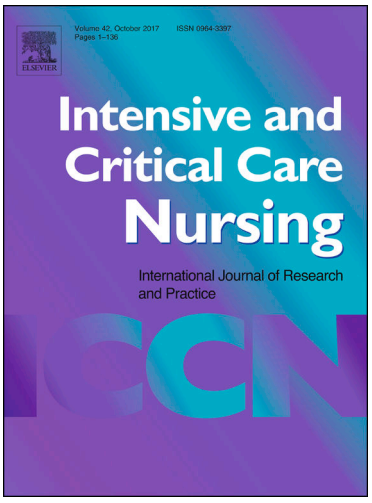
Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Journal Pre-proofs



ECMO retrieval before and during the COVID-19 pandemic: A retrospective analysis of 100 mobile ECMO missions

Alberto Lucchini, Roberto Gariboldi, Marta Villa, Luigi Cannizzo, Flavia Pegoraro, Letizia Fumagalli, Roberto Rona, Giuseppe Foti, Marco Giani, ASST Monza – Mobile ECMO team group,

PII: S0964-3397(22)00153-7
DOI: https://doi.org/10.1016/j.iccn.2022.103350
Reference: YICCN 103350

To appear in: *Intensive & Critical Care Nursing*

Received Date: 11 August 2022
Revised Date: 4 November 2022
Accepted Date: 7 November 2022

Please cite this article as: A. Lucchini, R. Gariboldi, M. Villa, L. Cannizzo, F. Pegoraro, L. Fumagalli, R. Rona, G. Foti, M. Giani, ASST Monza – Mobile ECMO team group, ECMO retrieval before and during the COVID-19 pandemic: A retrospective analysis of 100 mobile ECMO missions, *Intensive & Critical Care Nursing* (2022), doi: https://doi.org/10.1016/j.iccn.2022.103350

ECMO RETRIEVAL BEFORE AND DURING THE COVID-19 PANDEMIC: A RETROSPECTIVE ANALYSIS OF 100 MOBILE ECMO MISSIONS

Alberto Lucchini RN – alberto.lucchini@unimib.it - https://orcid.org/ 0000-0002-7475-277X

Roberto Gariboldi RN – r.gariboldi@asst-monza.it

Marta Villa RN, CCN – marta.villa418@gmail.com

Luigi Cannizzo RN – l.cannizzo@asst-monza.it

Flavia Pegoraro RN, CCN - f.pegoraro26@gmail.com

Letizia Fumagalli RN, CCN - letiziafumagalli3@gmail.com

Roberto Rona MD – roberto.rona@libero.it

Giuseppe Foti MD – g.foti@asst-monza.it

Marco Giani MD – marco.giani@unimib.it

ASST Monza – Mobile ECMO team group*

Department of Emergency and Intensive Care, San Gerardo University Hospital, Monza, Italy – University of Milano-Bicocca

Corresponding author:

Alberto Lucchini

Head Nurse, General Intensive Care Unit - San Gerardo Hospital – ASST Monza, Milan-Bicocca University – Italy Via Pergolesi 33 – Monza (MB), Italy

e-mail: alberto.lucchini@unimib.it , a.lucchini@asst-monza.it - Phone: +39 039 233 9824

Financial Support: None

Conflict of Interest Statement: The authors declare they have no conflict of interest.

Key words: ECMO, VV-ECMO, Mobile ECMO team, Transport, Prone position

ASST Monza – Mobile ECMO team group*:

Dario Minotti, RN,Stefano Elli R, Luciano Giannini RN, Stefania Vanini RN-CCN, Nicola Barreca RN, Luca Folliero RN, Alberio Gabriele RN-CCN, Michela Bombino MD, Alfio Bronco MD, Fabrizia Mauri MD, Vincenzo Russotto MD, Ferlicca Daniela MD, Miriam Panzeri MD, Vittoria Ludovica Sala MD, Andrea Coppadoro MD, Maddalena Teggia Droghi MD, Emanuele Previtali MD, Daniela Albiero MD, Annalisa Benini MD, Francesca Bettini MD, Rondelli Egle MD, Stefano Isgrò MD, Maria Cristina Costa CCP, Salvatore Capalbi CCP , Jeff Sardella CCP, Imen Ben-khalifa CCP, Riccardo Croci CCP, Giuseppe Colonna CCP, Antonello Labio CCP.

Acknowledgements :

The authors thank all the San Gerardo General ICU physicians, nurses, residents, and students for their enormous, continued efforts in caring for these complex patients. The authors also thank the excellent crew of the Milan-Carugate unit of the White Cross (Croce Bianca).

