Risk for Cardiorespiratory Instability Following Transfer to a Monitored Step-Down Unit

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BACKGROUND: Hospitalized patients who develop at least one instance of cardiorespiratory instability (CRI) have poorer outcomes. We sought to describe the admission characteristics, drivers, and time to onset of initial CRI events in monitored step-down unit (SDU) patients. METHODS: Admission characteristics and continuous monitoring data (frequency 1/20 Hz) were recorded in 307 subjects. Vital sign deviations beyond local instability trigger threshold criteria, with a tolerance of 40 s and cumulative duration of 4 of 5 min, were classified as CRI events. The CRI driver was defined as the first vital sign to cross a threshold and meet persistence criteria. Time to onset of initial CRI was the number of days from SDU admission to initial CRI, and duration was length of the initial CRI epoch. RESULTS: Subjects transferred to the SDU from units with higher monitoring capability were more likely to develop CRI (CRI $n = 133$ [44%] vs no CRI $n = 174$ [31%] $P = .042$). Time to onset varied according to the CRI driver. Subjects with at least one CRI event had a longer hospital stay (CRI 11.3 ± 10.2 d vs no CRI 7.8 ± 9.2 d, $P < .001$) and SDU stay (CRI 6.1 ± 4.9 d vs no CRI 3.5 ± 2.9 d, $P < .001$). First events were more often due to S_{pO_2}, whereas breathing frequency was the most common driver of all CRI. CONCLUSIONS: Initial CRI most commonly occurred due to S_{pO_2} and was associated with prolonged SDU and hospital stay. Findings suggest the need for clinicians to more closely monitor SDU patients transferred from an ICU and parameters (S_{pO_2}, breathing frequency) that more commonly precede CRI events. *Key words: cardiorespiratory instability; step-down unit; physiologic monitoring.* [Respir Care 2017;62(4):415–422. © 2017 Daedalus Enterprises]

Introduction

Step-down units (SDUs) were established to provide care for patients who do not require intensive care but cannot be safely cared for on a normal ward.[1] In the SDU, a variety of parameters are typically monitored continuously and noninvasively, including heart rate, breathing frequency, S_{pO_2}, and blood pressure, to detect the onset of cardiorespiratory instability (CRI). SDUs admit patients with varying demographics, admission characteristics, and comorbid conditions who are at risk for developing CRI. Having a better sense of which patients are more likely to develop CRI and when they will do so would help clinicians concentrate surveillance on patients at greatest risk and parameters that more commonly precede CRI.

Hospitalized patients who develop at least one instance of CRI have poorer outcomes,[2] and patients who display even a single recording of abnormal vital signs are at

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increased risk for critical events.[3] Respiratory distress, manifested by a change in frequency, is the vital sign most commonly associated with medical emergency team activation.[4-8] Other changes may signal deterioration, but few studies have examined the potential of patient admission characteristics, SDU admission source (eg, ICU, other), or timing of CRI to aid in the detection of risk.[9-12]

We have previously reported that CRI, when it occurs, is most likely to manifest in the hours closest to SDU admission.[13] However, there is limited guidance on what changes most commonly serve as the initial vital sign change (driver) preceding CRI or patient characteristics that confer added risk. Therefore, the purpose of this study was to describe admission characteristics, CRI drivers (defined as the first vital sign to cross threshold), and time to onset of initial CRI events in monitored SDU subjects. We sought to identify differences in admission characteristics in subjects who developed or never developed CRI, drivers of the initial CRI event, and number of days after SDU admission when initial CRI most commonly occurred. This information is important for decision making about which patients to more closely monitor and parameters that more commonly precede CRI.

QUICK LOOK

Current knowledge

Step-down units (SDUs) were established to provide care for patients who do not require intensive care but cannot be safely cared for on a normal ward. SDUs admit patients with varying demographics, admission characteristics, and comorbid conditions who are at risk for developing cardiorespiratory instability (CRI). Hospitalized patients who develop at least one instance of CRI have poorer outcomes.

