Spirometry not pain level predicts outcomes in geriatric patients with isolated rib fractures

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BACKGROUND: Geriatric patients with rib fractures are at risk for developing complications and are often admitted to a higher level of care (intensive care units [ICUs]) based on existing guidelines. Forced vital capacity (FVC) has been shown to correlate with outcomes in patients with rib fractures. Complete spirometry may quantify pulmonary capacity, predict outcome, and potentially assist with admission triage decisions.

METHODS: We prospectively enrolled 86 patients, 60 years or older with three or more isolated rib fractures presenting after injury. After informed consent, patients were assessed with respect to pain (visual analog scale), grip strength, FVC, forced expiratory volume 1 second (FEV1), and negative inspiratory force on hospital days 1, 2, and 3. Outcomes included discharge disposition, length of stay (LOS), pneumonia, intubation, and unplanned ICU admission.

RESULTS: Mean age was 77.4 (SD, 10.2) and 43 (50.0%) were female. Forty-five patients (55.6%) were discharged home, median LOS was 4 days (interquartile range, 3–7). Pneumonias (2), unplanned ICU admissions (3), and intubation (1) were infrequent. Spirometry measures including FVC, FEV1, and grip strength predicted discharge to home and FEV1, and pain level on day 1 moderately correlated with the LOS. Within each subject, FVC, FEV1, and negative inspiratory force did not change for 3 days despite pain at rest and pain after spirometry improving from day 1 to 3 ($p = 0.002$, $p < 0.001$ respectively). Change in pain also did not predict outcomes and pain level was not associated with respiratory volumes on any of the 3 days. After adjustment for confounders, FEV1 remained a significant predictor of discharge home (odds ratio, 1.03; 95% confidence interval, 1.01–1.06) and LOS ($p = 0.001$).

CONCLUSION: Spirometry measurements early in the hospital stay predict ultimate discharge home, and this may allow immediate or early discharge. The impact of pain control on pulmonary function requires further study. (*J Trauma Acute Care Surg.* 2020;89: 947–954. Copyright © 2020 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Diagnostic test, level IV.

KEY WORDS: Rib fractures; geriatric trauma; spirometry.

Rib fractures are a common consequence of thoracic trauma, although the epidemiologic evidence for the incidence of rib fractures and their impact is limited. Evidence from the National Trauma Data Bank suggests that mortality due to rib fractures is low unless concomitant injury is present.[1] This likely leads to the wide variation in the reported rate for rib fracture–related mortality of 2% to 20%.[2] Geriatric patients are particularly susceptible to the effects of rib fractures. When stratified by the number of rib fractures, mortality approximately doubles and hospital length of stay (LOS) increases within each stratum for patients 65 years or older compared with those younger than 65 years.[3] Up to one third of older adult patients with six or more rib fractures die of their injuries.[4] One strategy that has been used to improve outcomes is admission to a well-monitored setting such as an intensive care unit (ICU). A recent algorithm developed by the Western Trauma Association recommended admitting most patients older than 65 years with two or more rib fractures to a monitored setting.[5] This approach, however, may be unnecessary in many patients and has the potential to consume limited resources.[6]

Given the risk for complications and mortality, it may be helpful to identify those at high risk for complications early and provide subsequent focused interventions. Several approaches to predict outcomes in rib fracture patients have been previously developed. Scoring systems based on anatomic and radiographic criteria represent the simplest and most easily applicable approach. Example of such systems includes the Organ Injury Scale Chest Wall Grade, Rib Fracture Score, Chest Trauma Score, and the RibScore.[7–10] However, when applied to geriatric patients, measures of respiratory physiology and physiologic reserve may be more predictive.[11,12] Multiple studies have evaluated simple bedside incentive spirometry as a predictor of outcomes with reasonable correlation.[13] Unfortunately, commercially available incentive spirometers are of variable design and quality, making uniform application of this approach difficult. Bedside measurement of more quantitative and well-defined measures of lung function has been also been applied to rib fracture patients. Peak expiratory flow rate does not correlate well with outcomes.[14] By contrast, forced vital capacity (FVC) has been shown to predict outcome for patients with multiple rib fractures with respect to pulmonary complications and LOS.[12,15,16] The retrospective nature of these prior studies, however, creates several limitations. Two of the studies did not collect patient height, and as such, the vital capacity as a percent of predicted could not be evaluated.[12,16] None of the studies limited the population to patients with isolated acute rib fractures with fully intact cognition, and timing of pulmonary function tests (PFTs) was not standardized, nor was data collection of pain scores and interventions, all of which are potential confounders. All of the studies were retrospective evaluations of a care pathway, and therefore, the patients were treated based on the PFTs, which may have further biased the findings. Because of the retrospective nature of the data, some patients may have been more likely than others to have PFT data collected based on physician preference or a patient's clinical condition. This is critical if PFT data are not reliably collected from all patients but are more commonly collected from patients who are doing poorly as the physicians insist on this. This practice would have the potential to exaggerate or diminish the predictive capacity of the PFTs. If patient selection is not biased by clinical condition, a more reliable evaluation of the predictive capacity of PFTs is more likely to emerge.