Authors' contribution:

Alberto Lucchini: Conceptualization, methodology, Formal analysis, Original Draft Writing

Roberto Gariboldi: Conceptualization, Data Curation, conception, methodology,

Marta Villa: Data Curation, editing, original draft writing

Luigi Cannizzo: Data Curation, methodology

Flavia Pegoraro: conception, methodology, Data Curation

Letizia Fumagalli: Original Draft Writing, Data Curation

Roberto Rona: conception, methodology, Review & Editing, Formal analysis

Giuseppe Foti: conception, methodology, Review & Editing, Formal analysis

Marco Giani: Original Draf Writing, conception, methodology, Review & Editing

ONE HUNDRED ECMO RETRIVALS BEFORE AND DURING COVID-19 PANDEMIC: AN OBSERVATIONAL STUDY

ABSTRACT

Objectives: Patients with severe acute respiratory distress syndrome (ARDS) may require veno-venous extracorporeal membrane oxygenation (V-V ECMO) support. For ARDS patients in peripheral hospitals, retrieval by mobile ECMO teams and transport to high-volume centers is associated with improved outcomes, including the recent COVID-19 pandemic. To enable a safe transport of patients, a specialised ECMO-retrieval program needs to be implemented. However, there is insufficient evidence on how to safely and efficiently perform ECMO retrievals. We report single-centre data from out-of-centre initiations of VV-ECMO before and during the COVID-19 pandemic.

Design & Setting: single-centre retrospective study. We include all the retrievals performed by our ECMO centre between January 1st, 2014, and April 30th, 2021.

Results: One hundred ECMO missions were performed in the study period, for a median retrieval volume of 13 (IQR: 9-16) missions per year. Cause of ARDS was COVID-19 in 10 patients (10%). 98 (98%) patients were retrieved and transported to our ECMO centre. To allow safe transport, 91 of them were cannulated on-site and transported on V-V ECMO. The remaining 7 patients were centralised without ECMO, but they were all connected to V-V ECMO in the first 24 hours. No complications occurred during patient transport. The median duration of the ECMO mission was 7 hours (IQR: 6-9, range: 2 – 17). Median duration of ECMO support was 14 days (IQR 9-24), whereas the ICU stay was 24 days (IQR 18-44). Overall, 73 patients were alive at hospital discharge (74%). Survival rate was similar in non-COVID-19 and COVID-19 group (73% vs. 80%, p=0.549).

Conclusion: In this single-centre experience, before and during COVID-19 era, retrieval and ground transportation of ECMO patients was feasible and was not associated with complications. Key factors of an ECMO retrieval program include a careful selection of the transport ambulance, training of a

dedicated ECMO mobile team and preparation of specific checklists and standard operating procedures.

Keywords : ECMO, Mobile ECMO team, ECMO retrieval, COVID-19, transport

Implications for clinical practice

- To safely perform ECMO transports, a dedicated team, composed by experienced and trained critical care nurses and intensivists is required.
- The success of a retrieval program is directly proportional to team expertise and resources available, including human and non-human factors
- A dedicated protocol, the use of check lists and a careful selection of the ambulance help to reduce the occurrence of adverse events during transport

INTRODUCTION

Acute Respiratory Distress Syndrome (ARDS) is associated with high mortality in the adult population (Bellani et al., 2016). Despite improvements in ventilation techniques and other treatments, the mortality rate is around 40% (Bellani et al., 2016). Some patients with ARDS, despite being treated with lung protective ventilation strategies (Tidal Volume $\leq$ 6 ml / Kg of Ideal Body weight, Driving pressure < 14 cmH_2O e Plateau pressure < 30 cm H_2O) and prone position (cycles > 18-20 hours), develop refractory hypoxemia. (Bellani et al., 2016).

Veno-Venous Extracorporeal Membrane Oxygenation (V-V ECMO) support is a technique used on patients with respiratory failure aimed at improving oxygenation and minimising injury related to mechanical ventilation (Brodie and Bacchetta, 2011; Tonna et al., 2021, Gajkowski et al., 2022; Peek et al., 2009). For patients with severe forms of ARDS who do not respond to standard strategies, VV-ECMO can provide an additional source of recovery, making it a life-saving procedure (Gajkowski

et al., 2022; Peek et al., 2009). Veno-venous ECMO can provide complete respiratory support, even if this highly complex technique presents substantial risks, such as bleeding, thromboembolic events and infection (Gajkowski et al., 2022).

ECMO support requires an experienced and organized medical team to deliver technically sophisticated care (Combes et al., 2014). The Extracorporeal Life Support Organization (ELSO) has recommended that ECMO centers providing ECMO for adult respiratory failure perform at least 20 annual cases of total ECMO volume and at least 12 annual cases in the subset of adult respiratory ECMO (Barbaro et al., 2015). Due to the intensive hospital resource utilization during COVID-19 pandemic, substantial staff training, and multidisciplinary needs associated with starting an ECMO program, ELSO recommended against starting new ECMO centers for the sole purpose of treating patients with COVID-19 (Bartlett et al., 2020).