What this paper contributes to our knowledge

There were no demographic differences between subjects who did and did not develop CRI. However, subjects admitted from a higher-intensity monitoring setting were more likely to become unstable and develop CRI. Subjects who experienced one CRI event were more likely to have additional CRI events during their SDU stay and to remain longer in both the SDU and hospital. CRI was more frequent within the first 72 h of SDU admission.

Methods

Sample

With institutional review board approval, continuous vital sign data streams and admission characteristics were collected from 307 subject admissions to a 24-bed adult SDU of a level-1 trauma center during an 8-week period. These data streams, which provided the data set used for analysis, included heart rate (3-lead electrocardiogram), frequency (bioimpedance), S_{pO_2} (pulse oximeter model M1191B, Phillips, Boeblingen, Germany), and intermittent noninvasive oscillometric blood pressure. Frequency was measured by transthoracic bioimpedance using electrocardiogram electrodes, thereby providing a continuous respiration signal from electrocardiogram electrodes, as opposed to other techniques that obtain a frequency signal from a recorded electrocardiogram signal. Body temperature was monitored at variable intervals and therefore not included in the data set. Physiologic monitoring data for the 307 subject admissions were available for a mean of 80 h and median of 60 h each. Heart rate, breathing frequency, and S_{pO_2} data were recorded at 1/20 Hz frequency. Systolic blood pressure and diastolic blood pressure were recorded at a minimum frequency of every 2 h.

Cardiorespiratory Instability

Vital sign excursions beyond our local criteria for instability concern (heart rate <40 or >140 beats/min, breathing frequency <8 or >36 breaths/min, S_{pO_2} $<85\%$, systolic blood pressure <80 or >200, diastolic blood pressure >110) until the time all vital signs return to normality were defined as CRI events and occurred 271,288 times. Due to a high incidence of artifacts with pure threshold deviations, we additionally required that events had to persist for a minimum duration of 3 min, either continuously or sporadically, for 4 min out of a 5-min moving window (80% duty cycle) with or without changes in other vital signs, to be initially classified as CRI. Events that did not meet persistence criteria were termed artifacts. The events remaining were annotated by a team of expert clinicians to differentiate between artifacts and real CRI events,[14] with only real CRI events entered into the analysis. CRI epoch lasted from the time a vital sign crossed the stability threshold and met additional persistence criteria until it returned to normality. Time to onset of initial CRI was the time in days from initial admission into the SDU to initial CRI, and duration was length of the initial CRI epoch in minutes. The CRI driver was defined as the first vital sign to cross a threshold and meet persistence criteria.

Hospital Admission Characteristics

Hospital admission characteristics consisted of age, sex, race, medical history, Charlson comorbidity index (0, 1, ≥ 2),[15] and type of service. Service type was classified as

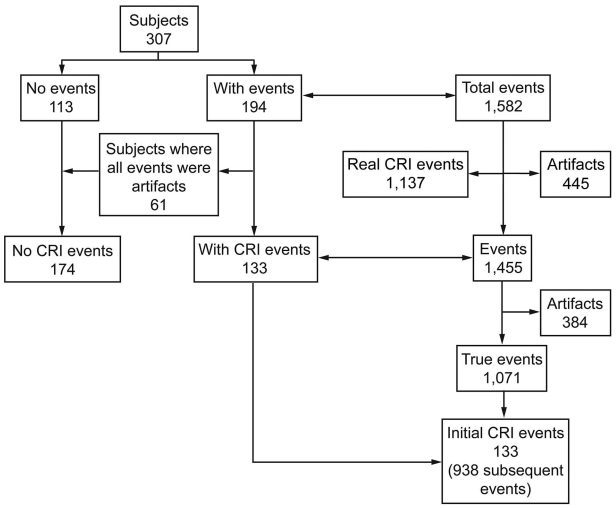

Fig. 1. Schematic diagram of subjects and events. The schematic details the process of deriving initial cardiorespiratory instability (CRI) events and the distribution of events due to CRI drivers. The resulting sample included 133 subjects with CRI, which accounted for 133 initial CRI events.

