Critical care ultrasound in geriatric trauma resuscitation leads to decreased fluid administration and ventilator days

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BACKGROUND: Geriatric trauma populations respond differently than younger trauma populations. Critical care ultrasound (CCUS) can guide resuscitation, and it has been shown to decrease intravenous fluid (IVF), lower time until operation, and lower mortality in trauma. Critical care ultrasound–guided resuscitation has not yet been studied in geriatric trauma. We hypothesized that incorporation of CCUS would decrease amount of IVF administered, decrease time to initiation of vasopressors, and decrease end organ dysfunction.

METHODS: A PRE-CCUS geriatric trauma group between January 2015 and October 2016 was resuscitated per standard practice. A POST-CCUS group between January 2017 and December 2018 was resuscitated based on CCUS performed by trained intensivist upon admission to the intensive care unit and 6 hours after initial ultrasound. The PRE-CCUS and POST-CCUS groups underwent propensity score matching, yielding 60 enrollees in each arm. Retrospective review was conducted for demographics, clinical outcomes, and primary endpoints, including amount of IVF in the first 48 hours, duration to initiation of vasopressor use, and end organ dysfunction. Wilcoxon two-sample, χ^2 tests, and κ statistics were performed to check associations between groups.

RESULTS: There was no statistical difference between PRE-CCUS and POST-CCUS demographics and Injury Severity Scores. Intravenous fluid within 48 hours decreased from median [interquartile range] of 4941 mL [4019 mL] in the PRE-CCUS to 2633 mL [3671 mL] in the POST-CCUS ($p = 0.0003$). There was no significant difference between the two groups in time to initiation of vasopressors, vasopressor duration, lactate clearance, intensive care unit length of stay, or hospital length of stay. There was a significant decrease in ventilator days, with 26.7% PRE-CCUS with ventilation longer than 2 days, and only 6.7% POST-CCUS requiring ventilation longer than 2 days ($p = 0.0033$).

CONCLUSION: Critical care ultrasound can be a useful addition to geriatric resuscitation. The POST-CCUS received less IV fluid and had decreased ventilator days. While mortality, lactate clearance, complications, and hospital stay were not statistically different, there was a perception that CCUS was a useful adjunct for assessing volume status and cardiac function. (*J Trauma Acute Care Surg.* 2021;91: 612–620. Copyright © 2021 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Therapeutic, level II.

KEY WORDS: Ultrasound; geriatric; resuscitation; CCUS.

The geriatric trauma population (defined as aged ≥65 years) responds differently to traumatic injuries with an increased risk of poor outcomes compared with the nongeriatric cohort. The physiologic complexities of aging combined with preexisting medical conditions serve as independent predictors of mortality, thus rendering the care of the geriatric patient particularly challenging.[1] Prior studies examining the effect of age on hemodynamics in trauma have demonstrated that the elderly have decreased cardiovascular performance, reduced tissue perfusion, and higher mortality.[2–4] Perdue et al. found that patients 65 years or older have as high as a 2.5-fold increased risk of early mortality (<24 hours) and a 4.6-fold increase of late mortality (>24 hours) after trauma.[5] In addition, the 2012 Eastern Association for the Surgery of Trauma Practice Management Guidelines on the Evaluation and Management of Geriatric Trauma state that a significant number of patients older than 65 years are undertriaged, resulting in an increased risk for adverse outcomes following injury and may benefit from liberal application of intensive care unit (ICU) care and invasive monitoring.[6–9]

A variety of noninvasive clinical parameters, such as vital signs, laboratory values, and clinical assessment of end-organ perfusion, have been validated as surrogates for resuscitation for several subgroups of trauma patients. However, ideal resuscitative goals for the geriatric patient remain ill-defined. Prior studies have attempted to further delineate resuscitation goals for this subgroup, but confounding factors often limit the interpretation and broader applicability of their results. More invasive strategies, such as pulmonary artery catheter placement, central venous pressure monitoring via central venous line, and arterial line placement with arterial pulse pressure variation monitoring, all have inherent risks and limitations with unproven outcome benefits.[10]

In recent years, Critical Care Ultrasound (CCUS) has evolved as an important diagnostic tool for the rapid, reproducible, and noninvasive assessment of cardiac function and volume status in critically ill patients. This examination is performed at the bedside by a trained intensivist, and its accuracy is largely based on the skill of the operator and the ability to obtain high-quality images for interpretation.[11,12] Indeed, Ferrada et al.[13] showed that trauma surgeons could reliably use limited thoracic ultrasound for resuscitation in hypovolemic patients. Real-time data can be used to guide resuscitation by evaluating both cardiac function and intravascular volume status.[14]

As such, CCUS is an internationally accepted means of obtaining timely hemodynamic parameters with little risk to the patient.[15] In the population of patients with undifferentiated shock, Kanji et al.[16] showed that the utilization of CCUS resulted in decreased intravenous fluid (IVF) administration, increased vasopressor use, and improved survival. Utilization of CCUS has also been demonstrated to improve outcomes for trauma patients. Ferrada et al.[17] found that using CCUS in the trauma bay to guide resuscitation of the hypotensive trauma patient resulted in less IVFs, lower time until operation, higher ICU admission rates, and lower mortality, particularly in the traumatic brain injury subgroup. However, CCUS has not yet been studied or widely used in resuscitation of the geriatric trauma patient.

