greater than for nonagricultural workers.[3] Immigrant workers are at a particularly high risk for heat-related illness (HRI), and high burdens of symptoms are experienced in this population.[4–6] It is well documented that immigrant agricultural workers have little control over their work environments[7–10] and often do not receive adequate access to water, shade, or rest breaks.

Although acute health symptoms and illnesses related to heat exposure in agricultural workers have been described, recently, there has been more interest in whether these workers are also at an increased risk of kidney disease. It has been hypothesized that occupational heat exposure and dehydration are related to the epidemic of chronic kidney disease of unknown etiology (CKDu) in Mesoamerica, among those who lack the traditional risk factors of CKD such as old age, obesity, diabetes, hypertension, and nephrotoxic drug use.[11,12]

The estimated glomerular filtration rate (eGFR) is a clinical assessment for kidney function, which decreases as kidney function declines, and can be estimated using serum creatinine and demographic information.[13] When dehydration leads to severe volume depletion in the body, the glomerular filtration rate can fall.[14] Although previously thought to be innocuous as long as rehydration occurs, chronic recurrent dehydration with volume depletion is hypothesized as a factor that may lead to CKD via vasopressin release, cortical aldose reductase activation leading to endogenous fructose production and uric acid, as well as hyperuricemia from heat-associated dehydration in the presence of subclinical rhabdomyolysis from strenuous activity.[14]

The majority of the U.S. agricultural workforce are immigrants from Mexico and Central America, but most of the studies examining kidney injury in agricultural workers have been performed in Central America. In a cross-sectional study performed in 189 male sugarcane cutters in El Salvador, it was found that measures of dehydration (urine-specific gravity, USG, urine osmolality) increased from pre- to post-shift, and 12% had a reduced eGFR ($<$60 mL/min/1.73 m^2).[15] Another cross-sectional study of 194 males working as subsistence farmers, construction workers, and sugarcane cutters in Nicaragua found that sugarcane cutters had a higher prevalence of kidney dysfunction than construction workers and small-scale farmers; 16% of sugarcane cutters had reduced eGFR ($<$ 80 mL/min/1.73 m^2), suggesting that dehydration-related blood volume depletion is related to kidney injury.[12] A longitudinal study in Nicaragua followed 284 sugarcane workers before and after a harvest season and found that field workers had decreased eGFR as compared with nonfield workers,[16] as well as a higher relative mean of neutrophil gelatinase-associated lipocalin (NGAL) and interleukin 18 (IL-18).[17] NGAL is an early indicator of kidney injury that may be elevated before changes in serum creatinine, and subsequently, before changes in eGFR.[18,19] Self-reported water intake was not associated with eGFR or kidney injury markers, but electrolyte supplementation use was associated with reduced kidney function in cane cutters and seed cutters.[17] A recent study reporting renal function in 295 agricultural workers in the Central Valley of California studied for one workday found that approximately 12% of the workers had cross-shift increases in serum creatinine consistent with the Kidney Disease Improving Global Outcomes (KDIGO) criteria for acute kidney injury (AKI), a risk factor for CKD.[20] In this same population, heat strain was found to be associated with AKI, but measures of hydration status were not considered.[21]

In Florida, the temperature in summer can reach dangerously high values. The objective of this study was to examine markers of hydration status and kidney function among immigrant agricultural workers in Florida during the hot summer months. Specifically, we aimed to (1) describe hydration status and kidney function markers among agricultural workers pre- and post-shift on three consecutive workdays; (2) investigate personal, work, and environmental factors associated with hydration status, and (3) evaluate the

From the Nell Hodgson Woodruff School of Nursing, Emory University, Atlanta, Georgia (Drs Mix, Mac, Stover Hertzberg, McCauley); Department of Biostatistics and Bioinformatics, Rollins School of Public Health, Emory University, Atlanta, Georgia (Ms Elon); Center for Governmental Responsibility, Levin College of Law, University of Florida, Gainesville, Florida (Ms Flocks); and Farmworker Association of Florida, Apopka, Florida (Economos, Dr Tovar-Aguilar).

Funding for this study was provided by the National Institute for Occupational Safety and Health award number R01OH010657.

The authors have no conflicts of interest.

Address correspondence to: Jacqueline Mix, PhD, MPH, Nell Hodgson Woodruff School of Nursing, Emory University, 1520 Clifton Rd NE, Atlanta, GA 30322 (jacqueline.mix@emory.edu).

DOI: 10.1097/JOM.0000000000001261

incidence of AKI during the workday and factors associated with its development.

METHODS

Study Design and Population

The *Girasoles* (Sunflower) study of heat exposure among immigrant agricultural workers was conducted by academic researchers in partnership with the Farmworker Association of Florida (FWAF). The overall objective of this collaborative study was to investigate physiologic indicators of HRI in agricultural workers laboring in hot occupational environments in Florida. The FWAF is a grassroots, statewide, community-based membership organization with a 35-year history of working with the agricultural worker community. Members of the FWAF were part of the research team and participated in all phases of developing the project, including recruiting research participants and collecting data.