Based on the aforementioned referenced limitations, we designed a prospective observational study evaluating FVC, forced expiratory volume 1 second (FEV1), and negative inspiratory force

Submitted: February 13, 2020, Revised: April 8, 2020, Accepted: April 27, 2020, Published online: May 26, 2020.

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This study was presented at the 50th Annual Meeting of Western Trauma Association, February 23–28, 2020, in Sun Valley, Idaho.

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DOI: 10.1097/TA.0000000000002795

(NIF) as predictors of outcome in older adult patients with isolated acute rib fractures and intact cognition. We chose to focus on this group of patients to better assess the relationship between rib fractures, pulmonary function, analgesia, and outcomes in a relatively high-risk group of patients. Our intent with enrolling only those with intact cognition was to minimize the impact of cooperation and effort on the pulmonary measurements. We hypothesized that spirometry values would identify patients who were discharged home with a short LOS. These patients would be unlikely to benefit from a higher level of care and may be either safely admitted to a standard hospital floor or potentially discharged directly from the emergency department.

PATIENTS AND METHODS

All patients at least 60 years or older with at least three acute rib fractures by imaging and admitted to the hospital were screened. Exclusion criteria included the following: screened more than 24 hours after presentation to the emergency department, injury occurring more than 24 hours before presentation, significant additional musculoskeletal injury, cognitive impairment either baseline or due to injury that precluded cooperation with testing, and unavailability of a surrogate if they were able to cooperate with testing but not capable of providing informed consent. Patients were approached for consent if not excluded, and if the patient and/or surrogate agreed, the patient was enrolled after signing informed consent. On initial evaluation medical history, any underling pulmonary disease, functional dependence as defined by the national trauma data standard, and smoking history were recorded. Pain was assessed using a visual analog scale, and use, type, and timing of analgesics were recorded including the use of epidural or paravertebral catheters. Hand grip strength was measured with Baseline Hydraulic Hand Dynamometer (Fabrication Enterprises Inc., White Plains, NY), FVC and FEV1 were measured with the Spirobank II bedside spirometer (Medical International Research, New Berlin, WI), and NIF was measured with a negative pressure meter (Instrumentation Industries, Inc., Bethel Park, PA). We chose to measure hand grip strength as a measure of overall frailty, which may contribute to lower than predicted spirometry volumes, and as a potentially simpler measure than spirometry.[17] Patients were coached through the process of obtaining the measurements, and measurements were repeated once with the best result recorded. All measurements were obtained by one of three investigators following a standard protocol in the same order. If the patient tolerated it, a nose clamp was used. The FVC, FEV1, and NIF were measured daily, and the visual analog scale pain score was measured daily before and after testing. Presence of chest tubes, presence of hemothorax, presence of pneumothorax, and analgesic use were assessed on all 3 days. The grip strength was measured only on day 1. If patients were discharged before day 2 or 3, no data were recorded on these days. Any complications including transfer to a higher level of care, intubation, pneumonia, mortality, and readmission were all abstracted from the medical record or trauma registry. All clinical decisions regarding patient management were made by the clinical team caring for the patient and were independent of any data collected by the research team. Patients were not provided feedback on their performance on the tests unless requested, and then, only qualitative information was provided.