Therefore, to examine the impact of CCUS in the resuscitative phase of geriatric trauma patients, we analyzed the effect of CCUS guided resuscitation on clinical outcomes at a Level I trauma center. The aim of this study was to establish the routine

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use of ultrasound-guided resuscitation and to improve outcomes in geriatric trauma patients. Primary endpoints consisted of volume of IVF administered within the first 48 hours, time to vasopressor initiation, duration of vasopressor use, and time to lactate clearance, which was used as a surrogate for end organ dysfunction. Secondary endpoints included days on the ventilator, ICU length of stay (LOS), hospital LOS, and inpatient mortality. We hypothesized that incorporation of the CCUS into geriatric resuscitation would decrease IVF administration, decrease the amount of time to initiate vasopressors, and decrease end organ dysfunction.

METHODS

Patient Population and Data Source

Carolinas Medical Center in Charlotte, North Carolina serves as the only American College of Surgeons (ACS) verified Level I Trauma Center of the Atrium Health Network and the only Level I Trauma Center in greater Charlotte-Mecklenburg region. The division of trauma and acute care surgery is staffed by 14 surgical intensivists, and all have completed a comprehensive national or regional CCUS course. Surgical intensivists completed ultrasound courses sponsored by the Society of Critical Care Medicine or courses conducted regionally by certified course directors within the year prior. The regional CCUS course consisted of a 1-day course including 3 hours of didactics and 5 hours of the hands-on training using live patient models. During the course, the intensivists had to demonstrate proficiency with a practical examination.

Electronic medical record and the institutional trauma registry were used to obtain patient demographics, clinical data, and clinical outcomes. Inclusion criteria consisted of patients older than 55 years sustaining traumatic injuries and admitted to the ICU between January 1, 2015, and December 31, 2018. Exclusion criteria included penetrating cardiac trauma, incarcerated patients, and those requiring operative intervention within 24 hours of admission. The project was reviewed and approved by the Atrium Health Institutional Review Board (Carolinas Healthcare System-03-16-03A, Geriatric Trauma Ultrasound Guided Resuscitation, Pro 00020200). All patients were consented prior to enrollment.

Variables

Data were collected from electronic medical record and the trauma registry and included: demographics, mechanism of injuries, vitals, Injury Severity Score (ISS), ICU LOS, hospital LOS, ventilator days, and mortality. Individual chart reviews were conducted to obtain IVF administration in first 48 hours, lactate at 24 hours, lactate clearance in hours, time in hours until vasopressor initiation, and total vasopressor duration in hours. Trauma registry data were queried for complications and comorbidities.

Study Design

Patients were divided into two subgroups: a PRE-CCUS subgroup and a POST-CCUS cohort. Sample size estimation was based on the primary hypothesis: POST-CCUS would decrease the amount of IVFs administered in the first 48 hours of admission to ICU. Assuming a mean of 5,000 mL and 3,200 mL in PRE-CCUS and POST-CCUS, respectively, and a common standard deviation (SD) of 3200 mL, a sample size of 51 per group has at least 80% power to detect such difference with a two-sided significance level of 0.05. With asymptotic relative efficiency (ARE) of 0.864, the sample size of 60 per group was chosen.

The propensity scores between PRE-CCUS and POST-CCUS were calculated using multivariable logistic regression. Greedy Nearest Neighbor 1-to-1 matching algorithm with a caliper distance of 0.05 was used to create the matching samples. We considered factors including age, sex, intubated on arrival to emergency department (ED), mechanism of injury, ED systolic blood pressure (ED SBP), ED Glasgow Coma Scale (GCS), lactate levels, and injury severity score. After the propensity score matching, 60 subjects were selected from 1,240 patients of PRE-CCUS group, and 78 POST-CCUS group, respectively.

TABLE 1. Patients' Characteristics

		PRE-CCUS n = 60	POST-CCUS n = 60	*p*
Sex	Female, n (%)	23 (38.33)	28 (46.7)	0.356
	Male, n (%)	37 (61.7)	32 (53.3)	
Race	Black or African American	9 (15)	5 (8.3)	0.266
	White	45 (75)	52 (86.7)	
	Others	6 (10)	3 (5)	
MOI	Assault	1 (1.7)	1 (1.7)	0.994
	Fall	35 (58.3)	34 (56.7)	
	MVC	15 (25)	17 (28.3)	
	Motorcycle Crash	2 (3.3)	2 (3.3)	
	Motorized Vehicle	3 (5)	2 (3.3)	
	Unmotorized	4 (6.7)	4 (6.7)	
Age, years	Mean (SD)	73.5 (11.8)	73.4 (10.9)	0.955
ED SBP	Mean (SD)	139.7 (29.3)	134.4 (33.4)	0.358
ISS	Median (IQR)	12 (9–17)	14 (9–18.5)	0.566
ED GCS	Median (IQR)	15 (15–15)	15 (15–15)	0.972
Comorbidities				
Psychiatric illness	n (%)	4 (6.7)	3 (5)	1
Alcohol use	n (%)	7 (11.7)	1 (1.7)	0.061
Drug use	n (%)	2 (3.3)	0 (0)	0.496
Dementia	n (%)	8 (13.3)	6 (10)	0.57
CVA_history	n (%)	3 (5)	6 (10)	0.491
Cardiac arrest	n (%)	1 (1.7)	0 (0)	1
HTN	n (%)	37 (61.7)	42 (70)	0.036
CHF	n (%)	2 (3.3)	6 (10)	0.272
Smoker	n (%)	11 (18.3)	12 (20)	0.817
COPD	n (%)	6 (10)	8 (13.3)	0.57
Obesity	n (%)	2 (3.3)	0 (0)	0.496
Cirrhosis	n (%)	1 (1.7)	0 (0)	1
DM	n (%)	16	19	0.55
PVD	n (%)	1 (1.7)	0 (0)	0.496
Bleeding disorder (anticoagulation)	n (%)	13 (21.7)	12 (20.3)	0.8589
Cancer	n (%)	1 (1.7)	1 (1.7)	1
Advanced directive	n (%)	4 (6.7)	2 (3.3)	0.679