Trained community partners recruited a convenience sample of agricultural workers through community outreach activities. Agricultural workers lived in three different communities, and the primary work activities and conditions differed substantially between communities. Fernery workers were recruited between May and July 2015 in the central Florida town of Pierson, known as the ‘‘Fern Capital of the World.’’ Harvesting ferns involves intense physical activities, including bending over, thrusting arms into masses of ferns, and cutting the fronds at their base. Fernery workers labor in fields enclosed on all sides and across the top by porous black shade cloth or less frequently, under tree canopy. Nursery workers were recruited in August 2015 and June 2016 in the central Florida town of Apopka, FL community, known as the ‘‘Foliage Capital of the World.’’ Work tasks at nurseries are varied and include planting at conveyor belts; loading pots of plants onto trays; and loading and carrying trays, boxes, or bags of soil. Most nursery workers labor inside greenhouse structures enclosed with nonporous heavy plastic. Field crop workers were recruited in September and October 2016 in the southwest Florida town of Immokalee, notable for its tomato crop. During data collection, workers were preparing fields for planting that included placing plastic over the growing rows, implanting growing stakes, and planting young tomato plants. Most field crop workers labor in open fields with limited protection from the direct sun.

Agricultural workers were eligible to participate in the *Girasoles* study if they were between 18 and 54 years old and had been working in agriculture for at least 1 month preceding their participation. Workers were excluded if they reported a history of Type 1 diabetes or were currently pregnant. Consented participants reported to the study site for a baseline clinical and survey assessment (on a nonworkday), followed by pre- and post-shift clinical assessments for up to three consecutive workdays in a single week. All study procedures were reviewed and approved by the Emory University Institutional Review Board; participation of human subjects did not occur until after informed consent was obtained.

Data Collection

Survey Data

At the baseline assessment, a survey adapted from an occupational HRI questionnaire used previously with the immigrant agricultural population[4] was administered to workers in their primary language by trained research partners. Sociodemographic characteristics queried included age, gender, country of origin, and years of education. Health and lifestyle-related characteristics included history of hypertension, history of type 2 diabetes, and smoking status (ever, never). Work-related characteristics included primary work type (fernery, nursery or field crop work), number of years in agriculture, usual number hours worked per day, access to clean water and toilets at the workplace, and types of beverages consumed at home and at work (water, sports drinks, energy drinks, soda, juice, coffee, and alcohol).

Clinical Data

Clinical and anthropometric measurements were taken by trained research staff. Body mass index (BMI) was calculated from height and weight (kg/m^2) measured at the baseline assessment and was classified based on WHO recommendations for obesity (BMI $\geq$30).[22] Resting heart rate was measured at the baseline visit and was categorized using the American Heart Association recommended criteria of systolic and diastolic values: normal (<120/80), prehypertension (120–139/80–89), or hypertension ($\geq$140/90).[23]

Urine and blood samples were collected during the baseline and pre- and post-shift visits. Workers were provided with a sterile specimen cup to collect their first morning void to bring to the study site before work. At the end of the work day, participants returned and provided another urine sample. USG is a dimensionless measurement that is widely used to measure hydration status in the field setting[24] that ranges from 1.000 for pure water to 1.050, the maximum concentration capacity of the renal system.[25] USG was measured using a Reichert TS Meter-D automatic digital refractometer (Fisher Scientific, Pittsburgh, Pennsylvania), which measures USG with a precision of 0.001.[26] Blood samples were obtained by finger prick and were analyzed with an iSTAT Blood Analyzer with CHEM 8+ cartridges (Abbott Point of Care, Inc, East Windsor, NJ) that measured serum creatinine, and blood urea nitrogen (BUN). Urine protein was assessed semi-quantitatively using a urine dipstick (Consult Diagnostics 10SG Urine Reagent Strips; McKesson Medical Surgical Inc., Richmond, VA).

Hydration Status and Kidney Function Indicators

Pre-shift and post-shift USG values were categorized into values at least 1.020 or less than 1.020, based upon the hypohydration threshold guideline of the American College of Sports Medicine.[27] USG values more than 1.030 were considered to represent severe clinical dehydration.[24,28] Indicators of kidney function examined were serum creatinine, eGFR, serum BUN, and urinary protein. Serum creatinine was categorized according to sex-specific normal range limits: at least 1.1 mg/dL (males) and at least 1.3 mg/dL (females). The Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation was used to estimate eGFR, which is based on serum creatinine, age, and race.[13] We categorized eGFR into less than 90 and at least 90 $mL/min/1.73\,m^2$, as too few of the workers in our sample had values below 60 $mL/min/1.73\,m^2$, the cutoff value associated with chronic kidney disease. High serum BUN was ($\geq$20 mg/dL) and high urinary protein ($\geq$30 mg/dL) were other kidney dysfunction parameters of interest. Development of AKI over the work shift was defined using the Kidney Disease Improving Global Outcomes (KDIGO) criteria,[29] which is defined as serum creatinine change at least 0.3 mg/dL over 48 hours, or serum creatinine increase at least 1.5 times a baseline value within the prior 7 days. Incident AKI over the workday was considered to be present if serum creatinine values after the work shift increased at least 0.3 mg/dL from values before work, or least 1.5 times the pre-shift measure. The stages of AKI were defined as stage 1 (serum creatinine increase of $\geq$0.3 mg/dL or 1.5 to 1.9 times the value before work), stage 2 (serum creatinine after work 2.0 to 2.9 times the value before work), and stage 3 (serum creatinine after work $\geq$3.0 times the value before work).[30]

Environmental Conditions

Heat index (HI) is used widely in environmental health research for estimating heat exposure and is used as an approximation of ‘‘apparent temperature,’’ which combines air moisture and temperature into a single scale, and is expressed in the same units of air temperature (°F).[31] We calculated HI in this study by using the

National Weather Service (NWS) algorithm, which correlates well with the original algorithm developed by Steadman.[31] Ambient temperature and relative humidity data during the study period work days were obtained from the Florida Automated Weather Network (FAWN),[32] and were used to calculate a daily average HI for each participant. FAWN collects data every 15 minutes on environmental conditions from 35 monitoring stations throughout the state of Florida; a monitoring station was located in each of the three study communities.