Previous literature showed that centralisation of severe ARDS patients to an ECMO-capable referral centre is associated with improved outcomes (Gajkowski et al., 2022; Patroniti et al., 2011; Peek et al., 2009). Moreover, higher ECMO case volume was associated with better outcomes (Barbaro et al., 2015). For these reason, deteriorating ARDS patients in non-ECMO centres should be promptly referred to large referral ECMO centres for consideration (Labib et al., 2022). Patients eligible for centralisation, however, are often too unstable to undergo conventional transport and need to be cannulated on-site before being transferred (Isgrò et al., 2011; Labib et al., 2022; Patroniti et al., 2011). Therefore, many ECMO centers have developed dedicated mobile ECMO teams, made up of a group of professionals (i.e.: physicians, ICU nurses, perfusionists) trained to cannulate on-site and to retrieve critically patients while on ECMO support (Broman et al., 2020; Fletcher-Sandersjöö et al., 2019; Patroniti et al., 2011).

In-hospital and out-of-hospital transport of critically ill patients are high-risk situations for complications and adverse clinical events (Harish et al., 2016; Murata et al., 2022). For ECMO patients, this risk is increased by the presence of ECMO circuits and cannulas. Severe complications have been reported in up to 20-45% of transportations (Broman and Frenckner, 2016). Nevertheless,

retrieved ECMO patients show comparable (survival rate:46%) (Lebreton et al., 2021) or better (52% vs. 40%) (Giani et al., 2022b) outcomes compared to patients cannulated in the referral centre. In the last years, the COVID-19 pandemic has put a strain on health care systems (Cucinotta and Vanelli, 2020). Although the Mobile ECMO team activity has been a well-established activity in many centers, the pandemic raised difficulties in managing intra-hospital transports, as the organisation of an ECMO team requires a lot of human and non-human resources.

Transport of patients on ECMO support should be undertaken by a specialised and well-trained multidisciplinary team of experienced ECMO practitioners (Combes et al., 2014; Labib et al., 2022). The team should be self-sufficient and readily available (Labib et al., 2022). None of the guidelines has defined the minimum personnel composition of the mobile ECMO team and therefore each of the centers developed its optimised concept. Depending on the legal and organisational conditions of a given country, different competences, duties, and local traditions, the number of its members can be different. Recently, the Extracorporeal Life Support Organization (ELSO) suggested that the teams should be composed of no less than: team lead (intensivist), cannulating provider, ECMO specialist and medical transport team (Combes et al., 2014; Labib et al., 2022). ECMO centers should collaborate with medical transport teams to develop standard operation procedures for all phases of the mobile ECMO transport team (Combes et al., 2014; Labib et al., 2022). For this reason, during the COVID-19 pandemic, ELSO suggested to carry out ECMO missions only when the appropriate human resources are available (Bartlett et al., 2020).

We performed a retrospective observational study to describe the characteristics, the complications and the outcomes of patients retrieved by the mobile ECMO team of an Italian university hospital, located in Lombardy, before and during the COVID-19 era.

Lombardy was the most affected region in Italy during first and second COVID-19 wave (Foti et al., 2020; Vinceti et al., 2021). To cope with this emergency, the COVID-19 Lombardy intensive care units (ICU) network was created. Network identified a list of best practice statements supported by the available evidence and managed the regional ECMO network (Foti et al., 2020).

MATERIALS AND METHODS

Ethics

Data were collected as part of a large observational retrospective and prospective study on V-V ECMO approved in July 2019 by the local ethics committee (Comitato Etico Brianza, ref. n. 3129). Due to the observational nature of the study, patient consent was waived.

Study design

We performed a retrospective study to analyse consecutive missions performed from our local ECMO team between January 1st, 2014, and April 30th, 2021.

Data Collection

Electronic medical records and transport reports were retrospectively reviewed to extract the following data: demographics, patient clinical conditions at arrival, transport specific endpoints (i.e. time spent out of the hospital, adverse events) and ECMO transport-related complications was collected. Since 2008, a specific data collection sheet was created to record mission data (Isgrò et al., 2011; Lucchini et al., 2014). Median mission time was defined as "*time spent from ECMO centre to peripheral centre, and back*". Distance between the ECMO centre and the referral hospital was calculated with "google Maps".

Extracorporeal membrane oxygenation-specific endpoints such as duration of ECMO, mode of ECMO support, and physiologic parameters before and after ECMO cannulation were collected. All parameters were recorded using the software Drager Medical Innovian Suite patient management system (Innovian Medical Suite© – Drager Medical, Lubeck, Germany). Finally, survival to hospital discharge were collected. All enrolled patients were transported from local trust to ECMO centre and subsequently admitted to a 10-bedded General ICU.

Settings

In resource-constrained environment, such as the first and second COVID-19 waves in Italy, the overall number of transports performed by the Italian mobile ECMO teams has been considerably reduced (Foti et al., 2020; Grasselli et al., 2020). The first and second COVID-19 waves in Italy,

especially in the Lombardy area, generated a shortage of intensivist and critical care nurses. For this reason, maintaining a larger ECMO team available on a 24/7 basis was not feasible. The study was conducted in a hospital in Lombardy, which include a total of approximately 800 beds, with about 25 ICU beds before COVID-19 pandemic. During the first COVID-19 wave ICU beds were increased up to one 100 and up to 60 during the second wave. The increase in intensive beds, achieved in a few days, significantly reduced the number of medical and nursing staff available for ECMO missions

ECMO team activation and patient retrieval protocol

Our institution (ASST Monza - University of Milano-Bicocca) is a tertiary referral hospital and has provided an ECMO retrieval programme since 2004 (Isgrò et al., 2011; Lucchini et al., 2019, 2014). Our centre is part of the Italian National Network for the Treatment of Acute Respiratory Failure and the Italian ECMO Network.

