Safety, Feasibility, and Efficacy of Early Rehabilitation in Patients Requiring Continuous Renal Replacement: A Quality Improvement Study

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Introduction: Early rehabilitation in critically ill patients is associated with improved outcomes. Recent research demonstrates that patients requiring continuous renal replacement therapy (CRRT) can safely engage in mobility. The purpose of this study was to assess safety and feasibility of early rehabilitation with focus on mobility in patients requiring CRRT.

Methods: Study design was a mixed methods analysis of a quality improvement protocol. The setting was an intensive care unit (ICU) at a tertiary medical center. Safety was prospectively recorded by incidence of major adverse events including dislodgement of CRRT catheter, accidental extubation, bleeding, and hemodynamic emergency; and minor adverse events such as transient oxygen desaturation >10% of resting. Limited efficacy testing was performed to determine if rehabilitation parameters were associated with clinical outcomes.

Results: A total of 67 patients (54.0 ± 15.6 years old, 44% women, body mass index 29.2 ± 9.3 kg/m²) received early rehabilitation under this protocol. The median days of CRRT were 6.0 (interquartile range [IQR], 2–11) and 72% of patients were on mechanical ventilation concomitantly with CRRT at the time of rehabilitation. A total of 112 rehabilitation sessions were performed of 152 attempts (74% completion rate). No major adverse events occurred. Patients achieving higher levels of mobility were more likely to be alive at discharge (P = 0.076).

Conclusions: The provision of early rehabilitation in critically ill patients requiring CRRT is safe and feasible. Further, these preliminary results suggest that early rehabilitation with focus on mobility may improve patient outcomes in this susceptible population.

Keywords: continuous renal replacement therapy; critical illness; CRRT; early rehabilitation; quality improvement

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receiving CRRT in the ICU. However, data supporting early rehabilitation and mobility in this population are limited. Therefore, the purpose of this quality improvement study was to elucidate the process of developing and implementing an interdisciplinary protocol to provide early rehabilitation to critically ill patients requiring CRRT in the ICU. We assessed the safety and feasibility of the protocol. Secondarily, we examined if early rehabilitation associates with clinical outcomes in this susceptible population.

METHODS

The CRRT and Early Rehabilitation Protocol: Local Problem

The University of Kentucky Albert B. Candler Hospital is an academic medical center with approximately 37,500 admissions in 2017, of which 2600 were admitted to the medical ICU (MICU). According to the Center for Health Services Research at the University of Kentucky, the MICU provides treatment to patients with admission mean sequential organ failure assessment (SOFA) of 8.6, mean ICU length of stay (LOS) of 5.7 days, mean mechanical ventilator (MV) support of 3.7 days, and all-cause hospital mortality of 29%. In 2017, 356 (14.5%) patients admitted to the MICU required CRRT (mean 7.1 days) with increased mortality rate at 50%. Historically at our institution, these patients would have been restricted to bed rest. Therefore, we decided to develop a protocol to provide early rehabilitation to patients receiving CRRT. This quality improvement project occurred in 4 phases: (i) team development, (ii) protocol creation, (iii) protocol implementation with data collection for safety and feasibility, and (iv) exploratory clinical outcome examination.

The CRRT and Early Rehabilitation Protocol: Team Development

To develop the protocol, we first assembled an interdisciplinary team that consisted of nephrologists, intensivists, critical care nurses, physical therapists, and occupational therapists. Team members met to establish the demand and practicality of initiating an early rehabilitation protocol with emphasis placed on teamwork and leadership commitment to early rehabilitation. Initial sessions included comprehensive literature review, delineation of stakeholder roles, and discussions on each step of the proposed protocol.

The CRRT and Early Rehabilitation Protocol: Protocol Creation

The team created a 2-phase early rehabilitation protocol for patients requiring CRRT. Phase 1 consisted of a multistep assessment of patient appropriateness to engage in the rehabilitation protocol:

(i) Morning review of the patient’s electronic health record to assess hemodynamic status, ventilator settings, and sedation completed by the rehabilitation clinician (Figure 1). If the patient met criteria, a bedside discussion with the patient’s nurse was conducted to assess for recent changes in clinical status or new contraindications.

(ii) Coordination between the interdisciplinary ICU team to schedule and conduct the rehabilitation session.

