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Clinical Decision Support Intervention for Rib Fracture Treatment

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Abstract

BACKGROUND: Rib fractures are associated with significant morbidity and mortality. Despite the publication of management guidelines and national outcomes benchmarking, there is

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significant variation in evidence-based (EB) adherence and outcomes. Systems for clinical decision support intervention (CDSI) allow rapid ordering of bundled disease-specific EB treatments. We developed an EB rib fracture protocol and CDSI at our institution. The purpose of the current study was to evaluate implementation and clinical outcomes using this CDSI.

STUDY DESIGN: A rib fracture care CDSI was developed, disseminated, and implemented in July 2018. Implementation outcomes were evaluated using the Proctor framework. Adherence was tracked monthly via run charts and acceptance was evaluated on a 7-point Likert scale using the Unified Theory of Acceptance and Use of Technology questionnaire. Propensity score matching was used to compare in-hospital morbidity and mortality in pre-implementation (January 1, 2016 through December 31, 2016) vs post-implementation (September 1, 2018 through April 30, 2019) cohorts.

RESULTS: A total of 197 patients were eligible for the intervention. Provider CDSI adherence was 83% at 1 month and reached 100% after 7 months. Acceptance of CDSI using the Unified Theory of Acceptance and Use of Technology had a mean Likert score higher than 6 (range 6.1 to 6.8, SD 0.5 to 1.5), indicating high acceptance. A significant reduction in hospital length of stay was found post implementation (incident rate ratio 0.80; 95% CI, 0.66 to 0.98; $p = 0.03$) comparing propensity-matched subjects.

CONCLUSIONS: The development and use of a CDSI resulted in improved provider delivery of EB practice and was associated with reduced hospital length of stay.

Rib fractures are the most common thoracic injury resulting from blunt trauma.¹ The presence of multiple rib fractures has been linked to increased morbidity and mortality, especially in patients older than 45 years of age.²⁻⁴ Bulger and colleagues² reported an overall 22% mortality rate in those age 65 years and older, with a 19% increase in mortality for each additional rib fracture. Older patients are at significant risk of morbidity and mortality compared with patients younger than 65 years of age, where the mortality rate from rib fractures averages 11%.

Implementation of rib fracture evidenced-based (EB) practices has been shown to improve patient outcomes, including decreased pulmonary infection, hospital length of stay (LOS), and mortality.^{5,6} Unfortunately, compliance with EB trauma practice is highly variable and often inconsistent.⁷⁻¹¹ Computerized clinical decision support interventions (CDSIs) have been shown to improve provider compliance with EB practice.^{12,13} Reduced errors and improved outcomes have been shown with CDSIs, but user acceptance has been a barrier to their adoption.^{12,13} There is a critical need to identify successful dissemination and implementation strategies using validated evaluation frameworks. Such evaluation tools include RE-AIM¹⁴ and the Proctor framework,¹⁵ informed by validated behavioral technology acceptance model, such as the Technology Acceptance Model¹⁶ or the Unified Theory of Acceptance and Use of Technology¹⁷ (UTAUT) tool.

The purpose of this study was to use the Proctor framework¹⁵ to evaluate both implementation and clinical outcomes for an EB CDSI for rib fracture patients treated at an urban American College of Surgeons-verified Level I trauma center. We hypothesized that the CDSIs would be accepted by providers and result in decreased morbidity.

METHODS

Planning

A multidisciplinary planning team was established to develop, disseminate, implement, and evaluate an electronic health record-based intervention to improve adherence with EB practice for managing patients with rib fractures. In response to significant variability in management of patients with rib fractures, we sought to develop an EB rib fracture protocol and deliver the protocol as a CDSI to improve EB adherence. The planning team included trauma providers, anesthesiology, nursing, respiratory therapy, pharmacy, and trauma administration. Biweekly planning team meetings were held and freeform brainstorming was used to identify barriers and facilitators for protocol adherence. Proposed system-based solutions were characterized and refined iteratively until consensus was achieved. Additional meetings were then held to develop a strategy for dissemination and implementation.

Intervention

A multifaceted CDSI was developed (eTable 1), which included the following domains: multimodal analgesic strategy (including geriatric vs nongeriatric dosing), multidisciplinary orders (respiratory therapy, physical therapy, and nursing), imaging, and surgical intervention. The CDSI was embedded in the standard trauma admission order set, as “Rib Fracture Care Module” and available to providers at the time of admission.