Analysis

In addition to FVC and FEV1, the predicted volumes were extracted from tables produced by calculations from the National Health and Nutrition Examination Survey III.[18,19] These predicted volumes were based on the patients height, age, sex, and race. In the event the tables did not include the patient's age, the original equations used by National Health and Nutrition Examination Survey III were used to find predicted values. Percent of predicted was then calculated for each spirometry measurement. The two leading outcomes of interest were discharge home and LOS. Because the primary goal was identifying an opportunity for early discharge, we compared spirometry, NIF, and pain measurements on day 1 with the primary outcomes of discharge disposition, recorded as home versus transfer to a rehabilitation facility, and LOS. Patients admitted from a facility were excluded from this analysis. We were also interested in testing early and rapid improvement as a predictor of home discharge. We therefore assessed the change in spirometry, NIF, and pain over the first 3 days. These changes were then compared with discharge home and LOS where hospital LOS was at least 3 days. We made similar comparisons between each of the patient measurements. Secondary outcomes included mortality, pneumonia, intubation, unplanned transfer to a higher level of care, and readmission. These outcomes were collected by chart review often at the time of discharge and after 30 days for readmission.

Statistical Analysis

Comparisons between continuous variables and discharge disposition were made with either a *t* test or Wilcoxon rank sum depending on the distribution of the data. When comparing the measurements on days 1 and 3, a repeated measures *t* test and the Wilcoxon signed rank test were used. Length of stay was compared with the various spirometric and NIF measures using linear regression. Because FEV1 was most correlated with the outcome measures, we also examined the relationship between FEV1 and the outcomes of LOS and discharge home using multiple regression. The models were adjusted for age, sex, number of rib fractures, the presence of a hemothorax, presence of a pneumothorax, presence of chronic obstructive pulmonary disease, presence of pulmonary contusion, and smoking history. All data analyses, graphing, and statistical testing were performed with the R programming language version 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria) using the installed packages plyr, dplyr, ggplot, gridExtra, summarytools, and pROC.

RESULTS

Patient Characteristics

Over the period of the study, June 2016 to December 2019, 346 patients with isolated rib fractures meeting the age criteria were admitted. Patients were excluded because of unavailability of an investigator, being more than 24 hours from injury, inability to cooperate with testing, inability to consent with no surrogate available, or refusal to consent. Eighty-six patients met the inclusion criteria and consented to enrollment. Over the time frame of enrollment, 322 acutely injured patients 60 years or older were also discharged from the emergency department without screening. None of these patients had acute rib fractures, but three had what were believed to be subacute rib fractures by

TABLE 1. Patent Characteristics on Hospital Day 1

Characteristic	n (%)
n	86
Age, mean (SD)	77.4 (10.2)
Sex, female, n (%)	43 (50.0)
Mechanism	
Fall	46 (53.5)
Motor vehicle collision	39 (45.3)
Motor cycle collision	1 (1.1)
Coronary artery disease	23 (26.7)
COPD	10 (11.6)
Other respiratory disease	3 (2.3)
Functional dependence	25 (29.1)
Hypertension	64 (74.4)
Smoker	8 (9.3)
No. fractures, median (IQR)	5 (4–6)
Number with bilateral fractures	5 (5.8)
Pulmonary contusion	6 (7.0)
Pneumothorax	4 (4.7)
Hemothorax	3 (3.5)
Thoracostomy	6 (7.0)
Paravertebral catheters during admission	16 (18.6)
Admitted to floor	20 (23.2)
Admitted from facility	5 (5.8)

COPD, chronic obstructive pulmonary disease; IQR, interquartile range.

imaging characteristics. Most patients were injured during a fall or a motor vehicle collision, and all but four patients had their injury evaluated with computed tomography scan. Patients were significantly older than 60 years, and underlying pulmonary disease and smoking were relatively uncommon in the overall cohort (Table 1). Admission from somewhere other than home was uncommon; however, almost one third had some functional dependence at baseline. On admission, 19 patients were admitted to the surgical ICU with a median ICU LOS of 3 days. Forty-five patients were admitted directly to a step-down unit (SDU) with a median SDU LOS of 2 days. The remaining 22 patients were admitted to the surgical floor with a median LOS of 3 days. The overall median hospital LOS was 4 days, and slightly more than half of patients admitted from home were discharged home. The median number of ribs fractured was five with less than 25% of patients having more than six fractured ribs (Table 1). Hemothorax, pneumothorax, and pulmonary contusion were uncommon. Of hemothorax and pneumothorax cases, all but one was drained.

