Active Rehabilitation in a Patient During and After Venovenous Extracorporeal Membrane Oxygenation With a Diagnosis of COVID-19: A Case Report

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ABSTRACT

Purpose: The coronavirus disease-2019 (COVID-19) pandemic has resulted in an influx of critically ill patients requiring mechanical ventilation, some receiving venovenous (VV) extracorporeal membrane oxygenation (ECMO). The benefits of early mobility while undergoing ECMO have been previously documented. However, the COVID-19 pandemic has presented physical therapists with novel challenges, balancing the risk of a widespread shortage of personal protective equipment (PPE) with the benefits of early mobility for patients on ECMO. The purpose of this case study is to report the successful rehabilitation of a critically ill patient with COVID-19 undergoing VV ECMO.

Methods: This is a case description of a 38-year-old man who presented to the hospital with COVID-19 and subsequent intubation and cannulation for VV ECMO. Physical therapy was initiated while the patient remained critically ill on VV ECMO. Focused coordination and education were employed to limit PPE usage by limiting the number of essential staff/therapists that entered the room as well as changing the frequency of therapy sessions dependent on how the patient was progressing functionally.

Results: On VV ECMO day 11, he was able to sit up and perform a sit-to-stand. ECMO decannulation occurred on hospital day 14 with extubation on hospital day 18. The patient progressed functionally while quarantined in the room until he was discharged home with supplemental oxygen after spending 29 days in the hospital.

Conclusion: This case study demonstrates the clinical decision-making used to provide physical therapy services for a critically ill patient with COVID-19. High-level team coordination resulted in limiting the use of PPE as well as reducing staff exposure frequency during rehabilitation. Despite his severe critical illness, the patient was successfully discharged home within 30 days.

The medical community has had to adjust rapidly due to the severe acute respiratory syndrome-coronavirus 2 (SARS-CoV-2) outbreak and resulting coronavirus disease-2019 (COVID-19) pandemic.[1-4] This includes the added pressure on all intensive care units (ICUs) to maintain adequate staffing, personal protective equipment (PPE), and medical equipment supplies in the face of an unknown novel virus. Extracorporeal membrane oxygenation (ECMO) in patients with advanced respiratory failure has increased over the past 10 years, and usage would most certainly be needed with a virus that primarily affects the lungs and heart.[5-7] Prior to the development of an ECMO mobilization protocol at our hospital, patients managed with ECMO were excluded from physical therapy (PT) protocols either because clinicians felt these patients would be unable to tolerate activity or the large-bore ECMO cannulae posed a safety risk due to the possibility of inadvertent dislodgement. Ambulatory ECMO has been reported to have been safely used in patients for over a decade with a highly trained interprofessional staff.[8,9] Ambulation on ECMO can be performed safely in any cannulation configuration, including venovenous (VV) and venoarterial, as well as groin (femoral artery/vein) or neck (internal jugular vein) cannulation.[9-11]

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Patients with pneumonia benefit physiologically and functionally from changing positions.[12] For example, the upright position allows patients to be ambulatory and socially interactive, providing the most effective vehicle for clinical recovery.[13] This physician also indicated patients with lung disease or pulmonary injury do not benefit from paralysis, sedation, and intubation with nonphysiologic positive pressure ventilation. These concepts become especially important in COVID-19 in patients who present with hypersecretion and ineffective cough.[14] By encouraging functional mobility, the patient can actively change positions to improve pulmonary hygiene as well as a host of other measurables in terms of effective patient outcomes, including blood pressure regulation, strength, and activity tolerance.[15,16]

Post-intensive care syndrome (PICS) is described as new or worsening impairments in physical, cognitive, or mental health that arise after critical illness and persist beyond hospital discharge.[17] Observational studies have suggested factors associated with this syndrome. However, few interventional studies have targeted the prevention of PICS.[18] Early mobilization and initiation of PT are integral components of the interprofessional management of patients in the ICU and may have implications for improved outcomes following hospital discharge. In a meta-analysis of 6 randomized controlled trials, early rehabilitation was shown to improve short-term physical functioning outcomes in critically ill patients otherwise at risk for PICS.[19] Further, a systematic review noted that early PT and related exercises had a positive effect on long-term physical functioning outcomes, including the Physical Functioning Scale of the Short-Form 36 and the distance achieved during the 6-minute walk test.[20]

Despite the limited body of literature regarding the detailed delivery of PT to critically ill patients with COVID-19, early recommendations favor the early mobilization of these patients.[21] Also, data regarding mobilization and rehabilitation of patients with COVID-19 undergoing and following ECMO are lacking. The purpose of this article is to provide a detailed description of PT delivery with a patient with COVID-19 who required VV ECMO.