Dissemination

The dissemination plan encompassed the time from April through October 2018 and overlapped with the first 2 months of implementation (Fig. 1). Discipline specific dissemination plans were developed as follows:

1. Trauma providers: The CDSI was reviewed by and approved by the Acute Care Surgery Steering Committee. Details explaining the CDSI were emailed to all providers. A journal club with roundtable discussion was held and supportive evidence for practice changes was discussed. The CDSI was presented at the monthly Trauma Performance Improvement and Patient Safety meetings.
2. Nursing: A formalized training session was delivered via web-based learning in Healthstream (Healthstream Inc). All trauma nurses attended a 1-hour mandatory CDSI education session and this was followed up with post-assessment test. An unsatisfactory grade required that nurses repeat the session.
3. Respiratory therapy: The departmental lead conducted monthly education with trauma respiratory therapy staff about the CDSI.
4. All: A laminated summary that fit on an identification badge was disseminated to all trauma providers, nursing, and therapists outlining the protocol. The CDSI was published on the institutional intranet for easy and rapid access.

Implementation strategy

The CDSI was developed by the clinical informatics development team in collaboration with the rib fracture planning team during a 3-month period from March through May 2018. The CDSI then underwent iterative user interface and experience improvement during June. The CDSI was implemented on July 31, 2018 (Fig. 1).

Evaluation

Implementation outcomes evaluation used the Proctor framework.¹⁵ Specifically, adoption and feasibility were evaluated by comparing the number of eligible patients with the number of patients that received the CDSI at monthly intervals. Effectiveness of the CDSI was evaluated by conducting a pre vs post propensity-matched analysis. The pre period included all patients age 45 years and older admitted during 2016 with rib fractures. The post period included all patients age 45 years and older admitted between September 1, 2018 and April 1, 2019. The period between January 1, 2017 and August 31, 2018 was excluded from the analysis as this was the planning and development time frame for this intervention.

Acceptability and appropriateness were defined by delivering a validated UTAUT survey to all trauma providers. Maintenance was evaluated at 9 months post implementation by evaluating CDSI use in eligible patients.

Survey analysis

To measure acceptance and appropriateness of the CDSI, we adapted the UTAUT survey developed by Venkatesh and colleagues.¹⁷ The UTAUT is a technology acceptance model that was developed to specifically identify determinants that influence behavioral intentions for use of technology. The UTAUT posits that technology use is affected by 4 user constructs: performance expectancy (belief that CDSI will increase performance), effort expectancy (belief that CDSI will be easy to use), social influence (belief that peers or supervisors think they should use the CDSI), and facilitating conditions (belief that technical infrastructure exists to support the CDSI system). This survey consisted of 17 items grouped into the UTAUT constructs (eTable 2) and was delivered electronically via Google Documents quiz function (Alphabet Inc) to 20 trauma providers. The items were ranked using a 7-point Likert scale (ranging from 1 [totally disagree] to 7 [totally agree]).

Statistical analysis

Summary data were expressed as the mean (SD) for continuous variables and as percentages for categorical variables. For univariate analysis, Pearson chi-square test was used for comparisons between categorical variables, Student's *t*-test was used for continuous variables with normal distributions, and the Wilcoxon rank-sum test was used for continuous variables that were skewed. To evaluate effectiveness, a pre vs post propensity-matched analysis was conducted. The study population was stratified into the following groups: pre-implementation (January 1, 2016 through December 31, 2016) and post-implementation (September 1, 2018 through April 1, 2019). All patients with rib fractures requiring hospital admission age 45 years and older were included, based on previous studies that identified increased rib fracture morbidity after age 45 years.³ Propensity scores were generated to match in a 1:1 ratio based on age, Injury Severity Score, sex, chest Abbreviated

Injury Scale score, insurance status, and packed RBC transfusion requirements, using a logistic regression model. These 6 confounders were selected for matching due to their association with the outcomes measures (ie mortality and pulmonary complication) and model calibration and discriminatory ability. Based on the calculated propensity scores, 2 evenly matched groups were formed with the common caliper (maximum difference that is acceptable for propensity score match) set at 0.01. Propensity score distribution and covariates were evaluated for balance between matched cohorts.

Outcomes differences were explored using logistic regression for binary outcomes and negative binomial regression for LOS. Outcomes of interest included all-cause in-hospital mortality, development of pulmonary complication (defined using the National Trauma Data Standard definitions for pleural effusion, acute respiratory distress syndrome, hospital-acquired pneumonia, unplanned intubation, pneumothorax, pulmonary embolism, and other pulmonary medical complication), development of nonpulmonary complication, and unplanned transfer to the ICU. Statistical analyses were performed using STATA MP, version 15 (Stata Corp). Statistical significance was defined as a p value < 0.05 .