Respiratory Parameters and Pain

No patients received epidural analgesics, and 20% were provided regional anesthesia using a paravertebral catheter(s). Higher spirometry values on admission were associated with a home discharge. Percent-predicted FVC, despite being 7% better, did not reach statistical significance nor did NIF. Grip strength was also significantly associated with discharge home (Table 2). Patients discharged home had slightly improved respiratory parameters by day 3 compared with baseline, although none of these reached statistical significance. Shorter LOS was also predicted by higher volumes on most of the measured respiratory parameters (Fig. 1). Although these trends were statistically significant, the slopes were not adequate to make strong predictions. All patients achieving a percent-predicted FVC greater than 50% or a predicted FEV1 greater than 60% had a LOS less than 5 days. Pain was poorly predictive of LOS; however, by dividing the most predictive respiratory parameter (percent-predicted FEV1) by the initial pain score, a more predictive parameter was created ($\beta = -0.10$, $p = 0.017$) (Supplemental Digital Content, Supplementary Fig. 1, http://links.lww.com/TA/B691). In addition, pain scores were not predictive of any of the spirometry volumes measured (several examples are displayed in Supplemental Digital Content (Supplementary Fig. 1, http://links.lww.com/TA/B691).

Respiratory Parameters Over Time and Outcomes

The change in the respiratory parameters was also assessed over time and was minimal over the first 3 days with

TABLE 2. Spirometry and Pain Characteristics Associated With Discharge Home

Patient Measurement	Discharge Home	Other Discharge	*p*
FVC day 1, L	1.64 (0.74)	1.25 (0.79)	0.033
Percent-predicted FVC day 1	48.2 (20.1)	41.7 (22.6)	0.202
FEV1 day 1, L	1.26 (0.58)	0.88 (0.43)	0.001
Percent-predicted FEV1 day 1	50.0 (21.5)	40.1 (16.7)	0.026
NIF day 1, cm water	35.2 (16.1)	30.1 (15.5)	0.165
Grip strength, lbs	45.3 (22.2)	33.1 (22.6)	0.010
Pain score at rest day 1, median (IQR)	5 (3–6)	4 (2–6)	0.277
Pain score with spirometry day 1, median (IQR)	6 (5–7)	6 (3–8)	0.227
Change in FVC days 1 to 3, L	−0.08 (0.81)	0.15 (0.67)	0.245
Change in FEV1 days 1 to 3, L	0.05 (0.39)	0.07 (0.44)	0.856
Change in NIF days 1 to 3 (cm water)	0.65 (16.1)	5.35 (15.0)	0.250
Change in pain at rest days 1 to 3	−1.00 (1.61)	−0.67 (2.86)	0.583
Change in pain with spirometry days 1 to 3	−1.76 (2.39)	−0.85 (3.23)	0.220

All data are reported as mean (SD).
IQR, interquartile range.