Statistical Analysis

The distributions of hydration and kidney function measures on all workdays were examined using normality plots and summary statistics. We utilized all data points to calculate pre-shift and post-shift mean values for continuous variables and proportions for categorical variables using the PROC GLIMMIX procedure in SAS, adjusting for the nested levels of the data structure (multiple workdays per participant, pre-shift and post-shift measurements within a workday, and members within the same household).

Factors analyzed for their association with USG more than 1.020 were selected a priori based on risk factors that have been identified in the literature as associated with dehydration. These factors included age, gender, time of day (pre- or post-workday); gender by time of day interaction; primary work type (fernery, nursery, or field crop); number of hours worked per day; BMI; self-reported types of beverages consumed during hot and humid weather (juice, soda, energy drinks, and sports drinks), and average HI corresponding to the workday. Age, years of education, BMI, years worked in agriculture, hours worked per day, and mean HI were entered into the models as continuous variables. First, a generalized linear mixed model (GLMM) with the three random effects representing the three nested levels of the data structure was examined; the model was simplified by eliminating the terms representing clustering of daily measurements and household, as they did not contribute to the total variance. Starting with a full model of all fixed and two random effects, variables were eliminated on the basis of Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) fit statistics (lower values indicating a better fit). Modeling assumptions were confirmed by using data visualizations including residual plots and scatterplots.

The associations of incident AKI with a priori risk factors (HI, hydration status, sociodemographic, and health-related and work-related characteristics) were examined using the same GLLM model selection strategy. For these models, we used the categories "no indication of dehydration before or after work," "dehydrated before work only," "dehydrated after work only," and "dehydrated both before and after work." Age, sex, nationality, and hydration status were retained in all models regardless of statistical significance. SAS version 9.4 (SAS Institute Inc., Cary, NC) was used for all statistical analyses.

TABLE 1. Study Sample Characteristics of Florida Farmworkers Girasoles Study 2015–2016 ($n = 192$)

Demographic Characteristics	Mean ± SD	n (%)
Age, years	38.0 ± 8.2	38.0 ± 8.2
Gender		
Male		76 (40%)
Female		116 (60%)
Nationality		
Mexico		124 (65%)
Guatemala		34 (16%)
Haiti		26 (13%)
United States		3 (2%)
Other[1]		8 (4%)
Years of education	6.5 ± 3.5	
Lifestyle factors	**Mean ± SD**	**n (%)**
BMI		
Male	27.9 ± 4.2	
Female	29.2 ± 4.5	
BMI ≥30		
Male		20 (26%)
Female		47 (41%)
History of hypertension		12 (6%)
Blood pressure		
Normal (<120/80)		63 (33%)
Pre-hypertension (120–139/80–89)		84 (44%)
Hypertension (<140/90)		45 (23%)
History of diabetes		12 (6%)
Smoking status		
Ever smoked		27 (14%)
Never smoked		165 (86%)
Work Characteristics	**Mean ± SD**	**n (%)**
Years worked in agriculture	12.0 ± 7.8	
Hours worked per day	7.5 ± 1.5	
Primary work type		
Nursery		59 (31%)
Fernery		67 (35%)
Crop		66 (34%)
Employer provides clean drinking water		172 (90%)
Drink more of beverage at work		
Water		188 (98%)
Sports drinks		132 (69%)
Soda		96 (50%)
Juice		74 (39%)
Energy drinks		31 (16%)
Coffee		18 (9%)
Alcohol		4 (2%)
Access to toilet at work		171 (89%)

RESULTS

The study sample included a total of 192 agricultural workers who provided baseline data and 555 workdays in three primary work settings: 35% fernery, 31% nursery, and 41% field crop. The mean age was 38 (SD 8.2) years, 60% were female, 63% listed Mexico as their country of origin, and the average years of education was 6.5 (SD 3.5) (Table 1). The average BMI was 27.9 (SD 4.3) for males and 29.2 (SD 4.5) for females, with females more likely to be obese (41% vs 26%). Six percent of workers reported a history of hypertension, and 23% were hypertensive on the basis of observed blood pressure measurements and 6% reported a history of type 2 diabetes. On average, agricultural workers in our sample reported working 7.5 (SD 2.1) hours per day. The mean ambient daytime temperature for the study period (6 AM to 6 PM) was 83°F (range 64°F to 100°F); average relative humidity was 77% (range 40% to 100%) and average HI was 89°F (range 64°F to 111°F).

The mean USG increased significantly from 1.020 (range 1.008 to 1.031) at the pre-shift assessment to 1.024 (range 1.003 to 1.035) at post-shift (Table 2); the pattern of increase was similar across the three workdays with no evidence of worsening dehydration as the week progressed (Fig. 1). On a typical workday, the proportion of agricultural workers who had pre-shift USG values indicating dehydration (USG ≥1.020) was 53%, increasing to 81% at post-shift. Approximately 3% of agricultural workers had USG values indicating a clinically dehydrated state (USG > 1.030) pre-shift, which increased to 13%, post-shift.