surgical if subjects were assigned to the general surgery service on admission to the hospital, irrespective of whether their hospital course warranted a surgical procedure or not. Medical subjects were assigned to services such as cardiology, critical care medicine, family medicine, internal medicine, hematology, otorhinolaryngology, pulmonary, and vascular. We also recorded the admission diagnosis as based on the ICD-9 classification code assigned at hospital admission. ICD-9 codes were grouped into 14 categories according to the classification system reported by Brown et al[12] and then reduced to 4 categories based on the majority of codes. The resulting 4 categories were trauma, diseases of the circulatory system, diseases of the digestive system, and all other diagnoses.

Step-Down Unit Admission Source

SDU admission source was recorded as transfer to the SDU from higher-intensity monitoring, direct SDU admission, or transfer to the SDU from a lower-intensity unit.

Outcomes

Outcomes were total hospital stay (LOS) in days, SDU LOS, discharge disposition (transfer to a higher- or lower-intensity monitoring unit or home), and mortality.

Statistical Analysis

Of 307 subjects, 113 never developed CRI, leaving 194 subjects to be considered, who demonstrated 1,582 events (Fig. 1). We annotated these events as real CRI (1,137 events) or artifact (445 events). We created a Gantt chart for each subject to record the occurrence of real and artifact events in the order in which they occurred during a subject's SDU stay. From that analysis, 61 subjects only had artifact events and were therefore included in the group that never developed CRI. This left a total of 133 subjects (43%) who experienced CRI and 174 (57%) who did not.

Data were analyzed using SPSS 22 (IBM Corp, Armonk, New York) for descriptive analysis and exploration. The Mann-Whitney U test was used to analyze non-parametric differences between groups for continuous variables, and a chi-square test was used to compare categorical variables. $P < .05$ was considered significant. Non-parametric tests were used when data were not normally distributed.

Results

Hospital Admission Characteristics

Characteristics of the 307 subjects (174 without CRI and 133 with CRI) are given in Table 1. There were no significant differences between subjects with and without CRI in regard to age, sex, race, or admission service. COPD was the most common comorbidity (16.6%), but there were no significant differences in comorbidities between groups. Slightly more than half (52.1%) had a Charlson comorbidity index of 0, indicating a relatively healthy population; however, there were no significant differences between the CRI and no-CRI groups.

Step-Down Unit Admission Source

There were significant differences between groups based on SDU intake admission source ($P = .042$) (Table 2). Almost half of subjects with CRI were admitted to the SDU from an ICU (44.4%), whereas less than a third (31%) of subjects without CRI were admitted from an ICU.

Drivers of Cardiorespiratory Instability

Collectively, the 133 subjects with CRI experienced 1,071 CRI events (Fig. 1). Of the total 1,071 events, the most common CRI driver for 536 (50%) was breathing frequency, followed by S_{pO_2} (346 events; 32%), heart rate (149 events; 14%), and blood pressure (40 events; 4%). When considering only the 133 initial events or initial CRI, S_{pO_2} was the most common driver (56%), followed by breathing frequency (33%) and heart rate (11%) (Fig. 2).

Table 1. Hospital Admission Characteristics in Subjects With and Without One Cardiorespiratory Instability Event During Step-Down Unit Length of Stay