MOI, mechanism of injury; MVC, motor vehicle collision; CVA, cerebral vascular accident; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; DM diabetes mellitus; PVD, peripheral vascular disease.

The balance of covariances between groups was assessed using the absolute standardized difference, and variance ratio. For continuous variable, the absolute standardized difference is the absolute different in means divided by a pooled SD gives equal weight to both groups before matching (formula 1). For the dichotomous variable, the absolute standardized difference was calculated using formula 2.

$$d = \frac{\left|\bar{x}_{\text{treatment}} - \bar{x}_{\text{control}}\right|}{\sqrt{\frac{s^2_{\text{treatment}} + s^2_{\text{control}}}{2}}} \quad (1)$$

$$d = \frac{\left|\hat{p}_{\text{treatment}} - \hat{p}_{\text{control}}\right|}{\sqrt{\frac{\hat{p}_{\text{treatment}}(1-\hat{p}_{\text{treatment}}) + \hat{p}_{\text{control}}(1-\hat{p}_{\text{control}})}{2}}} \quad (2)$$

For the variable of mechanism of injury, we checked the frequency and percentages in each group, and the results indicated balanced distribution between the two groups.

The absolute standardized differences ranged from 0 to 0.2, except ED SBP (0.9), and variance ratio ranged from 0.9 to 1.6. Although the standardized difference for ED SBP, the variances of the propensity scores between groups are close to one (not shown in Appendix table, http://links.lww.com/TA/C86), indicating that the variances of the propensity scores between the two groups are about equal.

The PRE-CCUS patients were admitted between January 1, 2015, and October 1, 2016, and patients were resuscitated per standard protocol. There was a 3-month intermission between the PRE-CCUS and POST-CCUS groups to allow for staff training. The POST-CCUS patients were admitted between January 1, 2017, and December 31, 2018. Trained intensivists then performed a cardiac ultrasound on each patient at the time of arrival to the ICU and 6 hours after ICU admission. The cardiac ultrasound consisted of parasternal long, parasternal short, apical 4, subcostal, and inferior vena cava (IVC) views. Inferior vena cava diameters and collapsibility index were measured and recorded. When able, patients were placed in the left lateral decubitus position to better aid in obtaining adequate images, especially the apical 4 view. Surgeons saved the video clips of the CCUS and filled out a short questionnaire regarding the view quality graded by Likert scale (excellent, good, adequate, poor or unable), ease of obtaining images (easy, mildly difficult, moderately difficult, extremely difficult, impossible), cardiac function (hyperdynamic, normal, moderately depressed, severely depressed), perceived helpfulness of the ultrasound (excellent, good, average, poor, none), and if intervention was completed based on CCUS results (crystalloid, colloid, or vasopressors). Surgical intensivists also recorded comments regarding cardiac findings (left ventricular hypertrophy, left atrial enlargement, pericardial effusion, right ventricular enlargement) and cardiac function. Intervention recommendations were based on cardiac function, IVC diameter, and if IVC diameter changed more than 50% with respiration.

In the final phase of the study, a board-certified emergency medicine physician with fellowship training in ultrasound reviewed all the ultrasounds and filled out the same worksheet as the surgical intensivists. The reviewer determined cardiac function and ranked the quality and utility of the images. Reviewer observations were then compared with original surgeon assessments to benchmark quality control.