Phase 2 of this early rehabilitation protocol was developed to standardize implementation and progression of physical activity and mobility. Progression of physical activity was driven by the rehabilitation specialist by assessing the patient’s hemodynamic response to increased activity. In addition, clinicians assessed and monitored changes in CRRT deliverables and functionality (Figure 2). This also included review of the “ASK” method to assess Appropriateness, Secured Site, and Kink & Pressures developed by Talley et al.

The CRRT and Early Rehabilitation Protocol: Patient Eligibility

Adult patients admitted to the MICU from March 2017 to September 2018 requiring CRRT were eligible for the protocol. Patients in deep sedation (Richmond Agitation and Sedation Scale < −2), severe agitation (Richmond Agitation and Sedation Scale >2), and high ventilator settings (FiO2 >0.60 and/or positive end-expiratory pressure >10 cm H2O) were excluded, as they would not be appropriate for early rehabilitation regardless of CRRT. This protocol constituted a quality improvement initiative to promote early rehabilitation as standard of care, consequently informed consent was waived. We received approval from the University of Kentucky Institutional Review Board, Office of Research Integrity, Institutional Review Board number 47751 for data collection and analysis. Figure 3 provides description of the number of eligible and participating patients.

The CRRT and Early Rehabilitation Protocol: Protocol Implementation and Data Collection

Demographic and clinical data were collected from the electronic health record, including age, sex, race, body mass index, severity of illness at ICU admission (SOFA score), preexisting comorbidities, Charlson comorbidity index, ICU LOS, hospital LOS, MV days, CRRT days, and cumulative fluid balance. Data of incident major adverse events, including dislodgement of CRRT or other catheter, accidental extubation (if intubated), bleeding, and hemodynamic emergency requiring immediate medical intervention (e.g., i.v. fluids and/or
vasopressor administration) were collected. Minor adverse events were defined as transient ≥10% oxygen desaturation below resting \( \text{SaO}_2 \), increase in respiratory rate >35 breaths per minute, mean arterial pressure drop below 60 or elevation above 120 mmHg, systolic blood pressure <90 or >200 mmHg, new arrhythmia or significant bradycardia <40 beats per minute or tachycardia >180 beats per minute, and/or new onset of chest pain/angina. Feasibility was assessed according to the 8 areas proposed by Bowen et al. in 2009. Specifically, we assessed feasibility by the implementation rate as a percentage of completed rehabilitation sessions in relation to the total number of attempts. We performed a limited efficacy analysis to determine if early rehabilitation interventions associated with clinical outcomes. Selected clinical outcomes (dependent variables) included hospital mortality, MV days, CRRT days, ICU LOS, and hospital LOS. Independent variables related to rehabilitation implementation included the following: (i) the number of completed rehabilitation sessions per patient, (ii) the ratio of completed rehabilitation sessions per CRRT days, (iii) the time from ICU admission to first rehabilitation session (days), and (iv) the highest achieved 5-level mobility category (Figure 2).

**Statistical Analysis**

Continuous variables were reported as median and IQR or mean and SD according to data distribution. Categorical variables were reported as counts and proportions. Data were assessed for normality (Shapiro-Wilk) and appropriate parametric or nonparametric tests were used. Spearman rho correlation analysis was performed to assess if rehabilitation variables correlated with continuous clinical outcomes (CRRT days, MV days, ICU LOS, and hospital LOS). Chi square and logistic regression were used to examine if rehabilitation variables were associated with all-cause hospital mortality. Candidate variables for multivariable models were selected according to univariable associations and clinical relevance and included SOFA score, Charlson comorbidity index, and presence of liver disease. Statistical significance was set as \( P < 0.05 \). All analyses were performed using SigmaPlot 14 (Systat Software Inc, San Jose, CA).
RESULTS

The CRRT and Early Rehabilitation Protocol: Patient Data

A total of 67 patients receiving CRRT in the MICU participated in at least 1 rehabilitation session during the 18 months of protocol implementation. Patients engaging in the protocol had mean age of 54.0 ± 15.6 years (44.1% women, 92.5% white) and had a median SOFA score of 13 (IQR, 11–15) at the time of admission to the ICU. Of the 67 patients participating, 96%
The CRRT and Early Rehabilitation Protocol: Safety Assessment