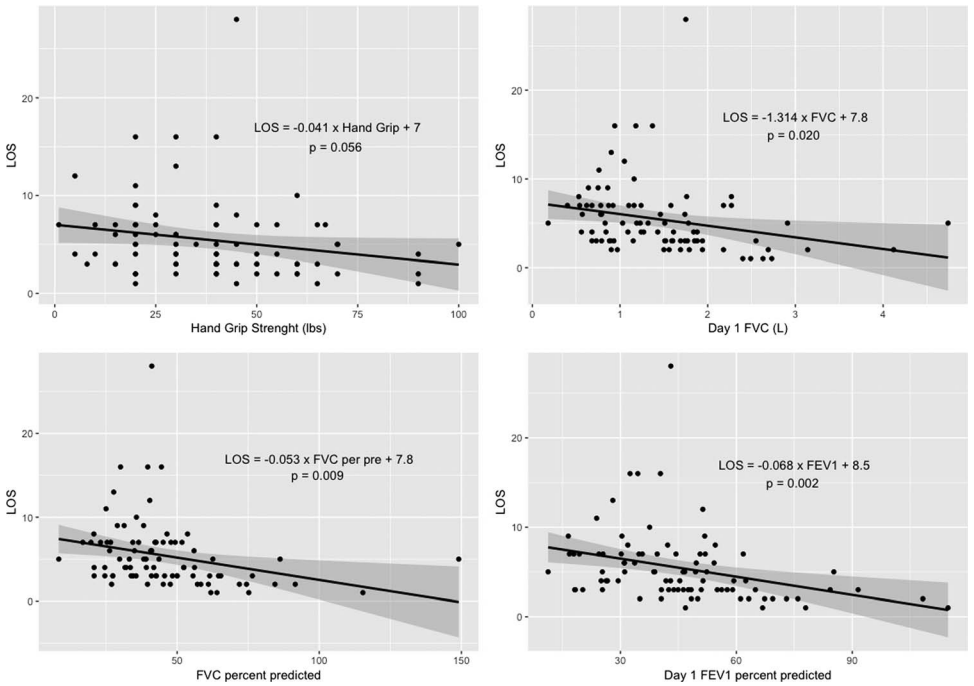

Figure 1. Length of stay as a function of admission grip strength and respiratory parameters.

only NIF improving (Table 3). The changes in the respiratory parameters over the first 3 days were also poorly predictive of LOS with the notable exception of the NIF. This was despite statistically significant decreases in the pain score both before and after spirometry over those 3 days. With respect to NIF, an improvement of at least 15 cm of water was associated with a LOS less than 5 days (Fig. 2).

Ultimately, the outcomes for this group of patients believed to be at high risk for deterioration were good. Three patients were upgraded from the floor or SDU to the SDU or ICU, and only one of these required endotracheal intubation and mechanical ventilation. One of these patients died after withdrawal of care. Those patients upgraded to the SDU or ICU did have lower percent-predicted FEV1 on admission (39.1% vs. 47.5%, $p = 0.044$). All three unplanned ICU transfers had a component of respiratory failure, but the main factors were myocardial ischemia, aspiration, and delirium. None of the patients was treated with noninvasive ventilation. Pneumonia, delirium, and readmission in the entire cohort were uncommon (Table 4). Comparing the volumes between those with pneumonia and those without, volumes were lower in the pneumonia patients; however, there were no statistically significant differences. With the exception of the previously described patients, the other complications were isolated events. Forty-five patients were discharged home, which represents 55.6% of those admitted from home. On multivariable analysis, the percent-predicted FEV1 on day 1 remained a significant predictor of discharge home with a 3% (95% confidence interval, 1–6%) increase in the odds of discharge home for every percent increase in percent-predicted FEV1 ($p = 0.023$) and model area under the receiver operating characteristic curve of 0.776. The only other predictor of home discharge was younger age ($p < 0.001$). Similarly, FEV1 remained a significant predictor of LOS ($\beta = -3.240$, $p = 0.001$) after controlling for potential confounders.

TABLE 3. Change in Patient Status From Hospital Day 1 to Hospital Day 3

Patient Measurement	Day 1	Day 3	*p*
FVC, mean (SD), L	1.45 (0.79)	1.31 (0.57)	0.825
FEV1, mean (SD), L	1.07 (0.54)	0.98 (0.45)	0.244
NIF, mean (SD), cm water	32.3 (16.0)	34.1 (14.3)	0.138
Pain score at rest, median (IQR)	4 (2–6)	3 (1–5)	0.002
Pain score with spirometry, median (IQR)	6 (4–8)	4 (3–5)	<0.001

IQR, interquartile range.