TABLE 2. Hydration and Kidney Function Markers Among Florida Farmworkers; Girasoles Study 2015–2016 ($n = 192$)

	Pre-shift[a,b] ($n = 190$) Mean (SE) or %	Post-shift[a,b] ($n = 192$) Mean (SE) or %	P[c]
Hydration markers			
Urine-specific gravity (USG)	1.020 (0.0004)	1.024 (0.0004)	<0.0001
USG ≥1.020	53%	81%	<0.0001
USG >1.030	3%	13%	<0.0001
Kidney function markers			
Serum creatinine, mg/dL	0.70 (0.01)	0.81 (0.01)	<0.0001
Above sex-specific limits or change ≥0.3 mg/dL[d,e]		31%	
eGFR, mL/min/1.73 m^2	112.8 (1.22)	102.5 (1.21)	<0.0001
eGFR <90 mL/min/1.73 m^2	5%	25%	<0.0001
BUN, mg/dL	14.5 (0.32)	15.8 (0.32)	<0.0001
BUN > 20 mg/dL	7%	10%	0.03
Urine protein >30 mg/dL	2%	10%	<0.0001
Acute kidney injury (AKI)[e]			
AKI, any		33%	
AKI stage 1		31%	
AKI stage 2		3%	
AKI stage 3		0.5%	

[a]The nested data structure of multiple values per person and individuals living in the same household were taken into account when calculating summary measures using the PROC GLIMMIX SAS function.
[b]Number of participants for day 1 was $n = 192$, day 2 was $n = 188$, and day 3 was $n = 175$; not all participants had both before and after work values (555 days of observations before work and 525 days of observations after work).
[c]Significance for the comparison of pre- and post-shift values, adjusting for random effects.
[d]Sex-specific limits for serum creatinine are ≥1.3 mg/dL for males and ≥1.1 mg/dL for females.
[e]Met criteria on at least one workday.

On average, serum creatinine increased from 0.70 mg/dL (range 0.37 to 1.50) to 0.81 mg/dL (0.43 to 1.63 during the work day); 31% of participants had at least 1 day with a level above sex-specific limits or an increase of ≥0.3 mg/dL during the day. The average eGFR of the workers before work was 112.8 mL/min/1.73 m^2 (range 44.0 to 147.9), which decreased over the workday to 102.5 mL/min/1.73 m^2 (range 38.0 to 140.8). The proportion of workers with an eGFR less than 90 mL/min/1.73 m^2 at the pre-shift assessment was 5%, which increased to 25% post-shift. Average BUN increased slightly from 14.5 (range 3.3 to 28.3) at pre-shift to 15.8 (range 4.0 to 28.7) at the post-shift assessment; the proportion of BUN more than 20 mg/dL increased from 7% to 10%. The proportion of workers with more than trace values of urinary protein increased from 2% at pre-shift to 10% at post-shift. One-third of workers with available serum creatinine data experienced AKI on at least one observed workday (63/187), 11 of these had multiple days of AKI. Most of these workers experienced stage 1 AKI (59/187), with stage 2 and 3 AKI being less common (6/187 and 1/187).

In models examining risk factors for USG more than 1.020, each 10-year increase in age was associated with a 32% lower likelihood of USG more than 1.020 [odds ratio (OR) = 0.68, 95% confidence interval (95% CI): 0.48 to 0.98]. Workers were four times as likely to have USG more than 1.020 post-shift (OR = 4.06, 95% CI: 2.99 to 5.52) than pre-shift (Table 3). Point estimates

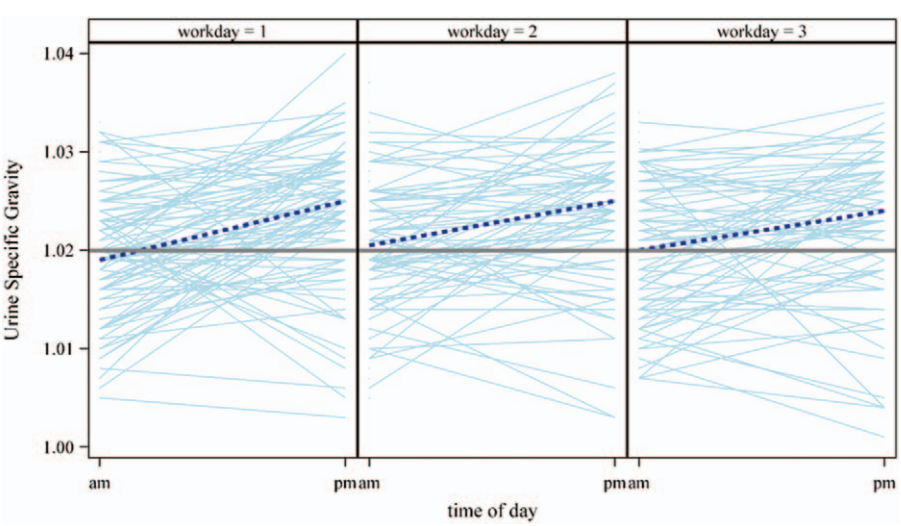

FIGURE 1. Urine-specific gravity by time of urine collection among Florida farmworkers, Girasoles Study 2015–2016. *Gray* lines indicate person-days and the *black* dotted lines are the overall means.