No major adverse events or unintended stoppage of CRRT occurred during the study period. Rehabilitation clinicians reported 5 minor adverse events (4.5%) in 5 distinct patients (2 hypotensive events with mean arterial pressure <60 mm Hg, 1 bradycardic event <40 beats per minute, and 1 event of new-onset atrial fibrillation). The fifth event occurred while the patient was sitting at the edge of the bed when a CRRT “low flow rate alarm” was triggered that coincided with a transient drop in oxygen saturation (SaO2 98% to 87%). Accordingly, the physical therapist selected to return the patient to supine position and such CRRT functionality and oxygenation returned to baseline. A sixth event was reported with the bedside nurse preventing the patient from sitting at the edge of the bed because of concerns with risk of accidentally dislodging the CRRT catheter. A review of the event by the implementation team determined that this preemptive termination of rehabilitation was related to nurse fear of mobility and not related to the protocol itself.

The CRRT and Early Rehabilitation Protocol: Feasibility by 8 Domains

The following are the 8 domains.25

(i) Acceptability: There were no reports of resistance to this protocol at any time. Nurse deferral of rehabilitation session not related to exclusion criteria occurred only 4 times of 152 total attempts. These deferrals occurred in 4 different patients: 2 occurred because the nurse requested rehabilitation clinicians to return later, as the nephrology team planned to transition the patient off CRRT; 1 deferral occurred to allow the patient to sleep, and 1 occurred because of patient anxiety.

(ii) Demand: The protocol was delivered and perceived as an important change in culture of early rehabilitation and remains active.

(iii) Implementation: A total of 152 rehabilitation sessions were attempted and 112 were completed (73.6%). Of the 40 deferred sessions, the primary reason for deferral of rehabilitation was a recent decline in clinical status (n = 18, 45%) such that the patient no longer met criteria for appropriateness listed in Figure 1 (Safety Screening). Additional reasons for deferral included increased sedation and are listed in Table 2. Of the 112 completed sessions, the median number of sessions per patient was 1.0 (IQR, 1.0–2.0), with a median rate of sessions per CRRT days of 0.21 (IQR, 0.15–0.33) and a median time from ICU to the first successful rehabilitation session not related to exclusion criteria occurred only 4 times of 152 total attempts. These deferrals occurred in 4 different patients: 2 occurred because the nurse requested rehabilitation clinicians to return later, as the nephrology team planned to transition the patient off CRRT; 1 deferral occurred to allow the patient to sleep, and 1 occurred because of patient anxiety.

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admission to first rehabilitation of 5.0 (IQR, 2.0–8.5) days.

(iv) Practicality: The protocol was routinely performed over an 18-month period by 2 full-time physical therapists and 1.5 occupational therapists (46 MICU beds). Moreover, patients refused only twice to engage in this protocol demonstrating, that these individuals can participate in rehabilitation.

(v) Adaptation: No changes were made to the protocol during the 18-month period of implementation.

(vi) Integration: Protocol implementation occurred without adding staff, demonstrating low-cost feasibility of this project.

(vii) Expansion: This study was implemented only in the MICU, but the protocol is currently being expanded to the trauma ICU.

(viii) Limited efficacy testing: An exploratory analysis was performed to determine if early rehabilitation with emphasis on mobility associated with clinical outcomes.

The CRRT and Early Rehabilitation Protocol: Limited Efficacy Testing

There were no associations between age, sex, race, body mass index, Charlson comorbidity index, and SOFA score at ICU admission and the number of completed rehabilitation sessions. The number of completed rehabilitation sessions directly correlated with MV days, hospital LOS, ICU LOS, and CRRT days ($r = 0.392, 0.254, 0.384$, and 0.467, respectively). The number of completed rehabilitation sessions was not associated with hospital mortality. The ratio of completed rehabilitation sessions per CRRT days directly correlated with MV days and CRRT days ($r = 0.345$ and 0.640, respectively). Time from ICU admission to first rehabilitation also directly correlated with MV days, hospital LOS, ICU LOS, and CRRT days ($r = 0.425, 0.289, 0.444$, and 0.399, respectively) (Table 3), but was not associated with hospital mortality. Patients achieving a higher level of mobility were more likely to be alive at time of hospital discharge, although statistically not significant ($\chi^2 = 9.96$, $P = 0.076$) (Supplementary Figure S1). In addition, shorter time from ICU admission to first rehabilitation session was associated with achieving higher mobility status ($r = -0.292$, $P = 0.017$).