Statistical Analysis

Normality distribution was checked for continuous variables before conducting any analysis. Patients' characteristics were described and compared between PRE-CCUS patient cohort with patients receiving CCUS to guide resuscitation (POST-CCUS). To assess the univariate association between PRE-CCUS and POST-CCUS, we used Wilcoxon two-sample or two-sample *t* test for nonnormal, or normal continuous variable, respectively, and χ^2 or Fisher's exact test for categorical variables. Since patients

TABLE 2. Clinical Outcome

	PRE-CCUS	POST-CCUS		Adjusted Results	
	n (%)	n (%)	Unadjusted *p*	OR (95% CI)	*p*
Lactate at 24 h					
≤2.3	53 (91.4%)	55 (91.7%)	1	0.9 (0.3–3.5)	0.922
Ventilator days					
≤2 d	44 (73.3)	56 (93.3)	0.003	4.9 (1.5–15.9)	0.007
Mortality	6 (10%)	2 (3.3%)	0.272	0.3 (0.1–1.7)	0.183
Complications	18 (30)	17 (28.3)	0.841	1 (0.4–2.1)	0.929
Time to initiate vasopressor, median (IQR)	0 (0–0)	0 (0–0)	0.324		
Time to initiate vasopressor = 0	56 (93.3%)	53 (88.3%)	0.342	0.5 (0.1, 1.9)	0.339
Pressor duration, median (IQR)	0 (0–0)	0 (0–0)	0.651		
Pressor duration = 0	54 (90%)	52 (86.7%)	0.57	0.7 (0.2, 2.2)	0.562
				Coefficient Estimates (95% CI)	***p***
IVF 48 h, Ml, median (IQR)	4,941 (2814–6833)	2,633 (1210–4881)	0.0003	−2013 (−3067,-960)	0.0002
Hospital LOS, median (IQR)	6 (3–12.5)	6 (4–9)	0.821	−0.4 (−2.2, 1.4)	0.657
ICU LOS, d	3 (2–7)	2 (2–4)	0.1	−0.5 (−1.3, 0.2)	0.144

Adjusted covariate: HTN.

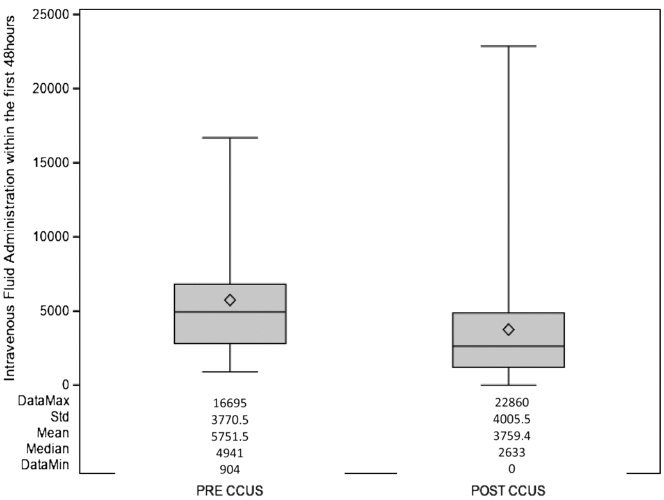

Figure 1. Boxplot of comparing of IVF Administration within the first 48 hours between PRE-CCUS and POST-CCUS.

showed difference in high blood pressure (HTN) between PRE-CCUS and POST-CCUS, we adjusted for it for binary multiple logistic regression or robust regression models. We reported adjusted odds ratios (OR) (95% confidence intervals) for binary outcome variables, and regression coefficients (95% confidence intervals) for continuous outcome variables, respectively. When comparing the agreement between surgeon and expert ultrasound reviewer, we used both the first and second ultrasound results. We combined "excellent" and "good" and grouped all other ratings for analysis. This grouping was used for analysis of subcostal, parasternal long, parasternal short, apical 4, and IVC. For cardiac function, we combined "hyperdynamic" and "normal" and "moderately depressed" and "severely depressed."

We calculated the observed agreement, which was defined as the total number of agreements between two raters divided by the total number of ultrasounds that both raters had reviewed. In addition, we used κ coefficient to measure the magnitude of the agreement.

Mean and SD, median and interquartile range (IQR) were reported for normally and nonnormally distributed continuous or ordinal variables, respectively. Frequency and percentages were reported for categorical variables. Two-tailed *p* values were calculated for all statistical tests, and a *p* value less than 0.05 was considered statistically significant. All data were analyzed using SAS 9.4 (SAS Institute Inc. Cary, NC).

RESULTS

Patient Characteristics

Table 1 presents 120 patient characteristics. In the PRE-CCUS group, 61.7% of the patients were men, average age was 73.5 years, and 75% were White, while the POST-CCUS group was 53.3% men (*p* value 0.36), average age was 73.4 years ($p = 0.96$), and 86.7% were White ($p = 0.27$). Fall was the most common mechanism of injury with 58.3% in the PRE-CCUS and 56.7% in the POST-CCUS group. Other injury patterns included motor vehicle collision (25% and 28.3%), motorcycle (3.33% and 3.33%), scooter (5% and 3.3%), and assault (1.7% and 1.7%). Median (IQR) ISS was 12 (9–17) in the PRE-CCUS group and 14 (9–18.5) in the POST-CCUS group ($p = 0.566$). Median (IQR) GCS score on presentation was 15 (15–15) in the PRE-CCUS group and 15 (15–15) in the POST-CCUS group. Initial systolic blood pressure on presentation to the ED was 139.8 mm Hg in PRE-and 134.4 mm Hg in the POST ($p = 0.28$). A total of two patients (3.3%) in the PRE-CCUS group and four patients (6.7%) in the POST-CCUS group were intubated on arrival. The patients in the PRE-CCUS and POST-CCUS had similar comorbidities. The POST-CCUS had higher rate of high blood pressure (70% vs. 61.7%, $p = 0.036$).