Variable	Total (N = 307)	No CRI (n = 174)	CRI (n = 133)	P
Age, mean ± SD	57.4 ± 20.2	55.9 ± 20.4	59.28 ± 19.9	.15
Sex, *n* (%)				.55
Male	179 (58.3)	104 (59.8)	75 (56.4)	
Female	128 (41.7)	70 (40.2)	58 (43.6)	
Race, *n* (%)				.14
White	220 (71.7)	117 (67.2)	103 (77.4)	
Black	43 (14)	29 (16.7)	14 (10.5)	
Other	44 (14.3)	28 (16.1)	16 (12.0)	
Type of service, *n* (%)				.54
Surgical	167 (54.4)	92 (52.9)	75 (56.4)	
Medical	140 (45.6)	82 (47.1)	58 (43.6)	
Hospital admission diagnosis, *n* (%)				.12
Trauma	176 (57.3)	106 (60.9)	70 (52.6)	
Diseases of circulatory system	46 (15)	27 (15.5)	19 (14.3)	
Diseases of digestive system	34 (11.1)	13 (7.5)	21 (15.8)	
All other diagnoses	51 (16.6)	28 (16.1)	23 (17.3)	
Medical history, *n* (%)				.28
COPD	51 (16.6)	25 (14.4)	26 (19.5)	
Diabetes	50 (16.3)	25 (14.4)	25 (18.8)	
Myocardial infarction	25 (8.1)	11 (6.3)	14 (10.5)	
Congestive heart failure	24 (7.8)	9 (5.2)	15 (11.3)	
Cerebral vascular disease	20 (6.5)	12 (6.9)	8 (6)	
Charlson comorbidity index				.51
0	160 (52.1)	94 (54)	66 (49.6)	
1	76 (24.8)	44 (25.3)	32 (24.1)	
≥2	71 (23.1)	36 (20.7)	35 (26.3)	

CRI = cardiorespiratory instability

Table 2. Intake Admission Source to the Step-Down Unit and Outcomes in Subjects With and Without One Cardiorespiratory Instability Event During Step-Down Unit Length of Stay

Variable	Total (N = 307)	No CRI (n = 174)	CRI (n = 133)	P
SDU intake admission source, *n* (%)				.042
Higher-intensity monitoring unit	113 (36.8)	54 (31)	59 (44.4)	
Direct admission or lower-intensity monitoring unit	182 (59.3)	109 (62.6)	73 (54.8)	
Unknown	12 (3.9)	11 (6.3)	1 (0.8)	
Outcomes				
Hospital LOS, mean ± SD d	9.2 ± 9.8	7.8 ± 9.2	11.3 ± 10.2	<.001
SDU LOS, mean ± SD d	4.7 ± 4.2	3.5 ± 2.9	6.1 ± 4.9	<.001
Transfer from SDU to a higher-intensity unit, *n* (%)	31 (10.1)	15 (8.6)	16 (12.0)	.45
Died, *n* (%)	5 (1.6)	5 (2.9)	0	

CRI = cardiorespiratory instability
SDU = step-down unit
LOS = length of stay

Onset of Initial and Subsequent Cardiorespiratory Instability Events

We computed the number of days from SDU admission to the development of initial CRI by driver. As shown in Figure 3, initial CRI driven by heart rate tended to occur between days 1 and 6. Initial CRI driven by breathing frequency varied in presentation between the first 10 d of SDU admission, with 34% developing initial CRI on days 1–2. Initial CRI driven by S_{pO_2} tended to occur between