In multivariable analysis, none of the rehabilitation parameters was independently associated with hospital mortality. However, higher Charlson comorbidity index and the presence of liver disease were significantly associated with hospital mortality (odds ratio: 3.296; 95% confidence interval: 1.00–10.82; $P = 0.049$ and odds ratio: 1.29; 95% confidence interval: 1.01–1.66; $P = 0.046$, respectively) (Supplementary Table S1).

**DISCUSSION**

The main finding of our study was that the implementation of an early rehabilitation protocol with emphasis on mobility for patients requiring CRRT in the ICU is safe and feasible. This quality improvement project confirms that patients on CRRT can safely engage in early rehabilitation interventions.15–19 Of interest, no major adverse events occurred and only 5 minor adverse events were reported; all transient in nature with no consequences in the patient’s clinical status or CRRT functionality. No unintended interruptions of CRRT occurred during these early rehabilitation interventions. However, these data should be interpreted cautiously, as the incidence of high levels of mobility was low (34% of sessions achieved active mobility). It is possible that passive activity is not enough physiological stimuli to elicit adverse events. Nonetheless, the achieved levels of mobility in our study are consistent with prior studies in the critically ill population.15,16,18

The safety and feasibility of early rehabilitation, activity, and mobility for patients requiring mechanical ventilation is well-established in the literature.8,9,13,14,26 Furthermore, early mobility has been shown to improve short- and long-term outcomes for patients with critical illness.7–11 Despite the supporting evidence, early interventions remain relatively low in clinical practice,17–30 particularly in patients on CRRT. Low incidence of early mobility in clinical practice is thought to be multifactorial, including patient factors, such as heavy sedation, complex catheters and tubes, and hemodynamic instability.31–34 ICU providers, staff, and culture also play important roles in preventing or
advocating for early mobility. In the past decade, these concepts have been extended to patients requiring CRRT. In 2010, Pohlman et al. reported performing rehabilitation interventions in patients requiring MV and CRRT. Although the focus was on mobility in patients with MV, 9% of the sessions performed included patients requiring both MV and CRRT. Three years later, Talley et al. published the first study implementing early mobility in patients on CRRT. In 2014, Hodgson et al. published expert consensus stating that CRRT has a low risk of an adverse event during early rehabilitation.

After our protocol creation, the implementation team identified nursing acceptability as a key component to the success of this project. A previous study by Anekwe et al. identified that early mobilization is not a top priority (49% of respondents) of ICU clinicians; moreover, 58% felt they were not trained to implement these interventions. Thus, our interdisciplinary team provided educational sessions to the nursing and rehabilitation staff to highlight the protocol and address any concerns. To support the practicality of this protocol, the team provided education at regular staff meetings and through identified clinician champions. We were able to integrate the protocol in a cost-effective manner without adding meetings or paying for additional resources. After education, the protocol was implemented and continues to remain active. A mixed methods analysis of the first 18 months of protocol activation was performed to assess safety, feasibility, and limited efficacy. The feasibility of this project, specifically, the rate of completed sessions in reference to the total number of attempts (74% success rate) may be questioned. Clinically, however, this is more an indication of the severity and heterogeneity of our patient population. Most of the deferred sessions were explained by an increase in sedation or a recent decline in clinical status that required interventions (e.g., vasopressor support for hypotension). Furthermore, the current rehabilitation clinician-to-patient ratio (1:22) in the MICU may have played a role in reducing the total number of completed rehabilitation sessions decreasing the number of patients who received more than 1 rehabilitation session while on CRRT. The clinician-to-patient ratio also could have prevented appropriate progression to higher levels of mobility. Prior literature demonstrates that increasing rehabilitation staff can affect outcomes.

Patients in this study had a high severity of acute illness (median SOFA score of 13), high percentage of concomitant MV, high frequency of receiving blood products, and a high prevalence of liver disease and end-stage kidney disease. Of the 112 rehabilitation sessions, 72% were performed in patients with both CRRT and MV. Therefore, the complexity of this medical ICU population may have limited the progression of active mobility supporting a higher frequency of passive interventions.