CASE DESCRIPTION

The patient was a 38-year-old man without any significant medical history other than a body mass index of 35.6 kg/m^2. He had competed in an Ironman competition in 2017 and remained active with his family prior to admission. His exposure to COVID-19 likely occurred during domestic business travel in which he had close contact with infected individuals. He initially presented to another hospital with 5 days of fever and cough. Chest x-ray and routine respiratory viral testing were negative, and he was discharged home without COVID-19 screening, based on the Centers for Disease Control and Prevention guidelines at that time. He self-quarantined at home due to concern for COVID-19, given his travel and subjective illness. The patient then presented to our facility on day 6 of quarantine with a persistent cough, worsening dyspnea, malaise, and fever (40°C) and was admitted to the ICU, where he underwent a medical workup, including COVID-19 polymerase chain reaction testing. His oxygen requirements rapidly increased from nasal cannula to facemask to noninvasive positive pressure ventilation and eventual mechanical ventilation within 24 hours. Despite these measures, the patient had refractory hypoxemia with peripheral oxygen saturation (Spo_2) in the 70% to 80% range, and the medical team elected to initiate VV ECMO. A 30F Crescent ECMO cannula (Medtronic, Dublin) was placed at the patient's bedside into the right internal jugular vein. Post-cannulation, Spo_2 rose to 95%. The patient's COVID-19 infection was confirmed shortly after that.

With the goal of early participation in PT as well as nursing-driven mobilization, the medical team minimized sedation to maintain a Richmond Agitation and Sedation Scale (RASS) score of 0 to −1. The RASS is used to quantify mental status in critical care settings and allows clinicians to titrate sedating medications to a specific goal dependent on medical status.[22] With an RASS level approaching but not quite 0, the patient was able to follow some commands and become a more active participant in nursing cares and mobility. Benefits of early mobilization are well documented in the literature, both with regard to cardiopulmonary improvements and in the management of delirium.[23-25]

On ECMO day 3, the patient demonstrated improvements in alertness and was consistently afebrile. Acute myocardial injury can occur in individuals with COVID-19. However, he did not present with any symptoms of reduced cardiac ejection fraction confirmed via echocardiography.[26] These improvements led the medical team to refer this patient to PT for rehabilitation. Despite the referral, the PT clinician delayed intervention due to factors including nursing reports of the patient's limited command following and diminished PPE resources. During this initial phase, the ECMO-trained PT team members participated in interprofessional discussions with the nursing team to provide recommendations, including mobilizing the patient to the chair via a ceiling lift for improved alertness. These types of critical decisions were made throughout the patient's hospitalization in efforts to balance patient care while minimizing the use of PPE and staff exposure.

Continuous renal replacement therapy was initiated on ECMO day 6 because of the patient's waning kidney function (creatinine measured at 7.46 mg/dL this date). Upon inspection of other laboratory values, bilirubin and C-reactive protein (CRP) had plateaued and were beginning to downtrend. At this time, the patient was able to follow direct commands, exhibited an RASS of 0, and had stabilized from a respiratory standpoint. Given

TABLE 1. Timeline of Medical Status, Therapy Intervention, Functional Status, and Associated Hospital and ECMO Days[a]