The alert protocol and procedure for patient eligible for ECMO support was based on phone call to our centre where eligibility for ECMO and retrieval are assessed. Specifically, each clinical case was discussed among two experienced physicians to provide an early decision: possible indication to ECMO, patient not eligible for ECMO (e.g. contraindications or poor prognosis), or no actual indication (i.e. patient without contraindications but who does not fulfil the severity criteria for ECMO yet). In case of disagreement, an external opinion (i.e. head of another ECMO centre of the Italian ECMO network) was sought. At this stage, telephone instructions to optimise patient's treatment were provided to the peripheral centre and a close follow-up over the phone was maintained until team arrival. According to current literature (Combes et al., 2018), our criteria for ECMO team activation were: potentially reversible respiratory failure, severe refractory hypoxia (PaO_2 to FiO_2 ratio < 80 mmHg despite prone positioning) and/or respiratory acidosis (pH ≤7.25 with $paCO_2$ > 60 mmHg despite maximisation of mechanical ventilation - respiratory rate 30-35/min and driving pressure up to 15 cmH_2O) (Bartlett et al., 2020; Gajkowski et al., 2022). Our exclusion criteria included the presence of intracranial bleeding, poor prognosis, and a body weight ≥ 140 Kg, due to our equipment limitations (mobilisation system dimensions). Through collaboration with the regional

ECMO transportation network, patients weighting more than 140 Kg were referred to another Lombardy ECMO centre, able to transport severely obese patients. In case of patients with an end-stage lung disease referred to our centre because of an acute exacerbation and considered suitable for ECMO as bridge to lung transplant, we immediately referred the patients to the ECMO centre in Lombardy where solid organ transplantation is performed.

Our standard procedure, in case of eligibility for retrieval, guarantees an activation of the ECMO team within 60 to 90 minutes. The standard team consisted of two intensivists, two Critical Care Nurses and one perfusionist. Whenever possible, other professionals in-training joined the ECMO mission for educational purposes. Roles of each member during mission planning, cannulation, and transportation are reported in Table S1 (Supplementary Material).

All transport were performed by a mobilisation system able to house all the biomedical equipment, composed of a x-ray compatible spinal board and a multi-level counter top (Isgrò et al., 2011; Lucchini et al., 2014). Since 2004, this tool underwent periodic review to optimise logistics and performance. The mechanical ventilator, the ECMO pump, syringe pumps for intravenous infusion and monitoring are placed on shelves. The countertop is equipped with an electrical junction box that provides power to all equipment via a single cable connected to the main electricity network. Figure 1a and 1b shows the system structure and the possible transport solutions.

All the ambulances used during this study were provided by the Croce Bianca (Carugate, Milano). Emergency vehicles were adapted to meet the special demands of extra power supply and medical gases. All the technology features are reported in Table S2 (Supplementary Material). An additional vehicle transported the team and the rest of the equipment (Table S3 - Supplementary Material), which is checked, sealed and stored before every transport.

All patients were cannulated percutaneously using real-time ultrasound and a dilation modified technique to reduce the enlargement stages (Grasselli et al., 2010). Multistage Maquet HLS (21–25 Fr, length 38 or 55 cm) cannulas were used for femoral blood drainage. Bio-Medicus (19–23 Fr, 60 cm, Medtronic, Minneapolis, MN) cannulas were used for femoral reinfusion, while Maquet HLS

(17–21 Fr, 23 cm) for jugular reinfusion. Centrifugal pumps (Rotaflow® and Cardiohelp® System, Maquet) and heparin-coated circuits (BIOLINE® coated, mod. PLS-BE or HLS-BE, Maquet) were utilised in all patients.

