Case Report

Management of a COVID-19-infected critically ill patient treated by extracorporeal membrane oxygenation: a case report

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Abstract: Coronavirus disease 2019 (COVID-19) is a new type of respiratory infectious disease that spreads among humans. People infected with COVID-19 present with severe acute respiratory symptoms, fever, cough, breathlessness and dyspnea, impaired physical conditions, kidney failure, and even death. Chest radiographs suggest diffuse inflammation in both lungs and show “white lung” changes. Patients may even experience multiple organ failures within a short period. The effects of general ventilator-assisted treatment are poor. While the application of extracorporeal membrane oxygenation (ECMO) for adjuvant therapy in COVID-19 patients may benefit, there is still a lack of clinical management experience to guide the treatment of the disease. Therefore, in this case, report, we describe the case of a COVID-19-infected patient who was managed with ECMO. During treatment, the patient’s vital signs, biochemical indicators, and hemodynamic changes were closely monitored, with strengthening the operation of ECMO and mechanical ventilation, the patients bleeding, infection and other related complications were actively prevented and managed. After active treatment and careful management, the patient was successfully weaned from ECMO after 13 days. This report has summarized the management experience of a severe case with ECMO management, which can provide a reference for the diagnosis and treatment of severe COVID-19 patients in the future.

Keywords: Case report; coronavirus disease 2019 (COVID-19); extracorporeal membrane oxygenation technology; management

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Introduction

Coronavirus disease 2019 (COVID-19) is an inflammatory lung disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (1). Recent research suggests that critically ill patients with comorbidities, advanced age, and impaired physical conditions have higher mortality rates. No vaccine or specific antiviral treatment is available for the prevention and treatment of this disease. Clinical management is currently based on symptomatic treatment (2).

COVID-19 patients may progress rapidly and experience serious complications such as acute respiratory distress syndrome, shock, and even multiple organ failure within a short period, and these complications can lead to death (3). Extracorporeal membrane oxygenation (ECMO) is a life-support technology enabling a patient’s blood to be oxygenated in an extracorporeal circuit using an artificial oxygenation membrane and pumps. ECMO supports the patient’s heart and lungs to sufficiently rest to minimize

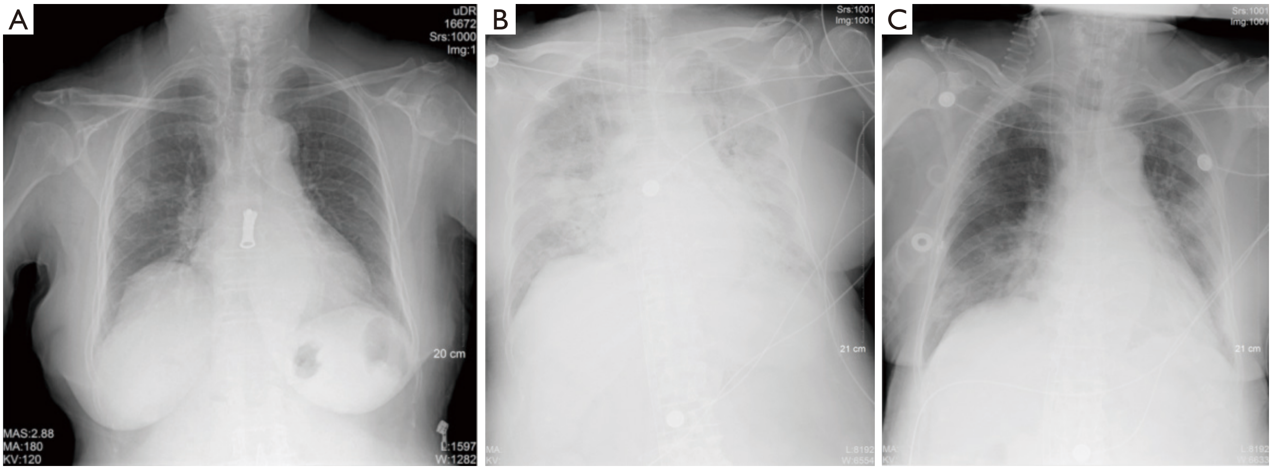

Figure 1 Chest X-ray images of the patient. (A) The chest radiograph on January 26 showed that the inflammation of the right lung and interstitial changes of both lungs, supporting COVID-19-infected. (B) The chest radiograph on February 8 showed that the inflammation of both lungs was significantly worse than before, and "white lung" changes were observed. (C) The chest radiograph on February 17 showed that the diffuse inflammation of both lungs, local lesions in the lower right lung field were slightly absorbed than before, and bilateral lung exudation was improved from before.