Hospital Day/Date	ECMO Status/ PT Status	Respiratory Support	Pertinent Laboratory Values	Therapy Intervention	Patient Response	AM-PAC IMSF
2 March 10, 2020	VV ECMO initiated	Full mechanical ventilation PCV+ Fio_2: 40%-100% PEEP: 10 mm Hg ECMO Fio_2: 100% Sweep gas flow: 3 L/min	CRP: 180 mg/L Creatinine: 1.05 mg/dL Bilirubin: 0.5 mg/dL	No orders	N/A	N/A
4 March 12, 2020	VV ECMO d 3	Full mechanical ventilation PCV +Fio_2: 40%-50% PEEP: 10 mm Hg ECMO Fio_2: 100% Sweep gas flow: 2-3 L/min	CRP: not drawn Creatinine: 3.40 mg/dL Bilirubin: 5.2 mg/dL	Consulted with nursing; patient to chair via ceiling lift	RASS: −1 to −2	N/A
7 March 15, 2020	VV ECMO d 6/PT d 1	Full mechanical ventilation PCV+ Fio_2: 40%-60% PEEP: 10 mm Hg ECMO Fio_2: 100% Sweep gas flow: 0.5-1 L/min	CRP: 240 mg/L (trending down from 380 mg/L 2 d prior) Creatinine: 7.46 mg/dL Bilirubin: 6.4 mg/dL (trending down from 7.1 mg/dL 1 d prior)	Initial evaluation including sitting edge of bed	RASS: 0; oxygen desaturation to 74% with sitting EOB, poor tolerance	8
12 March 20, 2020	VV ECMO d 11/PT d 6	Full mechanical ventilation PCV+ Fio_2: 60%-100% PEEP: 10-14 mm Hg ECMO Fio_2: 100% Sweep gas flow: 2-5 L/min	CRP: 17 mg/L Creatinine: 2.21 mg/dL Bilirubin: 2.6 mg/dL	Sit-to-stand with 3-person assistance	Oxygen desaturation to 78%-82% with activity	9
14 March 22, 2020	Decannulation ECMO d 13/PT d 8	Full mechanical ventilation PCV+ Fio_2: 50%-70% PEEP: 10 mm Hg ECMO Fio_2: 21% Sweep gas flow: 0 L/min	CRP: 8.5 mg/L Creatinine: 2.32 mg/dL Bilirubin: 1.5 mg/dL	PT not delivered this date due to scheduling demands	N/A	N/A
17 March 25, 2020	Post-ECMO d 3/PT d 11	Pressure support mechanical ventilation CPAP/PS Fio_2: 40% PEEP: 6 mm Hg Later extubated to HFNC	CRP: 10 mg/L Creatinine: 6.76 mg/dL Bilirubin: 1.3 mg/dL	Sit-to-stands and stand-pivot to chair with minimal assistance from therapist	Subjective dyspnea, oxygen desaturation to 88%, HR 140s with activity, prolonged rest breaks	16
18 March 26, 2020	Post-ECMO d 4/PT d 12	HFNC 70%-100% Fio_2	CRP: 10 mg/L Creatinine: 4.16 mg/dL Bilirubin: 1.4 mg/dL	Sit-to-stands and stand-pivot to chair with minimal assistance from therapist	Subjective dyspnea, oxygen desaturation to 85%, prolonged rest breaks	17

(*continues*)

TABLE 1. Timeline of Medical Status, Therapy Intervention, Functional Status, and Associated Hospital and ECMO Days[a] (*Continued*)

Hospital Day/Date	ECMO Status/ PT Status	Respiratory Support	Pertinent Laboratory Values	Therapy Intervention	Patient Response	AM-PAC IMSF
21-23 March 29, 2020, to March 31, 2020	Post-ECMO d 7-9/PT d 15-17	HFNC 60%-100% Fio_2 to 4-L/min O_2 per nasal cannula	CRP: 20 mg/L Creatinine: 4.28-5.07 mg/dL Bilirubin: 1.2-1.5 mg/dL	Twice-per-day sessions initiated, limiting therapist-to-therapist PPE use; step-ups, sit-to-stands, short distance ambulation	Subjective dyspnea, oxygen desaturation into 80th percentile with activity, prolonged rest breaks	19-20
25 April 2, 2020	Post-ECMO d 11/ PT d 19	4-L/min O_2 per nasal cannula	CRP: 9 mg/L Creatinine: 5.8 mg/dL Bilirubin: 1.0 mg/dL	Step-ups in room for stair simulation, PT frequency sharply decreased to minimize PPE use; patient safely mobilizing in-room with nursing directives/ education	Frequent rest breaks self-initiated	22
29 April 6, 2020	Post-ECMO d 15/ PT d 23	Room air at rest; 2-L/min O_2 per nasal cannula with activity	CRP: not drawn Creatinine: 3.78 mg/dL Bilirubin: not drawn	Discharge home with home exercise program and planned telerehabilitation	Maintaining >87% oxygen saturation while on supplemental oxygen with activity	22