Primary Endpoints

Administration of IVF within 48 hours decreased from median [IQR] 4941 mL [2814.5–6833 mL] in the PRE-CCUS group to 2633 mL [1210–4881 mL] in the POST-CCUS group ($p = 0.0003$). Table 2 and Figure 1 boxplot depicts the differences. Holding HTN constant, patients from POST-CCUS group decreased by average of 2013.8 mL (95% CI, −3067.4 to −960.1 mL; $p = 0.0002$).

There was no difference in time in hours to initiation of vasopressor therapy between the PRE-CCUS and POST-CCUS group (median, 0; IQR, 0–0; $p = 0.324$). There were 93.3% of PRE-CCUS and 88.3% of POST-CCUS that showed zero values in time to initiation of vasopressor therapy, and only four patients (range, 25–48 hours) of PRE-CCUS and seven patients (range, 0.25–57 hours) of POST-CCUS were higher than zero. Pressor duration in hours was also similar between PRE-CCUS and POST-CCUS (median, 0; IQR, 0–0; $p = 0.651$). Ninety percent of PRE-CCUS, and 87% POST-CCUS showed zero values, and only six patients (range, 4.15–61.5) of PRE-CCUS, and eight patients (range, 0.75–47.25) of POST-CCUS were higher than zero.

There was no difference in time to lactate clearance, with 91.4% cleared at 24 hours in PRE-CCUS, and 91.7% cleared at 24 hours in POST-CCUS ($p = 1$).

Both the univariate analysis and multivariate analysis showed consistent results with each other.

Secondary Endpoints

In the PRE-CCUS group, 73.3% spent less than 2 days on a ventilator, while in the POST-CCUS group, 93.3% spent less

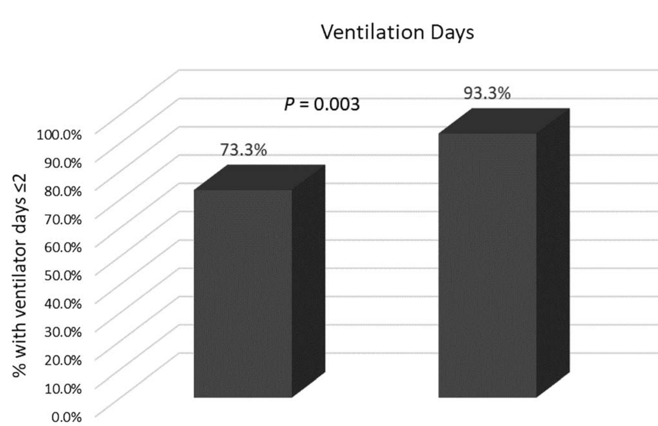

Figure 2. Comparing ventilation days between PRE-CCUS and POST-CCUS.

TABLE 3. Complications

		Total	PRE-CCUS	POST-CCUS
Death	n (%)	9 (7.5%)	6 (10%)	3 (5%)
Higher level care/BBICU/readmission	n (%)	11 (9.2%)	6 (10%)	5 (8.3%)
Neuro (seizure, stroke)	n (%)	5 (4.2%)	1 (1.7%)	4 (6.7%)
Cards (arrythmia, MI)	n (%)	5 (4.2%)	4 (6.7%)	1 (1.7%)
Pulm (intubation, PNA, PE, PTX)	n (%)	10 (8.3%)	5 (8.3%)	5 (8.3%)
GI (SBO, ileus)	n (%)	2 (1.7%)	1 (1.7%)	1 (1.7%)
GU (UTI, AKI)	n (%)	6 (5%)	4 (6.7%)	2 (3.3%)
MSK (decub, wound comp)	n (%)	1 (0.8%)	1 (1.7%)	0 (0)
Other	n (%)	9 (7.5%)	4 (6.7%)	5 (8.3%)

BBICU, bounce back to ICU; MI, myocardial infarction; PNA, pneumonia; PE, pulmonary embolism PTX, pneumothorax; GI, gastrointestinal; SBO, small bowel obstruction; GU, genitourinary; UTI, urinary tract infection; AKI, acute kidney injury; MSK, musculoskeletal.

than 2 days on a ventilator ($p = 0.003$). Figure 2 shows these differences. After adjusting for HTN, patients from POST-CCUS were 4.9 times more likely to spend less than 2 days on a ventilator compared with those from PRE-CCUS (OR, 4.9; 95% CI, 1.5–15.9; $p = 0.007$). Median (IQR) ICU LOS in PRE-CCUS was 3 days (2–7 days) and in POST-CCUS was 2 days (2–4 days) ($p = 0.1$). Median hospital LOS was 6 days (3–12.5 days) in PRE-CCUS and 6 days (4–9 days) in POST-CCUS ($p = 0.821$). There was a 10% mortality in the PRE-CCUS group and a 3.3% mortality in the POST-CCUS group ($p = 0.272$). Results from the adjusted associations were consistent with the unadjusted associations (Table 2).