DISCUSSION

The most recent Western Trauma Association critical decisions in trauma recommends admitting all patients older than 65 years with two or more rib fractures to an ICU.[5] This recommendation is based on poor outcomes of frail patients and expert opinion.[18,20,23] This approach has the potential to unnecessarily commit many older patients to the hospital and monitored settings, increasing length of hospital stay and hospital costs. Our study identifies several indicators that may improve prediction of both home discharge and the LOS. Almost all patients with an FEV1 greater than 60% of predicted were discharged home with a short LOS. Pain score had little impact on the potential for discharge home, although improving pain was associated with shorter hospital stays. Given these findings, for geriatric patients with isolated rib fractures who achieve percent-predicted FEV1 greater than 60% and who have no other indications for advanced

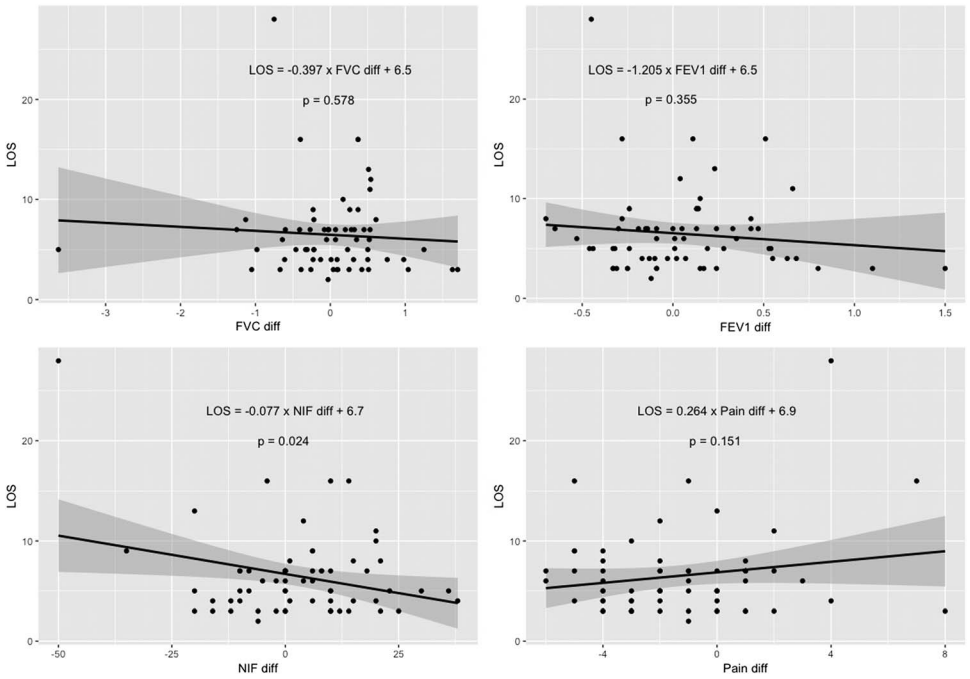

Figure 2. Length of stay as a function of change in respiratory parameters and pain.

monitoring, we recommend admission to a nonmonitored setting and potentially discharge home when there is adequate home support. This recommendation is further supported by the lower FEV1 for those patients admitted or readmitted to a monitored setting after floor admission or transfer, respectively.

The other interesting finding from our study was the lack of correlation of between pain levels and pulmonary function in this group of older adult patients. The sample size precludes any definitive conclusions regarding the relationship between pain control and spirometry. However, the nearly flat slopes of the fitted regression lines in Supplemental Digital Content (Supplementary Fig. 1, http://links.lww.com/TA/B691) suggest a minimal relationship and the need for further study. Since the paradigm shift away from binding and physical splinting for rib fractures, the focus has been on adequate analgesia. The doctrine has been to provide adequate analgesia, which in turn would result in larger title volumes and lower risk of pulmonary complications. Given the available evidence, it is likely that declining pulmonary function is associated with complications and worse outcomes.[16] However, whether this is due to inadequate pain control or as potentially suggested by our data independent of pain control is unclear.

TABLE 4. Patient Outcomes

Characteristic	n (%)
Mortality	1 (1.2)
Unplanned higher level of care	3 (3.5)
Pneumonia	2 (2.3)
Intubation	1 (1.2)
Delirium	5 (5.8)
Readmission	3 (3.5)
LOS, median (IQR)	4 (3–7)

The pain scores improved over the first 3 days of hospitalization with little change in spirometry values. Adequate pain control is important; however, it may be equally important to focus on other measures and not delay mobility or other interventions until pain control is adequate. Opioid addiction is less of a concern in the elderly; however, the delirium and respiratory depression may be considerations when managing pain in this cohort.[21] We would not suggest changing current pain treatment algorithms; however, given these findings, we plan further study of this finding to understand if better pain level correlates with spirometry.