AM-PAC IMSF, Activity Measure for Post-Acute Care Inpatient Mobility Short Form; CPAP/PS, continuous positive airway pressure/pressure support; CRP, C-reactive protein measured in milligrams/liter; ECMO, extracorporeal membrane oxygenation; EOB, edge of the bed; Fio_2, fraction of inspired oxygen; HFNC, high-flow nasal cannula; HR, heart rate; N/A, not available; PCV, pressure control ventilation/assist control; PEEP, positive end expiratory pressure measured in millimeters of mercury; PPE, personal protective equipment; PT, physical therapy; RASS, Richmond Agitation and Sedation Scale; VV, venovenous.

[a]Reference laboratory values: C-reactive protein, 0.0 to 8.0 mg/L; creatinine, 0.66 to 1.25 mg/dL; bilirubin, 0.0 to 0.2 mg/dL.

the patient's improvement in medical status, PT services were initiated. During initial PT sessions, sweep gas was increased in the ECMO circuit from 0.5 to 3.0 L/min to support the patient's respiratory function and optimize early mobilization efforts. Sweep gas is used to support the lungs by assisting with the removal of carbon dioxide (CO_2) that can increase during respiratory failure. Table 1 details the patient's medical status and outlines the PT interventions and patient response to activity at key points of his hospitalization. Additionally, in Table 1, the Activity Measure for Post-Acute Care (AM-PAC) Inpatient Mobility Short Form (IMSF) demonstrates the patient's progress on the mobility spectrum throughout his treatment course.

Course of Rehabilitation

The patient's rehabilitation while on VV ECMO and mechanical ventilation was progressed based on activity tolerance, given his medical complexity. He was seen 11 out of the initial 14 days after PT was initiated to progress mobility. Initially, the patient was unable to sustain sitting at the edge of the bed (EOB) secondary to subjective complaints of shortness of breath in addition to changes in vital signs. Objectively, the transition to sitting at EOB resulted in venous saturation of O_2 (SvO_2) decreasing from 50% and 55% to 31% and Spo_2 decreasing from 93% and 95% to 74%, with prolonged recovery periods up to 8 minutes and requiring a return to bed (semi-Fowler's position) due to medical instability.

Throughout the patient's course of rehabilitation, clinicians noted regular desaturations of Spo_2 to 75% to 85% during activity and prolonged recovery (5-8 minutes).

On ECMO day 11 (PT day 6), he was able to progress to standing with assistance from 3 staff members while on full mechanical ventilation (assist control; 60% Fio_2) and ECMO support (3 L/min of sweep gas). Spo_2 decreased from 96% to 77% and 79%, respiratory rate increased from 25 to 40 and 50 breaths/min, and heart rate (HR) increased from 110 and 120 to 140 and 150 beats/min. No abnormal heart rhythms were detected throughout the patient's hospitalization outside of sinus tachycardia. On ECMO day 12 (PT day 7), the sweep gas was turned off, and his O_2 and CO_2 blood levels remained stable for 24 hours. The following day, he was successfully decannulated from ECMO. Overall, he was able to participate in 6 sessions of PT while on ECMO.