TABLE 3. Factors Associated With Urine-Specific Gravity Among Florida Agricultural Workers; Girasoles Study 2015–2016

	Urine-Specific Gravity >1.020	
	OR (95% CI)*	OR (95% CI)†
Age (per 10 years)	0.68 (0.48, 0.98)	0.81 (0.61, 1.06)
Gender (male = ref)	0.62 (0.35, 1.11)	—
Nationality (ref = Mexico)		
Other	1.18 (0.58, 2.40)	—
Years of Education	0.98 (0.90, 1.06)	—
Body mass index	1.05 (0.99, 1.12)	—
History of hypertension (ref = no)	1.09 (0.34, 3.54)	—
Blood pressure [ref = normal (<120/80)]		
Prehypertension (120–139/80–89)	1.37 (0.76, 2.46)	—
Hypertension (<140/90)	1.50 (0.69, 3.29)	—
History of diabetes (ref = no)		
Yes	0.99 (0.35, 2.82)	—
Primary work type (ref = nursery)		
Fernery	1.79 (0.87, 3.69)	—
Crops	1.43 (0.67, 3.04)	—
Years worked in agriculture	1.01 (0.96, 1.05)	—
Hours worked per day	0.98 (0.79, 1.23)	—
Drinks more sports drinks at work (ref = no)	1.06 (0.60, 1.88)	—
Drinks more energy drinks at work (ref = no)	1.19 (0.62, 2.32)	—
Drinks more juice at work (ref = no)	0.74 (0.43, 1.27)	—
Drinks more soda at work (ref = no)	1.46 (0.89, 2.39)	—
Mean Heat Index‡	1.04 (0.87, 1.24)	—
Time of day (ref = am)	4.06 (2.99, 5.52)	3.81 (2.85, 5.08)

*Full model, mutually adjusting for all other variables in the model.
†Reduced model, keeping only variables with $P < 0.05$.
‡Heat index units are per 5 degrees Fahrenheit.

suggest that females were less likely to be dehydrated, and workers in fernery or field crops, or workers who drank soda at work were more likely to be dehydrated. However, these results were not significant. In a reduced model including age and time of day, age did not remain significant.

In the final model examining risk factors for of AKI with mean HI (Table 4), it was found that each 5-degree increase in the HI was associated with a 47% increase in the likelihood of AKI (OR = 1.47, 95% CI: 1.14 to 1.90). Point estimates suggest that females may less likely to have AKI (OR = 0.72, 95% CI: 0.41 to 1.29) and dehydration may be associated with increased AKI, but were not statistically significant.

DISCUSSION

There has been limited examination of hydration status, heat exposure, and kidney function in the U.S. agricultural workforce, although there is a substantial body of evidence emerging among Central American agricultural workers. In this study of Florida agricultural workers, a strikingly high proportion of workers were dehydrated before starting work shift and this dehydration had increased substantially by the end of the workday. A high proportion of the workers in our study had at least one day with a creatinine level above sex-specific limits or an increase of at least 0.3 mg/dL during the day. Additionally, higher heat indices were found to be significantly associated with increased incidence of AKI over the workday. These findings suggest that AKI is occurring in the U.S agricultural workforce exposed to hot working environments.

The prevalence of dehydration in this sample was comparable to hydration status studies on that used USG measures with other occupational groups laboring in hot conditions, including sugarcane workers in Central America,[15,33] construction and industrial workers in the Middle East,[24,34] and underground mine workers in Australia.[25] Overall, these studies indicate that workers laboring in hot outdoor settings are dehydrated before work. In a study of sugarcane workers in Central America, mean pre-shift was USG 1.016 and increased to 1.020 (range 1.003 to 1.037) at the post-shift assessment ($P < 0.001$).[15] In Nicaragua, a cross-sectional prevalence study of sugarcane workers, construction workers, and agricultural workers reported pre-shift USG levels at least 1.030 of 15%, 29%, and 20%, respectively.[33] In a cohort of construction workers in Iran, mean USG among a group who worked in the sun was significantly higher than those who worked in the shade [USG 1.026 (SD 0.0026) and 1.0213 (SD 0.0054), respectively].[24] An increase in USG of 0.005 could be clinically meaningful if this pushes a worker's USG over the 1.020 or 1.030 thresholds for hypohydration and severe clinical dehydration, respectively.[24,27,28] Our findings, and that of other studies indicate that many workers start their work shift dehydrated, which warrants efforts to increase prevention in this population. Future research and outreach efforts should include educating workers about the importance of hydration post-work shift, to facilitate recovery after working in hot conditions.

There are limited data that exist examining AKI in agricultural workers. In a recent study performed in California, 11.8% of workers were found to have AKI according to the KDIGO criteria.[20] In the current study, there was evidence of AKI with 33% of workers experiencing AKI on at least one workday; our protocol of following workers for three workdays and the vulnerability of this immigrant population are two factors that may have resulted in a higher prevalence of AKI in our study. There is a need for more robust longitudinal study designs of AKI and CKD in the United States, as CKD is endemic in Central America and other equatorial countries, and is likely to be underreported in the United States. Future evaluations should include continuous personal heat monitoring[35] over the course of a growing season and longer-term follow up. This type of evaluation is challenging in this population because of the mobile nature of agricultural work in the U.S. In addition, longitudinal personal heat monitoring requires advanced analytical

TABLE 4. Factors Associated With Acute Kidney Injury Among Florida Agricultural Workers; Girasoles Study 2015–2016