the deleterious effects of invasive mechanical ventilation and provides an opportunity for heart and lung function recovery (4). ECMO has been used to treat severe respiratory infections such as the Middle East respiratory syndrome (MERS), H7N9 avian influenza, and H1N1 influenza A (5-7).

The First Affiliated Hospital, Guangzhou Medical University, is a designated treatment center for novel coronavirus pneumonia in Guangdong Province. This hospital is responsible for the admission and treatment of severely sick patients and offers remote medical assistance to patients in need in Guangzhou. Between January and February 2020, ECMO was implemented in a COVID-19-infected patient. After active treatment and careful management, the patient was successfully weaned from ECMO. We present the following article following the CARE reporting checklist (available at https://dx.doi.org/10.21037/apm-20-1176).

Case presentation

Patient

The patient was an 84-year-old woman who had lived long-term in Guangzhou, Guangdong province. She had not been to Wuhan city but contacted her son, who had been positive for COVID-19. She was admitted to the hospital on January 26, 2020, with paroxysmal cough and chest tightness for 2 days as the main complaint. She had a history of coronary atherosclerotic heart disease and chronic renal failure for several years and was treated with oral drugs. Moreover, she had a right hip replacement due to necrosis of the femoral head 10 years ago. The chest radiograph showed inflammation of both lungs' right lung and interstitial changes, which indicated the possibility of COVID-19 pneumonia (*Figure 1A*). The neutrophil count was 9.97×10^9/L, and C-reaction protein was 70.2 mg/L.

Diagnosis and treatment

On January 26, 2020, this patient was admitted and diagnosed by the SARS-CoV-2 throat swab nucleic acid test. Arbidol, lopinavir/ritonavir, moxifloxacin, imipenem sodium, and cilastatin sodium were used for treatment. At 11:48 on January 31, the patient was transferred to the intensive care unit (ICU) due to worsening respiratory function. Two days later, the monitored oxygen saturation decreased to 85% (oxygen inhalation through a high flow humidified oxygen delivery device, 45 L/min, FiO_2 45%), PO_2 was 83.3 mmHg (*Table 1*), and mechanical ventilation therapy by oral intubation was immediately performed (CMV mode, FiO_2 100%, PEEP 12 cmH_2O, VT 450 mL). On February 5, the patient's creatinine (172.9 μmol/L) and

Table 1 Vital signs monitoring results

Vital signs	Jan 31	Feb 2	Feb 7	Feb 10	Feb 15	Feb 19
Temperature (℃)	36.7	36.5	35.6	36.5	36	36.4
Hear rate (bpm beat per minute)	67	54	116	80	78	80
Respiration rate (breaths per minute)	24	22	24	20	20	20
Systolic blood-pressure (mmHg)	136	100	75	119	132	136
Diastolic blood-pressure (mmHg)	61	50	45	62	72	78
Percutaneous oxygen saturation (%)	90	85	72	93	100	100

Table 2 Volume records of continuous renal replacement therapy (CRRT)

Parameter	Feb 7	Feb 10	Feb 15	Feb 19
Ultrafiltration volume (mL)	167	4,614	2,000	1,874
Total liquid intake (mL)	3,774	2,690	2,480	2,425
Total liquid output (mL)	807	3,531	2,092	3,485