RESULTS

From September 1, 2018 through April 1, 2019, there were 197 patients eligible for the CDSI, with 174 patients receiving the CDSI. After excluding individuals younger than 45 years of age, there were 167 evaluable subjects in the post-implementation group. Table 1 shows that subjects in the post-implementation group were less severely injured (median Injury Severity Score 10.0 vs 13.0; $p = 0.005$), older (age 71.0 vs 62.5 years; $p < 0.02$), and more likely to have Medicare vs commercial insurance status ($p < 0.001$) compared with the pre-implementation group.

Adoption and feasibility of the CDSI was assessed monthly (Table 2). Our predefined threshold target was 80% use of the CDSI. Post-implementation, we found the CDSI was used in 83% of patients after 1 month, 95.5% by after 4 months, and 100% by month 7.

Acceptance of the CDSI was assessed by surveying 20 trauma providers (8 physicians and 12 advanced practice providers) using the UTAUT. Fourteen providers responded to the survey (see eTable 2) and overall level of acceptance was high in each of the domains (mean [SD]: performance expectancy: 6.6 [0.7]; social influence: 6.8 [0.5]; effort expectancy: 6.6 [1.0]; facilitating conditions: 6.1 [1.1]; and behavioral intention: 7.0 [0.0]) (Fig. 2).

Effectiveness of intervention and impact on clinical outcomes

Table 1 compares the characteristics of the pre- and post-CDSI cohorts. Post-intervention subjects had fewer complications (pre: $n = 47$ [24%] vs post: $n = 25$ [15%]; $p = 0.03$), a lower proportion required mechanical ventilation (pre: $n = 41$ [21%] vs post: $n = 21$ [12.6%]; $p = 0.035$), and had a shorter hospital LOS (pre: 4 days [interquartile range 2 to 8 days] vs post: 4 days post [interquartile range 2 to 7 days]; $p = 0.04$) (Table 1). Due to these significant baseline differences in Injury Severity Score, age, and insurance status, a propensity-matched analysis was undertaken.

After propensity matching there were 286 patients available for analysis (143 pre-CDSI patients matched with 143 post-CDSI patients). There were no significant covariate baseline differences remaining in the propensity-matched cohorts (see Table 3) and propensity scores were optimally balanced (eFig. 1). Clinical outcomes in the propensity-matched cohorts are summarized in Table 4. We observed a trend that post-implementation subjects were less likely to develop pulmonary complication (odds ratio 0.35; 95% CI, 0.11 to 1.11; $p = 0.07$) compared with the pre-CDSI cohort. The post-implementation cohort had a 20% shorter hospital LOS (incident rate ratio 0.80; 95% CI, 0.66 to 0.98; $p = 0.03$), but there were no significant differences in mortality, development of any complication, unplanned ICU, ventilator requirements, or ICU LOS.

DISCUSSION

In this study, outcomes were compared before and after a CDSI using the Proctor framework. We observed an overall very high rate of adoption and use, with 100% use 7 months after implementation. Furthermore, the CDSI was rated as “highly acceptable” by the trauma providers surveyed. A statistically significant reduction in overall hospital LOS was noted, with a trend toward reduced pulmonary complication after the CDSI. In 2016, the National Academies of Sciences, Engineering, and Medicine identified inconsistent use of best practices as a major driver of preventable trauma deaths. Poor adherence with EB care has been shown to be a major factor that contributes to inferior clinical outcomes and preventable deaths.⁸⁻¹¹ Adherence with rib fracture EB practices has been shown to reduce complication and improve survival.^{5,6,18,19} The current study was undertaken to increase use of EB best practices to care for older trauma patients with rib fractures. Previously published results from Hermann Memorial Hospital showed that use of an EB protocol reduced pneumonia rates from 18% to 5% and mortality from 13% to 4% in trauma patients with rib fractures.⁵