On arrival at the referral centre, a briefing with the local team was held. After briefing, the ECMO team intensivists performed a patient assessment and optimisation of the mechanical ventilator setting (recruitment manoeuvre and PEEP titration, lung protective ventilation with tidal volumes <6ml/Kg Ideal Body Weight, trial of inhaled Nitric Oxide) (Gajkowski et al., 2022; Isgrò et al., 2011; Patroniti et al., 2011). The aim of the trial of inhaled Nitric Oxide was to assess the safety of a conventional transport (i.e. without ECMO). Nurses minimised apparatus dead space by removing any mount connector and/or heat-and-moisture exchanger (Shimoda et al., 2021) and positioned a close suctioning system and continuous $EtCO_2$ monitoring (Giani et al., 2022a; Lucchini et al., 2014), to evaluate the safety and feasibility of patient transport without ECMO. Criteria for transport without ECMO were: $pO_2 > 90$ mmHg with $FiO_2 = 1$ and PEEP < 20 cmH_2O, pCO_2 <60 mmHg and pH > 7.3 achieved with protective mechanical ventilation. If these criteria were not met or if transport without ECMO was not considered safe for other reason (e.g.: no improvement pO_2/FiO_2 ratio after inhaled Nitric Oxide trial, hemodynamic instability, distance between the hospital > 50 Km) an ECMO support was started on-site and the patients were then transferred while on ECMO support. After the ECMO was established, respiratory rate and tidal volume were progressively reduced according to end-tidal CO_2 values (Giani et al., 2022a) to avoid rapid carbon dioxide drop, then an arterial blood gas sample was performed (10 to 15 minutes after ECMO initiation). PEEP level and inspiratory/expiratory cycling were adjusted to avoid any abrupt reduction in mean airways pressure. For securement of ECMO components, our policy provides for the use of a suture point at the end of the metal spiral of the cannula combined with the use of three sutureless systems (the first positioned near the cannula-circuit connection, the second one on the thigh and third one on the leg) (Lucchini et al., 2021). All other vascular devices were secured with two sutureless device.

After stabilisation of ECMO circuit, ventilation setting and cardiovascular parameters, the nurses prepared the patient and all medical devices for the transport. All the intra-venous lines were replaced with needless valve lines and continuous infusion delivered by syringe pumps were positioned higher than the patients, to minimise the risk of "bolus-back-flow" (Elli et al., 2020; Poiroux et al., 2020). All medical devices were placed on the transport system described above, in the following order: ECMO pump, membrane lung fixation support plus swivel joint-bracket, ECMO manual backup pump, heater unit, mechanical ventilator and transport monitor. The last action performed during patient preparation for transport was to switch the gas source to oxygen tanks. Connection to ambulance main electrical and gases were tested prior to leaving for the receiving centre. At arrival, if patient's clinical conditions were stable and lung imaging was not available, CT scan was performed before admission to the ICU.

Staff training program

Since 2004, after the first ECMO transport, the staff was trained on fieldwork by tutoring, following evidence-based practice study findings. (Gajkowski et al., 2022; Labib et al., 2022). All nurses involved in the program, have a Critical Care Nursing Master degree. The master program included a 20-hour course on ECMO, including wet cannulation lab and a simulation session for ECMO transport. To be qualified for transport, these were the adjunctive minimum requirements: experience of two years in ICU, participation to two in-hospital cannulation, two intra-hospital and two out-of-hospital transport supervised by a qualified nurse. The nursing staff education (theoretical and practical) was managed by the head nurse and a senior qualified nurse.

Statistical Analysis

Continuous variables were expressed as median (interquartile range). Categorical variables were expressed as count (proportion). Difference in continuous variables between the two groups (COVID-19 vs non-COVID-19 patients) was explored using Mann-Whitney U test. Difference among categorical variables between the two groups was tested using the Pearson's Chi Square test or Fisher Exact test, as appropriate. A two-tailed p-value<0.05 was considered statistically significant.

Statistical analysis was performed using SPSS 24.0 (IBM, USA) and JMP 15.2 software (SAS Institute, Cary, USA).

RESULTS

One hundred consecutive ECMO missions were performed in the study period and were included in the analysis. 10% (n=10) were COVID-19 cases. (Figure 2). The median retrieval volume was 13 (9-16) missions per year (Figure 3). During the COVID-19 pandemic, the retrieval activity was lower: 3 missions were performed in 2020 and 8 in 2021. The ICU working experience of the ECMO team members was composed as follows: first intensivist median year 22 (17-25), second intensivist: 5 (2-8), first nurse 18 (10-23) and 8 (4-14) years for the second nurse (figure 4). Median mission time was 7 hours (IQR 6-9 h, range 2–17). The median distance from ECMO centre to referral hospital was 50 kilometres (IQR 39–119 km, range 5–600 km). All patients were transported by ground. One patient died before the arrival of the ECMO team, while another one was re-evaluated at the team arrival and was not considered a candidate for ECMO because of a poor prognosis. The remaining 98 patients were successfully transported to the ECMO centre. The demographic and clinical characteristics of these 98 patients, including ventilation parameters and blood-gas values at team arrival, are presented in Table 1, stratified by transport modality (i.e. with or without V-V ECMO).

3 COVID-19 patients (30%) were centralised without V-V ECMO, whereas among non-COVID patients 4 (5%) were transported without extracorporeal support (p=0.044). The 3 COVID-19 patients were transported while on prone position, whereas non-COVID patients who were retrieved without ECMO were all managed in supine position. All 7 patients who were transported without ECMO were then cannulated within 24 hours after ICU admission, due to persistence of life-threatening respiratory failure.