Table 3 Extracorporeal membrane oxygenation (ECMO) parameter record

Parameter	Feb 8	Feb 9	Feb 11	Feb 13	Feb 15	Feb 17	Feb 19
Centrifugal pump speed (rpm)	1,500	2,103	2,152	1,970	1,970	1,986	1,680
Blood flow (L/min)	2.2	2.35	2.56	1.93	1.78	2.04	1.52
Fraction of inspiration O_2 (%)	100	100	100	100	100	100	100
Air flow volume (L/min)	2	2	2	2	2	2	2

urea nitrogen (18.53 mmol/L) were significantly increased, and urine volume (435 mL/day) decreased. Considering the possibility of renal failure, continuous renal replacement therapy (CRRT) treatment was performed (*Table 2*). The chest radiograph on February 6 showed that the inflammation of both lungs was significantly worse than before, and "white lung" changes were observed (*Figure 1B*).

On February 8, the patient's oxygenation index had continued to drop below 100 mmHg and was accompanied by cardiogenic shock. Veno-arterial extracorporeal membrane oxygenation (VA-ECMO) was performed as the rescue therapy under the guidance of ultrasound. The bypass blood flow was 1.5–2.5 L/min, and the rotation speed was 1,500–2,200 rpm (*Table 3*). During the ECMO treatment period, the MV and CRRT were still performed based on the condition of the patient, and the signs of pneumonia significantly improved. Ventilator parameters were also gradually decreased (APV-CMV mode, PEEP 13–8 cmH_2O, VT 380–420 mL, FiO_2 100–45%, SPO_2 88–100%) (*Table 4*). On February 19, the bypass blood flow declined to 1.7 L/min, the rotation speed was 1,700 rpm, and the chest radiograph (February 17) showed that the signs of inflammation were improved (*Figure 1C*). The patient was removed from ECMO safely.

On March 12, the patient was conscious and mentally in good condition after ICU treatment, and her upper limbs were slightly active. Vital signs were stable; she had no fever symptoms, diffuse inflammation in both lungs had improved, oxygenation was stable, she had been separated from the ventilator, and a high-flow humidification therapy device assisted breathing. Furthermore, the detection of new coronavirus nucleic acid in 3 consecutive respiratory tract samples was negative. As her condition was stable, she was discharged from the hospital and transferred to a specialist ward to continue treatment (*Table 5*).

Table 4 Ventilator parameter record

Parameter	Feb 2	Feb 5	Feb 7	Feb 10	Feb 15	Feb 19	Feb 21
Mode	APV-CMV	APV-CMV	P-SIMV	P-SIMV	APV-CMV	APV-CMV	P-SIMV
Tidal volume (mL/kg)	390	400	386	385	330	420	430
Oxygen concentration (%)	95	70	100	90	53	45	40
Breath rate (breaths per minute)	19	19	24	12	20	20	16
Positive end expiratory pressure (cmH_2O)	12	13	12	10	9	8	6

APV-CMV, adaptive pressure ventilation - controlled mechanical ventilation; P-SIMV, pressure - synchronized intermittent mandatory ventilation.

Table 5 Detection results of novel coronavirus

Parameter	Jan 26	Feb 2	Feb 7	Feb 12	Feb 19	Mar 12
Nasopharyngeal swab	+	+	+	+	+	–
Oropharyngeal swab	+	+	+	+	+	–
Microbal blood culture	+	+	+	+	+	–

Table 6 Clinical laboratory results

Measure	Jan 31	Feb 2	Feb 5	Feb 7	Feb 10	Feb 15	Feb 19	Feb 21
Potential of hydrogen	7.274	7.1	7.328	7.304	7.413	7.382	7.434	7.452
Partial pressure of carbon dioxide (mmHg)	34.6	35.6	41.8	48.4	38.7	35.7	37.6	35.3
Partial pressure of blood oxygen (mmHg)	65.4	158	147	129	47.3	91.1	126	100
Potassium (mmol/L)	4.8	3.7	3.8	4.1	3.8	4	3.5	3.7
Sodium (mmol/L)	142	154	146	144	140	143	137	142
Lactate (mmol/L)	1.62	2.8	6.8	7.6	1.9	1.4	0.8	0.6
Glucose (mmol/L)	7.85	9.5	10.5	16.5	9.9	7.6	8.7	7.1
Procalcitonin (ng/mL)	0.491	1.38	2.45	3.14	4.76	1.31	0.8	0.6
B-type natriuretic peptide (ng/L)	888	855	832	750	2,560	1,293	764	750