Demonstrated in Table 3, overall, 30% of the PRE-CCUS had complications and 28.3% of the POST-CCUS group had complications ($p = 0.841$). A total of six patients in the PRE-CCUS were readmitted to the hospital or to the ICU compared with five patients in POST-CCUS cohort. For pulmonary complications, which included intubation, pneumonia, pulmonary embolism, and pneumothorax, there were five patients in PRE-CCUS and five in POST-CCUS groups, respectively. For cardiac complications, which consisted of myocardial infarction, new arrythmia, or non-ST elevation myocardial infarction, there were four patients in PRE-CCUS and one in POST-CCUS groups.

Ultrasound Findings

In addition to cardiac function assessment and IVC size and variation, surgical intensivists commented on other notable ultrasound findings. Atrial enlargement was noted in 2.2% of patients. Left ventricular hypertrophy identified in 3.7%. Atrial fibrillation or an arrythmia was identified in 4.4% of patients. A trace pericardial effusion seen in one patient, and one patient had right ventricular dilation.

TABLE 4. Ultrasound Examination Results

Intensive Examination Quality/Utility, Excellent or Good, n (%)	
Subcostal view	56 (41.5%)
Parasternal long view	63 (46.7%)
Parasternal short view	58 (43%)
Apical 4 view	54 (40%)
IVC view	105 (77.8%)
Clinical assessment	96 (75.6%)
Helpful	68 (57.6%)

IVC, inferior vena cava.

Surgeon Response

On review of the surgeon intensivist survey, they reported the quality of CCUS obtained to be excellent or good, which are as follows: 46.7% in parasternal long views, 43% excellent or good in parasternal short views, 40% excellent or good in apical 4 views, 41.5% excellent or good in subcostal views, and 75.6% excellent or good in IVC views. They reported that ease of use was mildly to moderately easy to obtain, and the most difficult views to obtain were the subcostal and apical 4 views. Additional interventions were made based on CCUS findings in 26% of the ultrasounds. Surgeons found CCUS helpful in 57.6% of the ultrasounds, and more commonly made an intervention based on the CCUS compared with those examinations rated less helpful (74.2% vs. 51.7%) Table 4.

Ultrasound Validation

For the quality review, a total of 95 ultrasounds were reviewed by the surgeon and expert ultrasound reviewer. A moderate agreement was observed between EM physician and surgeon for subcostal (observed agreement, 0.69), parasternal short (observed agreement, 0.66), apical 4 (observed agreement, 0.66), and cardiac function (observed agreement, 0.63). Weak agreement was observed for IVC (observed agreement, 0.4) and parasternal long (observed agreement, 0.59).

DISCUSSION

The geriatric trauma population can provide significant challenges to trauma surgeons. With this study, we aimed to make an impact on the outcomes in this group by introducing CCUS to our resuscitation strategy. Our initial hypothesis was that the POST-CCUS group would receive significantly less fluid over the first 48 hours of their resuscitation. Our study showed that patients in the POST-CCUS group received about 2300 mL less fluid, which supported the original hypothesis. In addition, we speculated that there would be shorter time to vasopressor therapy and shorter time to lactate clearance in the POST-CCUS group. These parameters were similar between the two groups. Our findings are consistent with data previously reported. For example, Ferrada et al.[17] demonstrated that limited transthoracic echocardiogram in the trauma bay resulted in decreased IVF administration. However, few studies have focused on examining the use of CCUS in geriatric patients as we have in this study.

Overresuscitation has multiple negative cellular effects on patients, including tissue edema, impaired oxygen delivery, reduced metabolite diffusion, and damaged cell to cell interaction. These cellular damages can be particularly detrimental in the lungs and kidneys.[18] Adequate and targeted resuscitation, but not overresuscitating, can be particularly challenging in the geriatric patient. Assessing cardiac function, IVC diameter, and IVC collapsibility led to decreased IVF administration in this study and may have helped minimize pulmonary edema and acute kidney injury in this vulnerable population. Similar to the Kanji et al.[16] study assessing fluid resuscitation in undifferentiated shock patients and Ferrada's observation regarding CCUS and fluid resuscitation in trauma patients,[17] the POST-CCUS group received significantly less IV fluid, approximately 2000 mL less than the PRE-CCUS group.

Patients in the POST-CCUS group had less ventilator days, with 93% being on a ventilator for less than 2 days compared with 73.3% in the PRE-CCUS group. This observation may be related to the decrease in IVF. On average, the PRE-CCUS group had 2.4 ventilator days, and the POST-CCUS group had 1.1 ventilator days. Despite promising results, only 20 patients in the PRE-CCUS and 12 patients in the POST-CCUS group were intubated, so the sample size is small. Reduction in ventilator days may result in decreased ICU LOS, decreased hospital LOS, and reduced hospital costs. Minimizing ventilator time can also decrease the risk of delirium, need for restraints, ICU readmission, and improve discharge to independent living.[19] These findings were not demonstrated in our study, as it was not powered to detect a difference in these data points, and the overall number of ventilated patients was low.