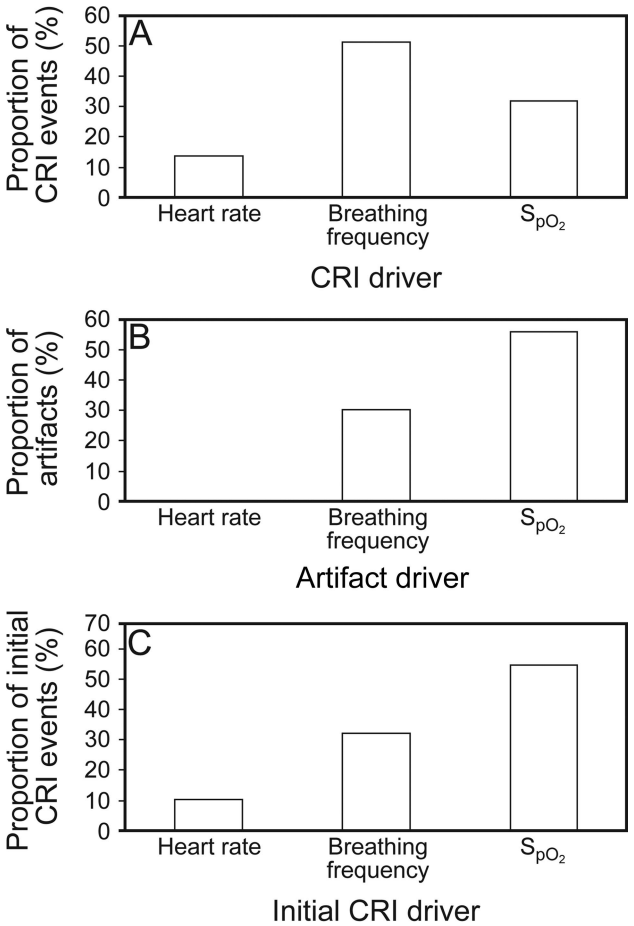

Fig. 2. Percentage of cardiorespiratory instability (CRI) events and artifacts in 133 subjects. The CRI driver was most commonly breathing frequency (A), whereas S_{pO_2} was the cause of most artifacts (B). S_{pO_2} was also the most common cause of the initial CRI event (C). Heart rate was a relatively infrequent cause.

days 0 and 6, with 47% occurring between days 0 and 2. As shown in Figure 4, a minority (23%) of subjects with one initial CRI event never developed a second CRI event, whereas the remaining 77% of subjects exhibited an average of 2–5 events each.

Duration of Initial Cardiorespiratory Instability Epoch

For heart rate, initial CRI duration lasted between 3 and 8 min, with most lasting 4 min. For breathing frequency, initial CRI duration ranged from 3 to 20 min, with 48% of subjects having duration of 3 min. For S_{pO_2}, initial CRI duration ranged from 3–56 min, with 76% lasting between 3 and 6 min.

Outcome

Subjects with CRI had a longer hospital LOS (11.3 d [95% CI 9.6–13.0]) than the subjects without CRI (7.8 d [95% CI 6.4–9.20], $P < .001$). The mean SDU LOS was also longer for subjects with CRI (6.1 d [95% CI 5.3–6.9]) than for the subjects without CRI (3.5 d [95% CI 3.1–3.9], $P < .001$). There was no significant difference between groups in terms of discharge destination or mortality.

Discussion

The major findings from this study are: (1) There were no demographic differences between subjects who did and did not develop CRI, except that subjects who were admitted from an ICU were more likely to become unstable; (2) subjects who developed at least one instance of CRI had a longer SDU and hospital stay; (3) the driver for most CRI events was breathing frequency; (4) time of initial CRI differed between drivers, and (5) S_{pO_2} was the most common initial CRI driver, but breathing frequency was the most common driver when all CRI events during the SDU stay were considered. Whereas initial CRI due to heart rate and S_{pO_2} tended to occur between the first and sixth day, initial CRI due to breathing frequency occurred later in hospitalization (up to the tenth day); duration of initial CRI due to S_{pO_2} tended to last longer, whereas duration of initial CRI due to heart rate was short-lived.

Patients are admitted to a SDU because they are viewed as potentially unstable and in need of closer monitoring for CRI, but knowing which vital signs to observe more carefully would be helpful. Breathing frequency, which has been termed the "neglected sign,"[16] caused more events within our sample than heart rate or S_{pO_2}. Our findings suggest that breathing frequency should receive greater emphasis as an important component of clinical monitoring. The importance of this finding is reinforced by the criteria we used to define breathing frequency as a driver of CRI (eg, a rate that was clearly abnormal [<6 and >36 min]). It is therefore likely that breathing frequency progresses toward abnormality even before these threshold values of serious derangement are reached.