Median age of enrolled patients was 53 years (43−63), BMI was 28.7 (25.0-34.0) kg/m2, 44 (45%) were female and median length of ICU stay before ECMO team activation was 3 (1-6) days. 73 patients (74%) underwent NIV before intubation and median duration of mechanical ventilation before ECMO was 2 (1-5) days, Before ECMO team arrival, 51 (52%) patients underwent prone

positioning, 21 (21%) received inhaled nitric oxide and 15 (15%) were treated with continuous renal replacement therapy (CRRT). At ECMO team arrival median PO_2/FiO_2 ratio was 74 (61-95). PO_2/FiO_2 was 75 (62-99) in patients cannulated on-site and 94 (92-120) fort those transported without ECMO (p =0.084). The distance from hospital to the ECMO centre was significantly lower for patients who were transported without ECMO (median distance: 11 [5-30] km vs 66 [40-119] km in those transported on ECMO, p<0.0001)

71 patients (72%) were transported with a norepinephrine infusion, (median dosage: 0.10 mcg/Kg/min [IQR 0.06-0.18]) and 13 patients with a dopamine infusion (median dosage: 5.0 mcg/kg/min [IQR 3.6-6.6]). No patient required a start of a new vasopressor during transport. Among the 98 patient transports in the study, we recorded neither ECMO related complications (e.g. decannulation, circuit failure or significant blood-flow decrease) nor transport-related adverse events (e.g. extubation, accidental removal of vascular access, failure of electrical power and medical gas availability). In the COVID-19 group, none of the members of the ECMO team contracted COVID-19 in the 30 days after transport.

As reported above, all patients centralised where treated with V-V ECMO. Median duration of ECMO support for the 98 patients, was 14 (9-24) days, median duration of mechanical ventilation days was 19 (12-25) days, whereas median ICU stay was 24 (18-44) days. Procedural characteristics for ECMO, mechanical ventilation at V-V ECMO start and ECMO outcome are reported in table 2. Prone position was used during V-V ECMO in 52 patients (54%). 48 (50%) patients required renal replacement therapy during their ICU stay. Intracranial haemorrhage occurred in 2 (2%) patients. Overall, 73 patients were alive at hospital discharge (74%) Hospital survival did not differ between non-COVID-19 and COVID-19 patients (73% vs 80%, p=0.549).

DISCUSSION

In this retrospective single-centre study, we described the last eight-year experience in transporting hypoxemic patients, with and without V-V ECMO, reporting clinical outcomes of 98 patients transported via ground ambulance in an urban setting, in the north of Italy. The program of

transportation was found to be feasible and safe, even during the COVID-19 era. Additionally, we observed similar outcomes in non-COVID-19 and COVID 19 patients. Our results confirm data reported in a recent systematic review, where the overall mortality rate of ECMO-supported COVID-19 patients was 41% (ranging between 14.7% and 67%), whereas non-COVID ARDS patients' mortality rate ranged from 14.3% to 50% (Aljishi et al., 2022).

Patients with acute, severe, reversible respiratory failure are eligible for V-V ECMO when conventional therapies do not allow to maintain adequate oxygenation and protective mechanical ventilation (Barbaro et al., 2015; Combes et al., 2020; Gajkowski et al., 2022). At centres not capable of initiating ECMO, early transfer to an ECMO centre should be planned. A conventional transport may be hazardous, and deaths have been described (Broman et al., 2020; Labib et al., 2022). According to the Extracorporeal Life Support Organization ELSO General Guidelines, an ECMO centre should guarantee a retrieval program to perform a safe transport of patients eligible for ECMO treatment (Broman et al., 2020; Gajkowski et al., 2022; Labib et al., 2022). We reported a high survival (74%) , which was comparable (or higher) to that reported in recent studies (Combes et al., 2020; Ramanathan et al., 2021). The decision of transporting a patient with or without ECMO support was based on several factors (e.g.: pO_2/FiO_2 ratio, hemodynamic stability versus instability, distance from the ECMO centre, response to iNO trial). In general, patients transported without ECMO support were less hypoxic (median $pO2/FiO_2$: 94 (92-120) vs. 75 (62-99) – p=0.084), had higher systolic blood pressure, albeit the difference was not statistically significant (130 (120-140) vs 115 (100-130) mmHg – p=0.370), and were at a closer distance (median distance from ECMO centre : 11 (5-30) vs .66 (40-119) – p<0.001) to the ECMO centre. These reasons are the main factors affecting the shortest mission time in the group transported without ECMO (2.0 [2.0-7.0] vs.7.0 [6.0-9.0)] hours – p=0.011).