Characteristics	Model 1*: OR (95% CI)	Model 2†: OR (95% CI)
Age‡	1.01 (0.96, 1.06)	1.00 (0.96, 1.03)
Gender (ref = male)		
Female	0.62 (0.30, 1.29)	0.72 (0.41, 1.29)
Nationality (ref = Mexico)		
Other	0.97 (0.39, 2.42)	0.91 (0.48, 1.73)
Years of education	0.98 (0.87, 1.09)	—
Body mass index	1.07 (0.98, 1.17)	—
History of hypertension (ref = no)	1.49 (0.36, 6.18)	—
Blood pressure [ref = normal (<120/80)]		
Prehypertension (120–139/80–89)	0.91 (0.41, 2.03)	—
Hypertension (<140/90)	0.90 (0.33, 2.46)	—
History of diabetes (ref = no)		
Yes	0.85 (0.20, 3.63)	—
Work type (ref = nursery)		
Crop	0.92 (0.36, 2.35)	—
Fernery	1.47 (0.55, 3.92)	—
Years worked in agriculture	0.96 (0.90, 1.02)	—
Hours worked per day	0.88 (0.67, 1.15)	—
USG >1.020 (ref = neither before or after work)		
Before work only	1.58 (0.42, 5.92)	1.34 (0.38, 4.75)
After work only	1.30 (0.52, 3.29)	1.47 (0.61, 3.54)
Before and after work	1.04 (0.42, 2.59)	1.13 (0.48, 2.68)
Drinks more sports drinks at work (ref = no)	1.52 (0.69, 3.32)	—
Drinks more energy drinks at work (ref = no)	1.24 (0.55, 2.78)	—
Drinks more juice at work (ref = no)	0.81 (0.39, 1.67)	—
Drinks more soda at work (ref = no)	0.78 (0.41, 1.51)	—
Mean Heat Index§	1.59 (1.19, 2.11)	1.47 (1.14, 1.90)

*Mutually adjusted estimates are based on farmworkers that had completed data for all variables shown in the table ($n = 192$).
†Reduced model retaining age, sex, nationality, urine-specific gravity, and mean heat index.
‡Age units are per 10 years.
§Heat index units are per 5°F.

techniques and standardized methods to efficiently deal with the complex data outputs from continuously monitored data over multiple time points.[36]

Many barriers to hydration exist in the agricultural environment. Guidelines from the Occupational Safety and Health Administration (OSHA) are charged with protecting agricultural workers and suggest that employers provide adequate water at the work site, rest breaks, and shade. When working in hot conditions, the American Conference of Governmental Industrial Hygienists (ACGIH) recommends that workers drink one cup of water every 15 minutes; if excessive sweating occurs for 4 or more hours in hot conditions, electrolyte replacement should be used.[37] Agricultural workers may refrain from drinking enough water because they do not want water or restroom breaks to interfere with their productivity; this is especially important in worksites that pay by the piece or volume harvested instead of an hourly wage. In addition, immigrant agricultural workers are often employed by subcontractors and labor crews. Field crop workers may travel to different locations during a workday and water may not always be available unless workers supply it themselves. Even then, food security regulations may prevent workers from bringing their beverages into the fields while they work.[38] Individual subcontractor supervisors and labor crews may not have the training or resources to know when to encourage others to hydrate, recognize signs and symptoms of HRI, or when to seek emergency care. HRI training is reported to be low in the agricultural worker population[4] and HRI-prevention knowledgeable workers may have little to no control over their environments to implement these measures. It is imperative that state and federal guidelines be reviewed and updated regularly to allow the infrastructure and education to reduce barriers to providing protections to agricultural workers.

Individual health characteristics, behavioral factors, and cultural factors also influence hydration levels in immigrant agricultural workers. Heat acclimatization is a significant factor influencing the risk of developing HRI[39]; acclimatized workers benefit from physiologic adaptations including sweating beginning earlier with greater volume, which improves heat dissipation; and less loss of electrolytes.[2] Participants in the current study had been working in agriculture for at least 1 month to mitigate the impact of lack of acclimatization; the average number of years participants reported working in agriculture was 12 years. However, given the variable nature of agricultural work, acclimatization may be hard to maintain, as even a small break from working in hot environments requires a re-acclimatization period.[37] Behavioral practices of agricultural workers indicate that the majority of workers know that water intake should be increased during prolonged activity in the heat.[4] Although not significant, males were more likely to be dehydrated than females; it is plausible that male agricultural workers are not as compliant with preventive health measures such as drinking water, resting, and seeking shade while at work because they do not want to be perceived as weak or not able to provide for their families.[40,41] Although more than 50% of workers in the current study had indications of pre-workday dehydration, nearly all workers reported drinking more water while working in the heat. The body's thirst mechanisms may be initiated after the body is already dehydrated and can be further delayed due to personal physiologic factors such as age[42]; it is important to determine the potential impact of hydration routines (frequency, amount, timing, composition) and electrolyte supplementation and how these measures could be implemented in this population.

There is very limited study of personal heat exposure, particularly among U.S. immigrant agricultural workers. The strong community partnership between the agricultural workers and the FWAF was crucial to reaching this vulnerable population of workers. The *Girasoles* study has provided information to individual workers, worker communities, and health care providers about HRI. In some cases, participants have been referred to health care providers for health conditions of which they may not have been aware.