Clinical decision support systems can provide timely information to inform and alert providers about a patient’s care and have been shown to be an effective tool to implement EB protocols.²⁰⁻²² The full potential of CDS systems might not have been realized because poor implementation strategies often lead to a high proportion of provider alert overrides and poor acceptance.^{12,13} Optimization of implementation strategies should help to overcome the barriers that have limited acceptance.¹³ In the current study, the CDSI was designed to achieve high acceptance and adoption. Inclusion of a multidisciplinary planning team, with stakeholders from all affected discipline, might well have been key to the success of this CDSI. The final rib fracture CDSI included the following critical treatment domains: multimodal pain therapy, discipline-specific order bundles, best imaging practices, and decision support surrounding surgical rib fixation. Dissemination plans were constructed based on discipline-specific stakeholder recommendations and the Healthstream platform was used to deliver formalized individual training. After CDSI development and education, the Epic electronic health record interface underwent iterative user interface and experience optimizations before launch. It might also be that the 2-month dissemination overlap after rollout contributed to the high rate of CDSI adoption and acceptance.

Multiple implementation evaluation frameworks (RE-AIM, Proctor's framework, PRECEDE-PROCEED) exist as methods to evaluate CDSI. Proctor and colleagues^{15,23} developed a core set of implementation outcomes and 2 years later described a conceptual evaluation framework. Proctor and colleagues proposed an implementation outcomes taxonomy that included acceptability, adoption, appropriateness, feasibility, fidelity, cost, penetration, and sustainability. This framework was used in the current study to evaluate the acceptability, adoption, appropriateness, feasibility, and sustainability of the rib fracture CDSI. In the past, deployment of many evidence-based interventions experienced waxing provider adherence with the intervention. However, in this study, we observed a positive use trend over time with 100% use in the last 2 study months.

The UTAUT theory posits that technology acceptance and use behavior is tied directly to performance expectancy, effort expectancy, social influence, and facilitating conditions. We used the electronic health record to embed the CDSI module within the standard trauma admission order set, which allows providers to order an entire bundled care pathway for rib fracture patients with a single mouse-click. Multidisciplinary stakeholder engagement might have contributed to the highest average Likert scale in the social influence component. Performance expectations were supported by electronically delivering transparent CDSI effectiveness reports and reporting at monthly provider performance improvement/patient safety meetings. It seems likely that the observed success in CDSI sustainability and use might have benefited from aligning the CDSI with the UTAUT model.

The current study focused on assessing the use of a CDSI, developed using the UTAUT model, to optimize adoption and end-user satisfaction. Nonetheless, we were also interested to see whether widespread adoption and use of the CDSI impacted clinically important outcomes. Previous studies reported improved clinical outcomes with protocolized care for patients with rib fractures⁵ and we also observed a reduction in hospital LOS, despite a small sample size. A nonstatistically significant reduction of pulmonary complication was seen, and it is possible that a larger sample would identify additional clinically important outcomes measures. The data showed an increase in the use of ICU admissions for patients with multiple rib fractures, but decreased ICU LOS (odds ratio 0.8; 95% CI, 0.5 to 1.3; $p = 0.4$) with the new protocol. It might be that pre-CDSI patients were transferred to the ICU after decompensation on the floor; and post-CDSI patients were admitted to the ICU directly and transferred to the floor only after optimization.

The main limitation of our study is that it was not a randomized controlled trial. Propensity-matched analyses were used to overcome some of the limitations inherent to the retrospective study design, but this approach is not ideal. The current study indirectly benefited from the short study time frame because major changes in clinical care were unlikely during the pre-/post-implementation time frame. The ability to assess end-user perceptions of the CDSI was limited by the small number of trauma providers surveyed and the inherent limitations of using a survey tool to ascertain opinions. As noted, the sample size of the current study was inadequate to assess the CDSI impact on many important clinical outcomes. Nonetheless, the analyses do not suggest that clinical outcomes were adversely impacted and a statistically significant decrease in hospital LOS was observed.

The current study supports the concept that a CDSI should be developed by a multidisciplinary group of stakeholders representing all disciplines affected; might require a minimum 1-year timeline from inception to dissemination; should incorporate a formal specialty-specific education program with a means of effectiveness assessment; should undergo user interface/experience testing to ensure ease of use, reduce provider “click burden,” and improving workflow; and evaluation plan guided by validated implementation evaluation framework should be developed before CDSI deployment.

CONCLUSIONS

The development and use of a rib fracture CDSI resulted in improved provider delivery of EB practice that was associated with a reduction in hospital LOS.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations and Acronyms

CDSI	clinical decision support intervention
EB	evidence-based
LOS	length of stay
UTAUT	Unified Theory of Acceptance and Use of Technology

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Figure 1.
Rib fracture clinical decision support intervention dissemination and implementation timeline. ACS, American College of Surgeons.