In addition, during the COVID-19 pandemic, the out-of-centre ECMO implantation, was limited by the number of human resources available (Foti et al., 2020; Grasselli et al., 2020). Before COVID-era, using a lean team, composed by 2 intensivists, 1 or 2 nurses and one perfusionist, the program

was able to expeditiously initiate ECMO (time from activation to start between 60 and 90 minutes) at referring hospitals and transport all patients to our institution (Isgrò et al., 2011; Lucchini et al., 2014). As a result, we decided to modify the ECMO team staff. If the local hospital was near to the ECMO centre, the team was limited to two intensivists and one ICU nurse. If the patient was in prone position when the team arrived at the local hospital, we evaluated the safety of transporting the patient in prone position, to prevent further delays and treatment interruptions. However, if conventional transport was deemed unsafe and ECMO placement was deemed necessary before the transport, a second nurse and a perfusionist had to join the team prior to cannulation. This strategy, applied in the missions carried out in hospitals less than 50 kilometres away from our ECMO centre, did not cause any delay in cannulation. The minimum material (see supplementary material S3 - ECMO cannulation kit) to proceed with cannulation was carried on each mission. As described in the results section, we performed three patient transports with patients in prone-position, all in COVID-19 patients. No patient complications occurred during these transportations, and there were no unprotected SARS-CoV-2 exposures or infections among the mobile ECMO team, as reported in recent case series (Pan et al., 2022; Seethala et al., 2020), including during the retrieval of our first COVID-19 ECMO patient in the pre-pandemic days, who was referred to our centre without a pre-existing diagnosis of Sars-CoV-2 infection (Giani et al., 2020).

All cannulations were performed at the bedside. No adverse events were recorded during the study period, either during cannulation/ECMO implementation/preparation to transport phase, or during transports (Broman et al., 2020; Broman and Frenckner, 2016; Lebreton et al., 2021). ECMO implantation adds further complexity to critically ill patients transports (Labib et al., 2022; Murata et al., 2022). Absence of adverse events, during the transport could be explain by some factors. First, according to ELSO guidelines, transports were performed by well-equipped teams acquainted with mobile transport (Labib et al., 2022). Notwithstanding the outbreak, all patients considered for ECMO could be retrieved, maintaining the standard of care established by the institution, following the recommendations for safe transport of COVID-19 patients. As shown in Figure 4, the ICU work

experience of nurses and doctors who carried out missions in the COVID period was lower than in the pre-COVID period. Despite this factor, the training program implemented after the first transport performed by our centre in 2004 and COVID-19 procedures ensured that all necessary steps of donning and doffing personal protective equipment and transport logistics were followed, reducing staff exposure and adverse outcomes (Broman et al., 2020; Broman and Frenckner, 2016).

Second, to sort out the mission, different paperwork (flow charts and checklists) was created to verify the equipment. ELSO guidelines recommended that the Mobile ECMO team should be completely self-autonomous for any needing (medication, equipment, monitoring, and diagnostic devices) and suggest the implementation of one or more equipment checklist, that should be completed by the mobile ECMO team before departure (Labib et al., 2022). Our check list covered all transport phases: preparation, cannulation, transfer to the transport stretcher and ambulance and specific transport considerations. Furthermore, check list helped nurse to check two key point: ensure sufficient medical gas for the transport and sufficient power and back-up power for all electrical equipment.

Third, all ground transportations were performed by means of a specially equipped ambulance, featuring a self-loading-heavy duty stretcher and a custom-made steal frame, mounted on an x-ray spine board, to accommodate all medical equipment. All equipment should be mounted, strapped, locked-in, housed, or otherwise secured for transport. Stabilisation is required for vibrations, acceleration, deceleration, turbulence, rough roads, inclement weather, etc., as unsecured equipment can act as a projectile in the event of sudden acceleration/deceleration. In addition, benefits of this system involve the absence of extra adjustments after patient's preparation, so patient will be ready to be transported straight to ambulance. There is no need to rearrange any equipment (syringe pumps, circuit, mechanical ventilator. ECMO circuit), because they are already in place, reducing the time of transfer and possible complications (Murata et al., 2022).

The ambulance choice required a strict collaboration between the ICU staff, the ambulance crew, and the hospital engineers, to rule out all the technical issues related to the vehicle (electricity power supply and medical gas circuit). Transport ECMO team must be familiar with electric specifications

of all transport equipment. Since 2004 we decided to use a dedicated ambulance for ECMO transport, made in collaboration with the "*White Cross*". The local rules of the Lombardy Region require a minimum inverter of 1000W for ambulances and a backup inverter is not mandatory. Based on the electrical absorption of the equipment necessary for the transport of a customer to ECMO and, considering the battery capacity of the ECMO console, we decided to have an ambulance with an 1800 Watt inverter and a backup inverter (1200 Watt). All the equipment's packs for transport are dedicated to ECMO transports only. This makes quality controls and battery packs level checks easier to perform. These are the reasons which may have contributed to the absence of adverse events related to electrical failure during the study. Battery and inverter failure were in fact described as a leading cause of adverse events during ECMO transports (Broman et al., 2020; Murata et al., 2022; Vieira et al., 2020).

LIMITATIONS

This study had some limitations. First, this is a retrospective evaluation of eight years of experience in a single centre, thus our results may not be representative of other ECMO retrieval services. Second, the study was conducted with a relatively small dataset, and we did not collect all daily data during the ICU stay of ECMO patients. However, our goal was only to report our 8-years' experience of inter-hospital transportation of critically ill patients and to demonstrate the feasibility and safety of a "Mobile ECMO team program". Third, data were collected from our medical records, and some information about the clinical data at the peripheral centre were not available.