There are some limitations to this study. First, there is no gold standard for measuring and diagnosing dehydration.[43] Urinary and serum biomarkers are often used to determine overall hydration status. Measuring USG on a first morning void sample is reliable, but real-time measures of USG may be confounded by factors such as volume of fluid intake, types of beverages consumed, food intake, medications, and sweating.[44] However, USG has been used for monitoring hydration status in other occupational groups laboring in hot environments.[15,24,25,34] In addition, a USG of at least 1.020 has been shown to be associated with a body mass loss of 3%.[45] As kidney function lags behind blood parameters,[44] calculated serum osmolality may be a more stable biomarker of hydration, but has been tested mainly in young, fit, and healthy individuals, which may not be applicable to this population. In addition, blood markers of hydration status are not practical for employers to monitor agricultural workers in the field setting due to cost. More research identifying the types biomarkers of hydration that are valid and reliable in the field setting, in diverse worker populations, as well as a consensus the optimal cut points for diagnosing and monitoring hydration in workers under thermal stress are needed.

Many of the studies of agricultural workers in Central America have focused on sugarcane workers and it has been postulated that a combination of factors, including medication use, chemical exposures, and heat exposure contribute to the access in renal disease. A strength of our study was the recruitment of workers across three different types of agricultural work. While we did not specifically examine chemical exposures such as pesticides that might theoretically have an effect on renal function, the inclusion of workers from different agricultural settings suggests that no one crop or agricultural setting exposed workers to chemicals that could increase the likelihood of AKI. Although the workers recruited into this study were a convenience sample, the inclusion of multiple agricultural settings strengthen the study's generalizability to other agricultural populations; studies that include diverse populations of agricultural workers are crucial to make changes in public health policy. In addition, our sample size may have hampered our ability to identify statistical significance in other predictors included in our models.

CONCLUSION

Our findings suggest that immigrant agricultural workers in Florida agriculture have a high burden of dehydration and experience adverse changes in kidney function during their workdays. Most interestingly, 33% of immigrant workers in our sample experienced AKI and HI was significantly related to the incidence of AKI. Increased global climate temperatures will increase the vulnerability of agricultural workers to HRI in the future and this presents a critical public health challenge. More research is needed to examine the complex relationship between hydration, heat exposure, and kidney function in this population.

REFERENCES

1. Centers for Disease Control and Prevention. Heat-related deaths among crop workers: United States, 1992–2006. *MMWR Morb Mortal Wkly Rep*. 2008;57:649–653.
2. Jackson LL, Rosenberg HR. Preventing heat-related illness among agricultural workers. *J Agromedicine*. 2010;15:200–215.
3. Hansen E, Donohoe M. Health issues of migrant and seasonal farmworkers. *J Health Care Poor Underserved*. 2003;14:153–164.
4. Fleischer NL, Tiesman HM, Sumitani J, et al. Public health impact of heat-related illness among migrant farmworkers. *Am J Prev Med*. 2013;44:199–206.
5. Bethel JW, Harger R. Heat-related illness among Oregon farmworkers. *Int J Environ Res Public Health*. 2014;11:9273–9285.
6. Arcury TA, Summers P, Talton JW, et al. Heat illness among North Carolina Latino farmworkers. *J Occup Environ Med*. 2015;57:1299–1304.
7. Arcury TA, Quandt SA, Russell GB. Pesticide safety among farmworkers: perceived risk and perceived control as factors reflecting environmental justice. *Environ Health Perspect*. 2002;110:233–240.
8. Flocks J, Kelley M, Economos J, McCauley L. Female farmworkers' perceptions of pesticide exposure and pregnancy health. *J Immigr Minor Health*. 2012;14:626–632.
9. Flocks J, Vi Thien Mac V, Runkle J, Tovar-Aguilar JA, Economos J, McCauley LA. Female farmworkers' perceptions of heat-related illness and pregnancy health. *J Agromedicine*. 2013;18:350–358.
10. Mayer B, Flocks J, Monaghan P. The role of employers and supervisors in promoting pesticide safety behavior among Florida farmworkers. *Am J Ind Med*. 2010;53:814–824.
11. Johnson RJ, Sanchez-Lozada LG. Chronic kidney disease: Mesoamerican nephropathy: new clues to the cause. *Nat Rev Nephrol*. 2013;9:560–561.
12. Wesseling C, Aragon A, Gonzalez M, et al. Heat stress, hydration and uric acid: a cross-sectional study in workers of three occupations in a hotspot of Mesoamerican nephropathy in Nicaragua. *BMJ Open*. 2016;6:e011034.
13. Levey AS, Inker LA, Coresh J. GFR estimation: from physiology to public health. *Am J Kidney Dis*. 2014;63:820–834.
14. Roncal-Jimenez C, Lanaspa MA, Jensen T, Sanchez-Lozada LG, Johnson RJ. Mechanisms by which dehydration may lead to chronic kidney disease. *Ann Nutr Metab*. 2015;66:10–13.
15. Garcia-Trabanino R, Jarquin E, Wesseling C, et al. Heat stress, dehydration, and kidney function in sugarcane cutters in El Salvador: a cross-shift study of workers at risk of Mesoamerican nephropathy. *Environ Res*. 2015;142: 746–755.
16. Laws RL, Brooks DR, Amador JJ, et al. Changes in kidney function among Nicaraguan sugarcane workers. *Int J Occup Environ Health*. 2015;21: 241–250.
17. Laws RL, Brooks DR, Amador JJ, et al. Biomarkers of kidney injury among Nicaraguan sugarcane workers. *Am J Kidney Dis*. 2016;67:209–217.
18. Soni SS, Pophale R, Ronco C. New biomarkers for acute renal injury. *Clin Chem Lab Med*. 2011;49:1257–1263.
19. Schmidt-Ott KM. *Neutrophil Gelatinase-Associated Lipocalin as a Biomarker of Acute Kidney Injury−−Where do we Stand Today?*. Oxford University Press; 2011.
20. Moyce S, Joseph J, Tancredi D, Mitchell D, Schenker M. Cumulative incidence of acute kidney injury in California's agricultural workers. *J Occup Environ Med*. 2016;58:391–397.
21. Moyce S, Mitchell D, Armitage T, Tancredi D, Joseph J, Schenker M. Heat strain, volume depletion and kidney function in California agricultural workers. *Occup Environ Med*. 2017;74:402–409.
22. World Health Organization. Body mass index - BMI [cited 2017 August 7]. Available from: http://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi.
23. American Heart Association. The Facts About High Blood Pressure [cited 2017 August 7]. Available from: https://www.heart.org/HEARTORG/Conditions/HighBloodPressure/GettheFactsAboutHighBloodPressure/The-Facts-About-High-Blood-Pressure_UCM_002050_Article.jsp.
24. Montazer S, Farshad AA, Monazzam MR, Eyvazlou M, Yaraghi AA, Mirkazemi R. Assessment of construction workers' hydration status using urine specific gravity. *Int J Occup Med Environ Health*. 2013;26:762–769.
25. Brake DJ, Bates GP. Fluid losses and hydration status of industrial workers under thermal stress working extended shifts. *Occup Environ Med*. 2003;60:90–96.
26. Fisher Scientific. Reichert TS Meter-D Automatic Digital Clinical Refractometer.
27. American College of Sports M, Sawka MN, Burke LM, Eichner ER, et al. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39:377–390.
28. Donoghue AM, Sinclair MJ, Bates GP. Heat exhaustion in a deep underground metalliferous mine. *Occup Environ Med*. 2000;57:165–174.
29. Kellum JA, Lameire N, Group KAGW. Diagnosis, evaluation, and management of acute kidney injury: a KDIGO summary (Part 1). *Crit Care*. 2013;17:204.
30. Kidney Disease Improving Global Health Outcomes (KDIGO) Working Group. Definition and classification of acute kidney injury. *Kidney Int*. 2012;2(Suppl 2):19–36.