One significant limitation of this study was the low ISS of many of the patients (range PRE-CCUS, 9–17; POST-CCUS, 9–18.5). The study required informed consent by patients or legally authorized representatives prior to enrollment, and this caused significant limitations in our ability to enroll high acuity geriatric trauma patients within 6 hours of admission. Therefore, most patients were awake, alert, and able to consent themselves. Most of the patients in this study were not multiple trauma or hemodynamically unstable. Many of the patients were in the ICU for frequent neurological checks or geriatric trauma score, which accounts for age, injuries, and comorbidities. While comorbidities may have had an impact on the decision to admit patients to the ICU, the rate of all categories of comorbidities, except hypertension, between the PRE-CCUS and POST-CCUS groups was similar, so it is likely to have no substantial impact on our outcomes. Critical care ultrasound would likely have a greater role in a hemodynamically unstable patient, especially in those who are no longer fluid responsive. In addition, the majority of our patients had normal lactates on admission. For this reason, our study did not demonstrate a difference in time to lactate clearance. While not statistically significant, patients with higher lactates tended to have a worse prognosis, as well as increased LOS. Patients with an increased lactate on admission and failure to clear lactate at 24 hours have a higher mortality rate, especially in the geriatric population.[20] Despite the POST-CCUS group receiving significantly less IVF than the PRE-CCUS group, mortality, complication rates, and type of complications remained similar in both groups.

Another limitation of the study design was the limited assessment of ultrasound evaluation in total. Our study focus was on cardiac function, IVC diameter, and IVC variation. In addition, we wanted to create a practical model for integration of CCUS into the resuscitation strategy at a busy trauma center. Surgical intensivists did not comment routinely on discrete ultrasound findings in favor of ascertaining an overall impression of resuscitation status. The intensivist at the bedside completing the ultrasound made fluid determinations in conjunction with generally accepted resuscitation management. Critical care ultrasound training ensured linkage of ultrasound findings to make an educated final impression and goal-directed therapy. Notable findings were commented on in the survey; however, the number of findings identified was low. This limits our ability to correlate additional ultrasound findings, such as atrial enlargement, to patient outcomes.

The use of CCUS has its own limitations. This modality can be time-consuming, especially in the setting of blunt chest injury and associated subcutaneous emphysema. Further, at a high-volume trauma center, CCUS may be difficult to obtain while managing multiple admissions and operative cases. Fifteen patients in the POST-CCUS group did not receive the second CCUS because of the other clinical obligations of the surgeon. Critical care ultrasound is also extremely user-dependent, relying on user skill in obtaining images and confidence in image interpretation. While 57.6% of the surgeons found the ultrasound helpful, only 26% of the time did the surgeons intervene based on findings. The emergency medicine physician reviewing the ultrasounds agreed with cardiac function 76% of the time; however, the EM physician noted that only about 20% of the images were of good or excellent quality. Many of the studies were missing one or two views because of the inability to obtain images. As the study progressed, more surgeons became proficient with CCUS. This could potentially have affected the results, as the comfort level of the surgeon intensivists increased over the duration of the study period. More interventions, to include stopping IVF, were seen near the end of the study as surgeon intensivists became better at CCUS. Another potential impact to this study was the initiation of the geriatric trauma team in April 2017, similar timing to the initiation of the CCUS study. A gerontologist helped manage patients older than 60 years and may have had input in management. This service was not available in the PRE-CCUS group.

In summary, our data demonstrated that the use of CCUS resulted in a reduction in IVF administration and decreased ventilator days in a geriatric trauma population. As such, CCUS is an important adjunct to resuscitation, especially in the geriatric patient. It is readily available, inexpensive, and has more sensitivity than vital signs alone. With a larger sample size, this methodology may result in a decrease in complications, hospital stay, and possibly mortality. As technology continues to improve, CCUS will become more mainstream in resuscitation of injured patients, especially in geriatric patients.

AUTHORSHIP

E.C. participated in the literature search, data collection, data interpretation, writing, critical revision. E.W. participated in the data collection, writing, critical revision. R.S. participated in the literature search, study design, data collection. M.L. participated in the data collection, data interpretation, critical revision. K.C. participated in the data collection, critical revision. H.W. participated in the study design, data analysis, data interpretation, writing, critical revision. T.H. participated in the study design, critical revision. R. B. participated in the literature search, study design, data interpretation, writing, critical revision.

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DISCLOSURE

The authors declare no conflicts of interest.

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DISCUSSION

PAULA FERRADA, M.D. (Glen Allen, Virginia): Congratulations, Dr. Cleveland and authors for an astounding presentation. I also want to thank the American Association for the Surgery of Trauma for the opportunity to read and review this article. I found it very well written and also I think it's going to be a great addition to the literature.

Dr. Cleveland and her collaborators found that the use of cardiac ultrasound to guide therapy resulted in a reduction in intravenous IV fluid administration and decreased ventilator days in the geriatric trauma population.

These findings are congruent with previous publications from other places, including and not limited to geriatric trauma patients.

I have a couple of questions for Dr. Cleveland and her group. The first one is practical. The second one is more philosophical.

While doing your research project you screened 120 patients with cardiac ultrasound and you mentioned that that helped you guide therapy. How did your providers, health care professionals were credentialed for these tests? And were they able to bill for the services provided?

My second question is about training and about the future of our educational trauma programs. Dr. Grace Rozycki taught us a long time ago that ultrasound can be used as an extension of the physical exam.

And for the last few decades we have been extending that ultrasound exams from the abdomen to the pleura to the chest to the heart finding similar findings, similar results.