Limitations

Our study was designed to minimize some of the limitations that were present in several prior studies. Most importantly, we developed a protocol that was implemented by a few investigators who did not share testing results with clinicians. This limited variation because of test administration and bias introduced by unblinded results. This may be seen as limiting the generalizability to more novice assessors; however, the protocols were relatively simple and our goal is to make this a first step. In the future, decision making based on spirometry and performance by less experienced assessors will be implemented. The other significant limitation that impairs our ability to generalize the results is the population capable of participating. This important factor is not discussed by other studies.[12–14] In elderly patients with rib fractures, many patients are not capable of cooperating to a level where spirometry results are reliable. We also did not enroll many admitted patients because of lack of investigator availability. Other than day of the week, this was likely a random event and unlikely to have modified our findings. With respect to the significance of negative findings for our secondary outcomes, although a formal power analysis was not done in this

noninterventional study, a rough estimate to find a difference between two groups would have required about 400 patients. This is well higher than the original number of patients we anticipated, about 150, based on estimates of these complications being around 20%.[22] Finally, although we recorded outcomes over the entire hospital stay, spirometry values were only followed for 3 days, and important improvements in respiratory function may have occurred after 3 days. In addition, the total LOS for patients not discharged home may have been influenced by factors unrelated to clinical improvement.

CONCLUSIONS

Bedside spirometry can be easily added to the early assessment of geriatric trauma patients with rib fractures with reproducible results. Initial values are predictive of both discharge home and LOS, suggesting that these measures may be used to support a decision to admit a patient to an unmonitored setting or potentially discharge a patient home from the emergency department. In addition, the impact of analgesia and medication adverse effects on spirometry should be further evaluated given our findings of minimal correlation.

AUTHORSHIP

K.M.S. contributed to the study conception, study design, data acquisition, data interpretation, article drafting, and final revisions. M.S. contributed to the study design, data acquisition, and final revisions. R.O. contributed to the data acquisition, data interpretation, article drafting, and final revisions. R.B. contributed to the data interpretation, article drafting, and final revisions. A.M. contributed to the data interpretation, article drafting, and final revisions. K.A.D. contributed to the data interpretation, article drafting, and final revisions.

DISCLOSURE

The authors declare no conflict of interest.

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CRITIQUE

Dr. Sperry and colleagues provide here a follow-up analysis to the previously published PAMPer Trial, which demonstrated a 10% survival benefit for severely injured patients at risk for hemorrhage that received prehospital plasma during air ambulance transport. PAMPer and other studies derived from PAMPer have already demonstrated the superiority of prehospital plasma for severely injured patients transported by air ambulance with longer time from injury to ED. In this article, the authors attempt to further characterize which patients lived, despite a high probability of death, as this may help identify effective practices that can be applied to all patients. As would be expected, their results suggest that patients that were expected to die but lived (unexpected survivors) were younger (despite severe injuries) than those that were expected to die that died, while patients that were expected to live but died (unexpected non-survivors) were older than those that were expected to live that lived. Unfortunately, the analysis did not take into account the impact of age on outcome as it makes sense that age is an important factor to consider when analyzing response to injury. Interestingly, unexpected survivors were also

characterized by high rates of prehospital cardiopulmonary resuscitation and most were intubated in the prehospital setting. As would also be expected, unexpected survivors spent more days in the ICU, more days on mechanical ventilation, and were in the hospital longer. Furthermore, all unexpected survivors developed multiple organ failure. As with many similar studies, this study is subject to a high degree of survival bias. In other words, severely injured patients (predicted to die) survive live long enough to experience complications. While this is frequently unavoidable, several analytic approaches are available to account for this, however this study presents only descriptive statistics. While the authors have characterized a group of unexpected survivors that may have benefited from prehospital plasma, one final question that remains is whether or not they identified a group of patients that had no benefit from plasma, and thus plasma should not be given. Overall, this is an important addition to the literature as it demonstrates an association between prehospital plasma administration and unexpected survival, consistent with previous studies demonstrating an association between unexpected survival and blood administration. Importantly, it underscores the impact that prehospital care has on outcome for injured patients.

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