31. Anderson GB, Bell ML, Peng RD. Methods to calculate the heat index as an exposure metric in environmental health research. *Environ Health Perspect*. 2013;121:1111–1119.
32. Florida Automated Weather Network (FAWN). Archived weather data. 2016. Available at: http://fawn.ifas.ufl.edu/data/. Accessed June 6, 2016.
33. Wesseling C, Aragon A, Gonzalez M, et al. Kidney function in sugarcane cutters in Nicaragua: a longitudinal study of workers at risk of Mesoamerican nephropathy. *Environ Res*. 2016;147:125–132.
34. Bates GP, Miller VS, Joubert DM. Hydration status of expatriate manual workers during summer in the middle East. *Ann Occup Hyg*. 2010;54: 137–143.
35. Kuras ER, Richardson MB, Calkins MM, et al. Opportunities and challenges for personal heat exposure research. *Environ Health Perspect*. 2017; 125:085001.
36. Hertzberg V, Mac V, Elon L, et al. Novel analytic methods needed for real-time continuous core body temperature data. *West J Nurs Res*. 2017;39: 95–111.
37. Jacklitsch B, Williams J, Musolin K, Coca A, Kim J-H, Turner N. Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments. Cincinnati, Ohio: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; DHHS (NIOSH) Publication 2016-106.
38. Horton SB. *They Leave Their Kidneys in the Fields: Illness, Injury, and Illegality among US Farmworkers.* Oakland, CA: University of California Press; 2016.
39. Hanna EG, Tait PW. Limitations to thermoregulation and acclimatization challenge human adaptation to global warming. *Int J Environ Res Public Health*. 2015;12:8034–8074.
40. Hunter JB, Fernandez ML, Lacy-Martinez CR, Dunne-Sosa AM, Coe MK. Male preventive health behaviors: perceptions from men, women, and clinical staff along the U.S. Mexico border. *Am J Mens Health*. 2007;1:242–249.
41. Roy P, Tremblay G, Robertson S, Houle J. Do it all by myself'': a salutogenic approach of masculine health practice among farming men coping with stress. *Am J Mens Health*. 2017;11:1536–1546.
42. Kenney WL, Chiu P. Influence of age on thirst and fluid intake. *Med Sci Sports Exerc*. 2001;33:1524–1532.
43. Armstrong LE, Kavouras SA, Walsh NP, Roberts WO. Diagnosing dehydration? Blend evidence with clinical observations. *Curr Opin Clin Nutr Metab Care*. 2016;19:434–438.
44. Cheuvront SN, Kenefick RW, Zambraski EJ. Spot urine concentrations should not be used for hydration assessment: a methodology review. *Int J Sport Nutr Exerc Metab.* 2015;25:293–297.
45. Casa DJ, Armstrong LE, Hillman SK, et al. National athletic trainers' association position statement: fluid replacement for athletes. *J Athl Train.* 2000;35:212–224.