The period post-ECMO allowed for increased frequency of therapy sessions and decreased need for additional staff. To maintain safety throughout these sessions, close monitoring of respiratory status and coordination with the medical teams were essential as continued desaturations, tachypnea, and tachycardia (HR elevation to 140-150 beats/min during initial sessions) were regularly observed. PT sessions lasted for 45 to 75 minutes, longer than the typical duration for hospital therapy sessions at this facility, whereby 30- to 45-minute sessions are the standard. Concurrently, the patient demonstrated symptoms of lethargy, reduced attention, and disorientation during rehabilitation sessions. This could be related to the delirium he had experienced earlier in the hospitalization, the continued subjective complaints of dyspnea/tachypnea with mobility, and/or perhaps neurological sequelae of his infection.[27,28] As such, the Cognitive Assessment Method for the ICU (CAM-ICU) completed during his hospitalization was positive during the first 7 days of his critical illness. While no formal diagnosis of anxiety was made, his self-reported anxiety symptoms were magnified when he mobilized early in his course of rehabilitation. Having identified the association between mobilization and anxiety symptoms, the medical team and the therapists were able to use nonpharmacological approaches to treat him. These included guiding him during mobilization while acknowledging self-reported anxiety, providing reassurance, and enacting measures to make the patient feel safer. Specific examples of these include setting expectations of the session with the patient prior to mobilizing and always having a surface available for him to sit/lie and rest when fatigued and tachypneic. On post-ECMO day 3 (PT day 11), the patient progressed during the rehabilitation session to pivoting bed-to-chair with minimal assistance while mechanically ventilated. His Spo_2 decreased to 88%, and HR increased to 140 beats/min during the activity. That same day, he was extubated and placed on a high-flow nasal cannula (HFNC) at 20 to 40 L/min and 60% to 100% fraction of inspired O_2 (Fio_2).

The patient's mobility was restricted to the room due to infection prevention. However, on post-ECMO day 4 (PT day 12), he was able to initiate short-distance ambulation during PT sessions while on 100% Fio_2 via HFNC. Again, desaturations of Spo_2 from the 95% to 97% range to the mid-80s with associated tachypnea limited functional progress during this time. On post-ECMO day 7 (PT day 15), to limit PPE usage (being able to reuse certain PPE items) and take advantage of a window where his energy was increasing, the frequency of PT was increased to 2 sessions per day. During this time mobility was emphasized, as access to training equipment was prohibited. Guided progression under physiological monitoring was employed to maximize functional gains. He soon progressed to performing multiple sets and repetitions of sit-to-stands, bouts of short-distance ambulation, and step-ups onto an aerobic step. Varying levels of O_2 support (40%-100% Fio_2) on HFNC were used while the patient participated in therapy sessions to mitigate his dyspnea complaints during activity.

The care plan was changed on post-ECMO day 10, and he was seen only twice over the final week of his hospitalization. This decision was made to preserve PPE again and to reduce unnecessary exposure events, as he was mobilizing without physical assistance. The physical therapist continued to provide direction on progressing aerobic activity independently with nursing assistance as needed. Prior to hospital discharge, he was able to perform repetitions of 6- to 8-inch step-ups without upper extremity support or physical assistance to mimic the necessary stair negotiation task at home. On post-ECMO day 15 (PT day 23—last session), the patient was stable on room air at rest and 2 L/min of O_2 via nasal cannula with activity, maintaining Spo_2 more than 87%.

OUTCOMES

After 29 total days in the hospital, the patient was discharged to his home with his spouse's full-time assistance/supervision. The physical therapist provided patient education on initiating an aerobic home exercise program and functional strengthening. He was referred to telerehabilitation for PT follow-up to ensure ongoing progress. Due to his illness nature and intermittent self-reported anxiety, he was given referrals to cognitive and psychological services for use at his discretion upon discharge. He was also provided with education on signs/symptoms of PICS, as this condition is prevalent in those who receive ICU care.[29]

As outlined in the case description earlier, substantial limitations were observed in this patient's physical strength and cardiovascular endurance. Nearing the end of his hospitalization, the 30-second sit-to-stand and 3-m preferred gait speed tests were used to track the progress of the patient's strength and endurance and

TABLE 2. Timeline of Outcome Measures			
Hospital Day	**ECMO Status/PT Status**	**30-s Sit-to-Stand in Number of Repetitions**	**3-m Gait Speed, m/s**
23	Post-ECMO d 9/PT d 17	5	N/A
25	Post-ECMO d 11/PT d 19	10	1.4
29	Post-ECMO d 15/PT d 23	16	1.9

ECMO, extracorporeal membrane oxygenation; N/A, not available; PT, physical therapy.