How can we help train our residents, our fellows, our attendings? And how can we incorporate ultrasound as a useful tool in every and any program?

Thank you so much for the opportunity to review this wonderful article. And I am looking forward to publication.

ELAINE M. CLEVELAND, M.D. (Charlotte, North Carolina): Great. Well, thank you. Thank you, Dr. Ferrada, for reviewing our presentation and excellent questions.

Regarding the first one, regarding credentialing: all the surgical intensivists had to do a course within one year that was both didactic and had a hands-on approach. They also had to complete a practical prior to completing the surgical ultrasounds. Unfortunately, they were not able to bill for these services as this was in an IRB study.

Regarding the second question, using this as an extension of physical exam and getting it more integrated, this is definitely a culture change for this program. Since we did this study, we have seen more and more people doing bedside ultrasounds, not only in our geriatric patients, but also in our just critical care patients.

The other aspect of this is that, as a fellow, which I am currently, we have been doing an ultrasound month in the ED and really getting better at our ultrasound skills. This personally has helped me use this as an extension of the physical exam. I think it's going to become more and more integrated in the program as this goes forward.

DR. MARTIN: Great study! One major factor in how much IV fluid they get over first 48 hours is their NPO status. Did you compare that between groups? And why do you think only about 50 percent felt the ultrasound was helpful? Why wasn't it higher?

ELAINE M. CLEVELAND, M.D. (Charlotte, North Carolina): Regarding the NPO status, we were not able to qualify this or quantify this in our research, though that definitely plays a role in how much fluid patients received.

Regarding the surgeon perception of usefulness, I think this has to do with just a culture change, in general. As the study progressed more and more people found it helpful and, also, were doing more interventions as the study progressed.

When it initially came out I think a lot of the surgeons felt that it was a little bit time-consuming and was not necessarily giving us the results that we expected.

DR. RIOJAS: Any other changes at your facility regarding resuscitation endpoints between your pre- and post-group? Were there specific guidelines based on ultrasound findings? Or was it still at the discretion of the attending based on their personal interpretation of the findings?

And were the intensivists the only providers directing resuscitation? What about APPs, residents, et cetera? Were they similarly following the ultrasound findings?

ELAINE M. CLEVELAND, M.D. (Charlotte, North Carolina): There was a protocol in place that was approved from the IRB. It looked at the cardiac function as well as the IVC diameter. And based on that, there was an algorithm that we followed to determine if they needed to get additional fluids, to stop fluids, or to start vasopressor therapy.

DAVID H. LIVINGSTON, M.D. (Newark, New Jersey): Did you include enough sick patients to really show a difference? Was using ultrasound just a proxy for actually watching and limiting the usual excess amount of fluid these patients get?

ELAINE M. CLEVELAND, M.D. (Charlotte, North Carolina): Unfortunately, due to our initial IRB restrictions we had to get consent before performing the first ultrasound and so this made most of our patients less severely injured.

However, once we were granted an extension of consent from the IRB we were able to do this on more critical patients, we did show more difference. But it is a nice proxy just in general.

DR. BUTLER: How many ultrasounds could not be performed due to inadequate windows? What was your success rate?

Volume status is one component of resuscitation; volume responsiveness may be an important strategy to optimize resuscitation in elderly trauma patients.

Any experience with non-invasive fluid responsiveness devices? Did you track post-resuscitation new onset a-fib?

ELAINE M. CLEVELAND, M.D. (Charlotte, North Carolina): We had two ultrasounds for every patient so there was 120 ultrasounds total. There were about 20 that were unable to be performed due to inadequate windows, so about one-sixth of the studies. For our critical patients, many of them were monitored with atrial waveform devices such as Vigileo or FloTrac. There were only 3 patients who had new onset afib, and due to this low number, it was difficult to correlate fluid volume to afib status.

DR. KIM: Were measurements performed quantitatively or purely qualitatively? Did you consider performing passive leg raising? And did you adjust for whether or not patients were on positive pressure ventilation?

ELAINE M. CLEVELAND, M.D. (Charlotte, North Carolina): These were just quantitative, not qualitative. This was done in order to streamline the process rather than gaining measurements.

We did not record if a passive leg raise was done or if they were on positive pressure ventilation during the ultrasound studies.

DR. COE: Besides IVC measurements, what other findings did those in the study base their resuscitation on, i.e. b-lines, contractility, et cetera?

ELAINE M. CLEVELAND, M.D. (Charlotte, North Carolina): B-lines were assessed but they were not formally recorded. That was an indication of fluid overload if those were identified.

Other things that were assessed was just lactate and other parameters that we would normally assess with our trauma patients.

DAVID A. SPAIN, M.D. (Stanford, California): And then, finally, I warned you before, this really recapitulates a study done like in 1990 by Scalea et al. that showed improved survival of geriatric trauma patients with early invasive monitoring where they were actually using PA catheters in those patients. And, again, a lot of it was decreasing time to intervention.

I was wondering if you had any comments about whether or not we're just sort of substituting ultrasound now for PA catheters.

ELAINE M. CLEVELAND, M.D. (Charlotte, North Carolina): I think it can be. And it's also just spending more time at beside and really reassessing these patients as a measure to help reduce fluid overload.