Clinical laboratory results

Clinical laboratory test results showed that during the worsening of the patient's condition, the blood pH, partial pressure of carbon dioxide, and partial oxygen pressure were low. Simultaneously, the values of lactic acid, glucose, procalcitonin, and B-type natriuretic peptide were high. After ECMO treatment, laboratory test indexes gradually returned to normal, except the B-type natriuretic peptide index, which remained high (*Table 6*).

Clinical management

Quarantine protection and infection control

The known transmission routes of COVID-19 include spread via respiratory droplets and contact transmission (8). If isolation and protection measures are not adequate, cross-infection will easily occur. On February 14, 1,716 medical personnel across the country were unfortunately infected with COVID-19, which resulted in 6 deaths (9). Therefore, during the treatment of COVID-19 patients, the rules of isolation protection should be strictly followed to ensure medical safety.

Patient isolation

A single-room, negative-pressure, laminar-flow isolation ward was used to treat patients independently. A circulating air sterilizer was installed in the ward. Dedicated bedside medical equipment such as sphygmomanometers, thermometers, and stethoscopes were used on patients. Chlorine disinfectant at a concentration of 1,000 mg/L was used twice a day for disinfection. The closed endotracheal sputum suction method was used to clean up sputum and secretions. Excreta and human waste were wrapped in a double-layer yellow garbage bag with a special red infection mark attached, and then subsequent processed through inactivation of the virus and other ways before being detected.

Isolation and protection of medical personnel

Medical personnel implemented isolation protection following relevant guidelines and were equipped with N95 masks, disposable one-piece protective isolation clothing, double-layer disposable latex gloves, protective eye masks, hats, protective screens, and protective shoe covers. The seven-step washing method was strictly implemented, and medical personnel had to bathe and change clothes before ending their shift and leaving the quarantine area.

As the disease continued to worsen, the patient's immune function further declined, and invasive treatments such as ECMO, mechanical ventilation, and CRRT may easily lead to secondary infections (10). Therefore, medical personnel should pay attention to aseptic operations when nursing various catheters, pipelines with residual blood or secretions should be cleaned up in time to reduce human infection factors, and blood culture examinations should be regularly conducted as required. The patient showed multiple drug-resistant Burkholderia infections during blood culture on February 19, and the isolate was sensitive to colistin and meropenem. The anti-infection drug treatment plan was adjusted in time, and antibacterial drugs were used in combination. The chest radiograph on February 22 showed that the inflammation of both lungs was disappeared compared to a previous scan, and the infection was well controlled.

Patient perspective

During treatment in the ICU, the patient was in a sedative state, and the condition and treatment effects could only be evaluated through the relevant examination results.

Basic care

Body temperature monitoring

During ECMO treatment, the patient's blood flow was directed outside the device's body. During the extracorporeal tubing and oxygenator operation, the temperature drops, and body temperature will be low, which is not conducive to maintaining the patient's normal metabolism. They may even lead to adverse events such as hemodynamic disturbances and coagulopathy (11). Therefore, it is necessary to closely monitor the patient's body temperature and keep their body temperature fluctuating between 36.0 and 37.5 ℃. No abnormal body temperature was observed during the implementation of ECMO treatment. The ward's temperature was set at 22–24 ℃, while the control water tank was 36.5–37.0 ℃. The patient's body temperature was recorded every 30 minutes and observed for chills, muscle tremors, and other behaviors.