Breathing frequency is altered by numerous clinical states commonly seen in SDU patients, such as pain, preexisting lung disease, infection, and opioid use. An increase in breathing frequency signals increased work of breathing, which places additional stress on the cardiovascular system. Consequently, an increase in breathing frequency is an important predictor of cardiopulmonary arrest.[17] Findings of our study can be best paired with those of Nurmi et al,[18] who found that the most common medical emergency team trigger criterion was respiratory distress. Goldhill et al[19] identified breathing frequency and heart rate as the vital sign most often abnormal before unexpected death. Despite these known associations, breathing frequency is too commonly dismissed as an indicator of distress and recorded as an approximate value or consistently recorded as either 16 or 18.[20] Education regarding the importance of

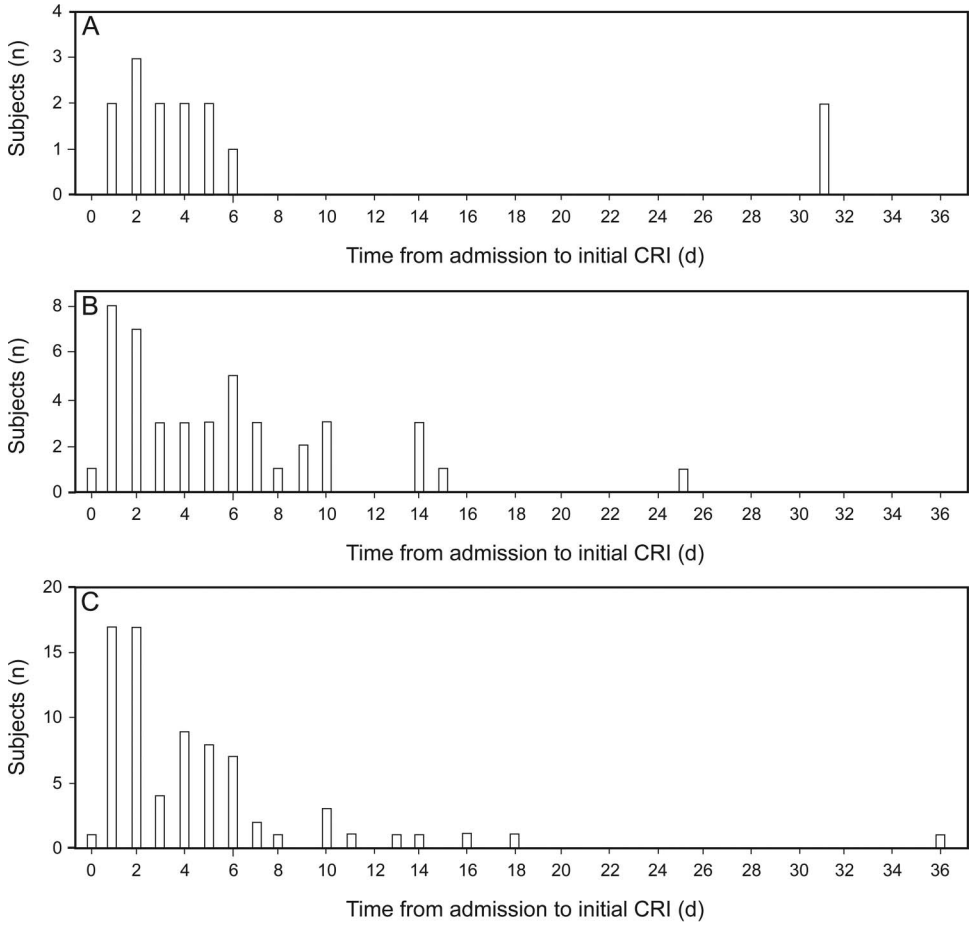

Fig. 3. Number of days from admission to development of the initial cardiorespiratory instability (CRI) event according to heart rate (A), breathing frequency (B), and S_{pO_2} (C). Initial CRI events most commonly occurred in the days following step-down unit admission.