The limited efficacy analysis revealed that patients achieving higher levels of mobility were more likely to survive the hospitalization, although not statistically significant. These results should be interpreted cautiously, as the sample size is small and there is lack of a control group. Therefore, it is likely that patients achieving higher levels of mobility were less acutely ill and as such may have had favorable outcomes regardless of rehabilitation interventions. We also observed a relationship between shorter time from ICU admission to first rehabilitation session and higher mobility status. This observation suggests that early rehabilitation may be beneficial for delivery of more effective therapy. However, we did not find an association between shorter time to first rehabilitation and improvement in clinical outcomes such as reduced MV or length of hospital or ICU stay, perhaps limited by the small sample size of the study. Others previously demonstrated that longer time to first physical therapy was associated with longer hospital LOS. This is an important relationship that should be examined further to understand if reducing time to first rehabilitation therapy can affect clinical outcomes in these patients.

Our study has limitations. The primary limitation is the low frequency of rehabilitation sessions that included high levels of mobility, as most of these interventions were passive. This can be explained by a combination of reasons, including significant number

### Table 3. Correlations of CRRT and critical illness parameters with selected rehabilitation parameters

| Selected critical illness parameters | Completed rehabilitation sessions | Ratio of completed rehabilitation sessions to CRRT d | Time (d) to first rehabilitation session | Highest mobility achieved |
|-------------------------------------|-----------------------------------|-----------------------------------------------|------------------------------------------|--------------------------|
| MV, d                               | 0.392, P = 0.001                  | 0.345, P = 0.004                              | 0.425, P = 0.004                         | −0.004, P = 0.974       |
| Hospital LOS                        | 0.254, P = 0.038                  | −0.014, P = 0.908                             | 0.289, P = 0.018                         | 0.125, P = 0.311        |
| ICU LOS                             | 0.384, P = 0.001                  | −0.190, P = 0.123                             | 0.444, P < 0.001                         | 0.182, P = 0.141        |
| CRRT, d                             | 0.467, P < 0.001                  | 0.640, P < 0.001                              | 0.399, P < 0.001                         | −0.013, P = 0.92        |

CRRT, continuous renal replacement therapy; ICU, intensive care unit; LOS, length of stay; MV, mechanical ventilator.

There were no significant correlations between rehabilitation parameters and age, body mass index, sequential organ failure assessment score at intensive care unit admission, and Charlson comorbidity index (data not shown).

Statistical analysis using Spearman rho test. Data presented as correlation coefficient, P value.
of patients with high rates of sedation and high acuity of illness and comorbidity that would have prevented high levels of mobility regardless of CRRT. In addition, the culture of early mobility is improving in our institution but remains limited in complex patients in the ICU. Moreover, nursing fear of mobility despite the education provided may have prevented high levels of mobility. Another limitation is the absence of measures of functional outcomes, such as Physical Function ICU Test, gait speed, and sit to stand time in the limited efficacy testing facet of the study. Finally, as this was established as a quality improvement project, a control group was not available; consequently, we were not able to examine clinical outcomes in patients who did not receive rehabilitation interventions.

CONCLUSIONS

Implementation of an early rehabilitation protocol with focus on physical activity and mobility is safe and feasible in critically ill patients receiving CRRT, albeit only a low proportion of patients achieved high levels of mobility. These data are consistent with prior literature demonstrating that critically ill patients can safely engage in rehabilitation interventions without major adverse events and/or unintended CRRT interruptions. In our study, high comorbidity and acuity of illness may have played a role in preventing high levels of mobility. Further evidence is required to determine the efficacy of early rehabilitation in improving patient outcomes; specifically, interventional trials are warranted.

DISCLOSURE

All the authors declared no competing interests.

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SUPPLEMENTARY MATERIAL

Supplementary File (PDF)

Figure S1. Highest level of mobility achieved during rehabilitation sessions stratified by hospital mortality. Patients achieving higher levels of mobility were more likely to be alive at discharge, although not statistically significant ($\chi^2 = 9.96, P = 0.076, \text{Cramer’s } V = 0.39$).

Table S1. Multivariable logistic regression models of hospital mortality as the dependent variable and selected rehabilitation parameters analyzed as the main independent variable.

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