Monitoring of circulation

During the implementation of ECMO or CRRT treatment, blood rapidly flowing inside and outside the body will increase the heart's burden and cause a relative shortage of effective blood volume, which may easily lead to heart failure (12). This elderly patient had a history of heart disease and relatively impaired heart function. To understand the patient's dynamic circulation, we conducted arterial blood pressure monitoring and accurately recorded the daily access volume to assess circulatory function. The patient's blood pressure decreased to 77/46 mmHg when CRRT was performed on February 6. We then suspended dehydration and appropriately supplemented the crystal and colloid solutions. Dobutamine and norepinephrine were used to maintain blood pressure. After the active rescue, the patient's blood pressure was restored to 99/53 mmHg. Then, the vasoactive drug concentrations and the infusion rate were adjusted according to the patient's condition, and the ECMO blood flow rate and CRRT dehydration amount were properly adjusted under the condition of stable circulation. After active treatment, the patient's circulation status was stable. On the day of weaning off the ECMO, the patient's dobutamine was adjusted to 1.81 μg/kg/min, norepinephrine was 0.14 μg/kg/min, and blood pressure was maintained at 120–140/60–75 mmHg. The heart rate was between 80–85 beats/min.

Management of mechanical ventilation

Management of ventilator parameters

The “Novel Coronavirus Pneumonia Diagnosis and Treatment Program (Trial Version 7)” clearly states that patients with severe new coronary pneumonia should be treated with lung-protective ventilation strategies during mechanical ventilation, that is, low tidal volume (6–8 mL/kg ideal body weight) and low inspiratory pressure (plateau pressure <30 cmH_2O) mechanical ventilation (13). In this case, we carefully monitored and recorded ventilator parameters such as positive end-expiratory pressure, tidal volume, and oxygen concentration during mechanical ventilation. According to the patient’s condition, we made timely adjustments to protect the patient’s lung function to the greatest extent. This patient was treated with the APV-CMV, SCMV, and P-SIMV modes when appropriate during ECMO treatment. We set the pressure between 11–25 cmH_2O, PEEP between 8–13 cmH_2O, the respiratory rate between 12–20 times/min, and FIO_2 control between 45–100%. During the treatment period, the patient had no pneumothorax or subcutaneous emphysema complications.

Sedation and analgesia management

Affected by wide-spread lung inflammation, patients’ oxygenation status with severe novel coronavirus pneumonia is relatively poor. It is necessary to continue applying sedative and analgesic drugs to reduce the body’s oxygen consumption caused by agitation and human-machine confrontation and improve the patient’s comfort during mechanical ventilation (14). In this case, the patient was treated with sedation and analgesia throughout mechanical ventilation. Morphine was used for analgesia, midazolam was used for sedation, and atracurium was used to relax the muscles according to the patient’s condition. Nurses used the Richmond agitation-sedation scale (RASS) to assess the patient’s sedation status every 2 h or when necessary (such as ECMO catheterization, rollover, etc.). They controlled the sedation score between −5 and −3 to prevent the patient from being agitated and uncomfortable and to avoid the pipeline falling off or shifting. No serious human-machine confrontation or other accidents occurred after mechanical ventilation in this case.

Suction care

With the disease’s progression, inflammation of the lungs in patients with severe novel coronavirus pneumonia continues to increase, and the oxygenation state further decreases. To maintain the oxygenation state and maintain lung capacity, closed sputum suction throughout the treatment was performed for this patient. The spread of respiratory droplets is a known important transmission route for novel coronavirus pneumonia (15). Closed suction can effectively prevent the virus from spreading into the air, thereby protecting medical staff from infection. Meanwhile, when using closed sputum suction, the ventilator and oxygen therapy kept running. This is conducive to maintaining a certain positive end-expiratory pressure and preventing the secondary collapse of the expanded alveoli from aggravating lung injury (16). To ensure the patient maintained a good oxygenation state, the oxygen concentration was appropriately increased before and after sputum suction for 1 to 2 minutes, and the number and duration of sputum suctions were reduced as much as possible. The volume, color, and viscosity of sputum that was collected each time were recorded, and the patient’s reaction status during oxygen inhalation was observed. The sputum of this patient was thin, and there was no sputum scab or bleeding.