Figure 2.

Provider response for Unified Theory of Acceptance and Use of Technology acceptance and appropriateness survey. Mean Likert scale response from provider survey assessing acceptance of rib fracture clinical decision support intervention. Error bars represent SD. BI, behavioral intention; EE, effort expectancy; FC, facilitating conditions; PE, performance expectancy; SI, social influence.

Table 1.

Patient Demographics Pre Implementation Compared with Post Implementation

Variable	Pre implementation (1/2016 through 12/2016)	Post implementation (9/2018 through 4/2019)	p Value
n	196	167	—
Injury Severity Score, median (IQR)	13.0 (9.0–22.0)	10.0 (9.0–14.0)	0.005
Age, y, median (IQR)	62.5 (54.0–80.5)	71.0 (59.0–84.0)	0.02
Sex, m, n (%)	112 (57.1)	104 (62.3)	0.3
Chest AIS, n (%)			0.4
1	0 (0.0)	1 (0.6)	
2	52 (26.5)	51 (30.5)	
3	137 (69.9)	113 (67.7)	
4	6 (3.1)	2 (1.2)	
5	1 (0.5)	0 (0.0)	
Insurance status, n (%)			0.002
Self-pay/Medicaid	17 (8.7)	17 (10.2)	
Commercial	136 (69.4)	87 (52.1)	
Medicare	43 (21.9)	63 (37.7)	
Received packed RBCs, n (%)	4 (2.0)	1 (0.6)	0.2
In-hospital mortality, n (%)	14 (7.1)	14 (8.4)	0.7
Any complication, n (%)	47 (24)	25 (15)	0.03
Pulmonary complication, n (%)	13 (6.6)	5 (3)	0.1
Unplanned ICU, n (%)	11 (5.6)	5 (3)	0.2
Required ventilator, n (%)	41 (20.9)	21 (12.6)	0.04
Hospital LOS, median (IQR)	4 (2–8)	4 (2–7)	0.04
ICU LOS, median IQR	0 (0–2)	1 (0–2)	0.2

AIS, Abbreviated Injury Scale; IQR, interquartile range; LOS, length of stay.

Table 2.
Number of Rib Fracture Patients and Compliance with Rib Fracture Decision Support Intervention

CDSI compliance	September 2018	October 2018	November 2018	December 2018	January 2019	February 2019	March 2019	April 2019	Total
No, n	7	6	4	1	1	4	0	0	23
Yes, n	34	21	17	21	18	22	17	24	174
Total, n	41	27	21	22	19	26	17	24	197
Compliance, %	82.9	77.8	81.0	95.4	94.7	84.6	100	100	88.3

CDSI, clinical decision support intervention.

Table 3.

Patient Demographics Propensity-Matched Cohorts

Variable	Propensity-matched pre-implementation (2016)	Propensity-matched post-implementation (9/2018 through 4/2019)	p Value
n	143	143	—
ISS, median (IQR)	13.0 (9.0–17.0)	12.0 (9.0–17.0)	0.9
Age, y, median (IQR)	65.0 (56.0–84.0)	70.0 (58.0–83.0)	0.7
Sex, m, n (%)	85 (59.4)	82 (57.3)	0.7
Chest AIS, n (%)			0.7
1	0 (0.0)	1 (0.7)	
2	44 (30.8)	40 (28.0)	
3	98 (68.5)	100 (69.9)	
4	1 (0.7)	2 (1.4)	
Insurance status, n (%)			0.2
Self-pay/Medicaid	10 (7.0)	16 (11.2)	
Commercial	97 (67.8)	82 (57.3)	
Medicare	36 (25.2)	45 (31.5)	
Received packed RBCs	0 (0)	1 (0.7)	0.3

AIS, Abbreviated Injury Scale; IQR, interquartile range; ISS, Injury Severity Score.

Table 4.

Effect on Clinical End Points for Propensity-Matched Analysis

Variable	OR	IRR	95% CI	p Value
In-hospital mortality	1.69	—	0.68–4.21	0.3
Any complication	0.61	—	0.34–1.11	0.1
Pulmonary complication	0.35	—	0.11–1.11	0.07
Unplanned ICU	0.56	—	0.16–1.95	0.4
Required ventilator	0.62	—	0.32–1.18	0.1
Hospital LOS	—	0.80	0.66–0.98	0.03
ICU LOS	—	0.82	0.52–1.31	0.4

IRR, incident rate ratio; LOS, length of stay; OR, odds ratio.