determine his risk for falls. These specific assessments were chosen because of their reliability, validity, and appropriateness for patient populations with respiratory compromise.[30-34] Importantly, these assessments could be used within his hospital room's limited space. The patient's performance of these measures is noted in Table 2. On post-ECMO day 9 (PT day 17), the patient completed 5 repetitions of the 30-second sit-to-stand test. Two days later, he doubled that figure, and on post-ECMO day 15 (PT day 23), he more than tripled that result. No specific cut-off scores exist in either measure for a patient of this age. However, the patient was initially well below normative data of 14 to 19 stands for a moderately active older adult and progressed to within this range before discharge.[35] His measured preferred gait speed on post-ECMO day 11 (PT day 19) was 1.4 m/s. Four days later, his rate had increased by 36%. These improvements demonstrated a minimal detectable difference of at least 0.11 m/s for 4-m preferred gait speed testing.[36] Please note that normative data do not exist for 3-m preferred gait speed testing. The patient's AM-PAC IMSF scores progressed from an initial score of 8 to a discharge score of 22 out of a maximum score of 24. This indicates a significant functional improvement in basic mobility, as the minimal detectable difference is 4.5 or greater.[37]

DISCUSSION

Based on the ECMO decannulation date, we present the first North American case describing the use of ECMO for an individual with COVID-19 who survived to hospital discharge.[38,39] During this unprecedented time in our hospitals and ICUs, a consensus on when to initiate rehabilitation with those who are critically ill secondary to COVID-19 is lacking. Due to being in the unique position of navigating this novel environment, where sophisticated coordination with the care team and limited use of PPE was needed, sharing this experience from a medical and rehabilitative perspective is prudent. Every health care system will have to make decisions regarding balancing risk to staff, PPE usage, meeting the patient's needs appropriately, and discharge planning. Due to the high death rate once COVID-related mechanical ventilation is required, physical therapists (as well as the rest of the medical team) need to make sound clinical decisions to determine when a physical therapist should commence therapy for patients diagnosed with COVID-19.[40-42]

Engaging in open dialogue with the medical team and closely examining laboratory values and impairments in functional status are key factors associated with success. In this case, thoughtful monitoring of respiratory status (ECMO/ventilator settings), inflammatory state (CRP), and liver/renal panels occurred. Once clinical improvement slowly began, and survival was likely, an interprofessional decision was made to initiate PT, knowing that aggressive rehabilitation was necessary to optimize the patient's functional status. Once he had been extubated and was requiring progressively less medical intervention, mobilization was prioritized by all medical staff. The treating physical therapists collaborated to initiate twice-daily sessions with the same clinician to maximize his function and limit PPE utilization from therapist to therapist. To limit the PT team's exposure as much as possible, a total of 5 therapists saw this patient throughout his hospitalization, minimizing the patient hand-off between therapists. At our large academic hospital, utilizing more than 5 physical therapists to treat patients undergoing prolonged lengths of stay is common due to variable therapist schedules. We would also like to highlight that a second patient with a similar disease course was admitted to our hospital in late March and was placed on ECMO/mechanical ventilation for COVID-19. Due to success with the patient described in this case report, a comparable care planning approach was employed. Therapists were able to mobilize this patient while on ECMO, and the patient was also able to discharge directly to home within 19 days of admission.

Once discharged, patients who have recovered from COVID-19 will likely have limited resources available for rehabilitation due to societal social distancing, infection control measures, and staff-to-patient ratio changes.[43] Therefore, once the medical team felt the patient was preparing to discharge the hospital, an emphasis was made to ensure the patient could go home safely. This was determined based on his successful progression to independence with bed mobility, transfers, ambulation, and stairs, with supplemental O_2 only needed during repeated trials of transfers and ambulation. The PT staff felt the patient would have benefitted from formal in-person outpatient pulmonary rehabilitation, but that service was unavailable due to the pandemic and closure of local rehabilitation clinics. Consequently, an emphasis on education toward the independent progression of aerobic exercise was placed before discharge. Combining the nature of the illness, the creative interprofessional care planning to limit PPE, and the patient's outcome, the approach outlined in this report was appropriate and can serve as a model for the rehabilitation of critically ill patients with COVID-19 moving forward.

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