ECMO monitoring care

ECMO circuit management

The ECMO system consists of connecting lines, centrifugal pumps, oxygenators, and some other parts. It is critical to maintaining the effective connection of pipelines to ensure the successful operation of ECMO. After insertion of the catheter is completed and the position is confirmed by B-ultrasound, the doctor who performed the catheterization fixed the end of the tube with surgical sutures and then fixed it with an elastic bandage after sterile dressings for protection. The nurse changed the puncture site’s dressings daily and checked the pipe’s placement and exposed length. Simultaneously, the nurse used the “holding high platform method” to properly fix it to ensure that the pipe was free from tension, twisting, and discounts. We used the Ampel patch for local decompression protection at the location where the pipeline passes, preventing device-related skin damage. There was no loss during ECMO use in this patient, and there was no pressure sore on the skin around the duct.

Observation and nursing of the membrane oxygenator

The membrane oxygenator is the core part of ECMO, and this is where the blood completes gas exchange to improve the oxygenation state. During continuous blood circulation, the fibrous membrane easily reduces the effective area due to fibrin adhesion and reduces the exchange capacity of oxygen and carbon dioxide (17). Therefore, during ECMO, the color change of the oxygenator should be observed, along with whether there are blood clots or color deepening. If there is blood clotting, the oxygenator should be replaced in time. Additionally, during ECMO, the oxygenator should be closely observed for bubbles and abnormal shaking to avoid the occurrence of air embolism. This patient had no blood clots and air embolism during ECMO.

Anticoagulation management

Blood is inevitably exposed to and interacts with artificial materials during ECMO. To avoid activation of the coagulation system and prevent thrombosis, systemic anticoagulation drugs are needed for supportive treatment. ECMO anticoagulation's basic goal is to maintain the balance of anticoagulation, coagulation, and fibrinolysis, but many factors affect the coagulation function of severe patients. Therefore, multiple coagulation indicators need to be monitored in the clinic to understand the complete picture of coagulation (18) fully. The patient, in this case, continued to be administered heparin sodium anticoagulation therapy during ECMO treatment. The plasma prothrombin time (PT) fluctuated between 15.2–18.6 s and the partially activated prothrombin time (APTT) was between 43.1–93.2 s. The international normalized ratio (INR) was between 1.18–1.54, the platelet (PLT) level was between 28–104×10^9/L, and fibrinogen (Fib) was between 1.51–5.13 g/L. On the day of catheterization, the patient bled approximately 500 mL from the femoral artery puncture of the right lower extremity, which was compressed by an arterial compression device. PLT, plasma, and red blood cells are transfused according to the patient's routine blood condition. The punctured wound did not continue to bleed after active treatment.

Ethical statement

All procedures performed in studies involving human participants were following the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Each of ECMO, HFOV, and prone positioning procedures was approved by the Medical Ethics Committee of The First Affiliated Hospital of Guangzhou Medical University (No. 187).

We did not commence any experimental use of a novel procedure or tool in this case. Informed consent for each procedure was obtained from the next of kin of the patient and this case is reported retrospectively.

Discussion

In this case, we first reported a COVID-19-infected elderly patient who had successfully withdrawn from ECMO after ECMO-assisted treatment. Meanwhile, we accumulated some management experience for the readers' reference—however, successful ECMO treatment cases for children or young people infected with COVID-19 warrant further exploration.

During the implementation of ECMO, the ward's temperature was set at 22–24 ℃, and the temperature of the water tank was controlled at 36.5–37.0 ℃. The patient's temperature was recorded every 30 minutes and observed for chills, muscle tremors, and other behaviors. The incidence of hypothermia in critically ill patients during ECMO treatment is as high as 50–70% (10). However, hypothermia is not conducive to maintaining patients' normal metabolism and even leads to adverse events such as hemodynamic disorders and coagulation dysfunction (11). During ECMO treatment, the patient's body temperature fluctuated between 36.0 ℃ and 37.5 ℃, and she did not experience abnormal body temperature.