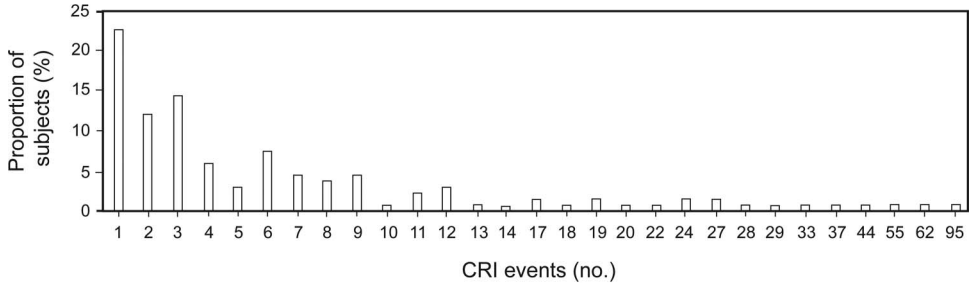

Fig. 4. Frequency of further cardiorespiratory instability (CRI) events in subjects who developed at least one instance of CRI. Most events occurred in the first days of step-down unit admission, with a progressive decline over time.

proper monitoring and reporting of values that exceed expected norms should become an integral part of orientation and continuing education for all clinicians who provide SDU care. We also found that subjects admitted from a higher-intensity monitoring unit were more likely to develop CRI, a finding that also has implications for detection of patients at highest risk. Although objective criteria exist for determining optimal time for transfer out of the ICU, the decision is often driven by a variety of factors, including subjective judgment.[21] In addition, bed availability, both in the ICU and SDU, can influence the timing of transfer.[22] The process of transfer itself can lead to increased stress and the potential for instability. ICU readmission rates can be as high as 2–4%.[23,24] Our findings suggest that close observation is indicated in the initial hours following transfer and for the next several days. In our sample, CRI tended to occur early following SDU admission. Critical care transition programs have been

found to be helpful in assisting with nursing surveillance following ICU discharge.[25]

Notably, 77% of subjects who had one CRI event subsequently experienced additional events. This suggests the need to monitor patients more closely following SDU admission and to monitor patients who experience an initial CRI more closely still. Conversely, more than half of our sample never became unstable. If models could be developed that could predict patients who never become unstable, they would have implications for patient triage and enable clinicians to focus attention on those with greater likelihood of instability.[26]

Subjects who developed CRI had increased SDU and hospital stay, similar to the findings obtained by Fuhrmann et al.[27] Lighthall et al[3] reported that subjects with abnormal vital signs had an LOS twice that of subjects with normal vital signs. We also demonstrated that subjects with CRI had both hospital LOS and SDU LOS that were twice those of the subjects without CRI. The literature reports increased 30-d mortality in subjects with abnormal vital signs,[19,27] with a greater number of abnormal vital signs correlating with greater risk of mortality. Although it is likely that mortality increases with increasing numbers of abnormal vital signs, in our study, mortality between subjects with and without CRI was not statistically significant, probably due to our small sample size.

The study has several limitations. The sample size was small, and our thresholds for abnormality were set externally and independently of the subject's baseline. However, these are the threshold values commonly used as medical emergency team trigger criteria.[28,29] The use of lower thresholds might have altered our results. Besides the stay, our study did not have other metrics to characterize severity of illness. Our data apply to the SDU of one level-1 trauma center and may not be reflective of other settings or patient populations. In our study, mortality between subjects with and without CRI was not statistically significant, probably due to our small sample size. Finally, our process of identifying events as real versus artifact may have resulted in some misclassified events.

Conclusions

Our analysis of CRI in monitored subjects with SDU demonstrates that those admitted from a higher-intensity monitoring setting were more likely to become unstable. Furthermore, subjects who experienced one CRI event were more likely to have additional CRI events during their SDU stay and to remain longer in both the SDU and hospital. The driver for most CRI events was respiratory (breathing frequency or oxygen saturation). Finally, initial CRI was more frequent within the first 72 h of SDU admission. Interestingly, there were no other demographic differences in subjects who did and did not develop CRI. Findings suggest the need for clinicians to more closely monitor patients with SDU who are transferred from an ICU and parameters (S_{pO_2}, breathing frequency) that more commonly precede CRI events.

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