With ECMO treatment, continuous anticoagulant therapy with heparin sodium can easily cause bleeding. Close clinical and laboratory monitoring should be performed to manage anticoagulation. From December 2009 to January 2010, 18 critically ill patients with new influenza A (HlNl) were treated with ECMO in 5 ICUs of 5 hospitals in Beijing and Tianjin. Among them, 6 cases suffered from severe hemorrhage at tracheotomy, among them, 4 cases hemorrhage at the ECMO catheter site, 3 cases from gastrointestinal bleeding, 3 cases from pulmonary hemorrhage, 2 cases from intravascular hemolysis, and 1 case from disseminated intravascular coagulation. ECMO management's basic goal is to maintain the basic balance of anticoagulation, coagulation, and fibrinolysis. However, many factors affect the coagulation function of severe patients. Therefore, it is necessary to monitor multiple coagulation indicators in clinical practice to understand the whole picture of coagulation (18) comprehensively. PT fluctuated between 15.2–18.6 s, APTT was between

43.1–93.2 s, INR was between 1.18–1.54, PLT level was between 28–104×10^9/L, and Fib was between 1.51–5.13 g/L. In addition to the timely treatment of approximately 500 mL of blood leakage at the puncture site on the day of ECMO catheterization, patients should be treated promptly. There was no bleeding complication in this case.

In this case, especially as the patient was elderly, it was difficult to take treatment steps. However, ECMO management's basic goal is to maintain the basic balance of anticoagulation, coagulation, and fibrinolysis. ECMO assistance can provide hemodynamic support for the refractory cardiogenic shock that fails the initial treatment (11,12). In recent years, as an extracorporeal life-support technology, VA-ECMO has shown important therapeutic value in cardiogenic shock (13-16). VA-ECMO catheterization paths include femoral vein-femoral artery catheterization and femoral vein-axillary artery catheterization, and which are the most commonly used vascular access sites. Compared with other paths, the body's anatomical location is simpler, and there are no surrounding adjacent important blood vessels, nerves, and organs. Catheterization can be established by surgical incision or percutaneous puncture (conventional ultrasound guidance) (17). We chose femoral vein-femoral artery catheterization as this path has the advantage of being fast and minimally invasive. Due to severe edema of the lower limbs, heart failure, and weak femoral artery pulsation, it is difficult to perform blind femoral vein puncture. Therefore, the right femoral vein puncture under the guidance of color Doppler ultrasound was used in the case. The patient was locally anesthetized with 2% lidocaine, a deep venous catheter was inserted into the femoral vein cavity under ultrasound, then observed that the infusion and blood return are smooth, following, extend the guide wire into the 21# ECMO blood vessel, depth 47 cm, suture fixation, sterile 3M tape fixation, procedure. Smoothly, during the VA-ECMO catheterization period, it is necessary to check the speed, flow, oxygen concentration, ACT, APT, heparin dose, etc. Therefore, in the case, we choose for VA but not VV ECMO.

Finally, through this case report, we found that the application of ECMO for adjuvant therapy in COVID-19 patients is a positive development.

Conclusions

COVID-19 is a new type of respiratory infectious disease. There is still a lack of clinical management experience to guide the treatment of the disease. In this paper, we described a COVID-19-infected patient who was managed with ECMO, and after active treatment and careful management, the patient was successfully weaned from ECMO after 13 days and eventually recovered. Through this case, we found that the application of ECMO for adjuvant therapy in COVID-19 patients is a positive development. We therefore summarized the experience of the management of patients with ECMO to provide a reference for the diagnosis and treatment of severe COVID-19 patients in the future.

Timeline

The management methods involved in this case run through the entire treatment process and need to be strictly implemented every day. The response measures should be adjusted in time according to the changes in the patient's condition. There is no time sequence.

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Footnote

Reporting Checklist: The authors have completed the CARE reporting checklist. Available at https://dx.doi.org/10.21037/apm-20-1176

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). We did not commence any experimental use of a novel procedure or tool in this case, and each of the procedures of ECMO, HFOV, and prone positioning were approved by the Medical Ethics Committee of The First Affiliated Hospital of Guangzhou

Medical University (No. 187). Informed consent for each procedure was obtained from the next of kin of the patient.

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