CONCLUSIONS

Although ECMO retrieval is not a new concept, in this single-centre experience in an urban setting, before and during COVID-19 era, out-of-centre initiation of ECMO was feasible, utilising ground transportation for transport. We described an entire process for ECMO retrieval that we believe will benefit other retrieval service providers. To enable a safe transport of patients, a specialised ECMO-retrieval program is mandatory. The overall survival of retrieved patients was as high as 74%. To

safely perform ECMO transports, a dedicated team, composed by experienced and trained intensivists and critical care nurses, that maintains stringent adherence to well-designed management protocols, is required. The challenge of ECMO retrieval during the COVID-19 pandemic has led to refinement in the system and process for the future.

Figure captions:

Figure 1a and 1b

Title: *Patient seated for transport.*

A : syringe pumps, B : volumetric infusion pumps, C : ECMO centrifugal pump, D : intensive care mechanical ventilator, E : x-ray spine board compatible and multi-storey counter top, G : oxygen tanks, F: vital sign monitor

Figure 2

Title : *Study flow chart*

Legend : V-V ECMO (Veno-venous Extracorporeal Membrane Oxygenation)

Figure 3

Title : *ECMO team missions in the study period.*

Figure 4

Title : *ECMO Team members' working experience in the study period.*

Legend : The dotted line identifies the start of the COVID-19 pandemic. Median ICU experience before and during COVID-19 was 22.0 (19.0-25.0) years vs 17.5 (9.0 vs. 24.0) – p=0.246 for first intensivist, 5.5 (2.0-9.0) vs 3.0 (3.0-5.0) - p=0.199 for the second intensivist – 20.0 (10.0-24.0) vs. 9.0 (6.0-11.5) for the first nurse - p=0.076 and 8.5 (4.0-19.0) vs 6.25 (4.0-11-) p=0.729 for the second nurse (Mann-Whitney test).

REFERENCES

Aljishi, R.S., Alkuaibi, A.H., Al Zayer, F.A., Al Matouq, A.H., 2022. Extracorporeal Membrane Oxygenation for COVID-19: A Systematic Review. Cureus 14, e27522. https://doi.org/10.7759/cureus.27522

Barbaro, R.P., Odetola, F.O., Kidwell, K.M., Paden, M.L., Bartlett, R.H., Davis, M.M., Annich, G.M., 2015. Association of hospital-level volume of extracorporeal membrane oxygenation cases and mortality. Analysis of the extracorporeal life support organization registry. Am J Respir Crit Care Med 191, 894–901. https://doi.org/10.1164/rccm.201409-1634OC

Bartlett, R.H., Ogino, M.T., Brodie, D., McMullan, D.M., Lorusso, R., MacLaren, G., Stead, C.M., Rycus, P., Fraser, J.F., Belohlavek, J., Salazar, L., Mehta, Y., Raman, L., Paden, M.L., 2020. Initial ELSO Guidance Document: ECMO for COVID-19 Patients with Severe Cardiopulmonary Failure. ASAIO J 66, 472–474. https://doi.org/10.1097/MAT.0000000000001173

Bellani, G., Laffey, J.G., Pham, T., Fan, E., Brochard, L., Esteban, A., Gattinoni, L., van Haren, F., Larsson, A., McAuley, D.F., Ranieri, M., Rubenfeld, G., Thompson, B.T., Wrigge, H., Slutsky, A.S., Pesenti, A., LUNG SAFE Investigators, ESICM Trials Group, 2016. Epidemiology, Patterns of Care, and Mortality for Patients With Acute Respiratory Distress Syndrome in Intensive Care Units in 50 Countries. JAMA 315, 788–800. https://doi.org/10.1001/jama.2016.0291

Brodie, D., Bacchetta, M., 2011. Extracorporeal membrane oxygenation for ARDS in adults. N Engl J Med 365, 1905–1914. https://doi.org/10.1056/NEJMct1103720

Broman, L.M., Dirnberger, D.R., Malfertheiner, M.V., Aokage, T., Morberg, P., Næsheim, T., Pappalardo, F., Di Nardo, M., Preston, T., Burrell, A.J.C., Daly, I., Harvey, C., Mason, P., Philipp, A., Bartlett, R.H., Lynch, W., Belliato, M., Taccone, F.S., 2020. International Survey on Extracorporeal Membrane Oxygenation Transport. ASAIO J 66, 214–225. https://doi.org/10.1097/MAT.0000000000000997

Broman, L.M., Frenckner, B., 2016. Transportation of Critically Ill Patients on Extracorporeal Membrane Oxygenation. Front Pediatr 4, 63. https://doi.org/10.3389/fped.2016.00063

Combes, A., Brodie, D., Bartlett, R., Brochard, L., Brower, R., Conrad, S., De Backer, D., Fan, E., Ferguson, N., Fortenberry, J., Fraser, J., Gattinoni, L., Lynch, W., MacLaren, G., Mercat, A., Mueller, T., Ogino, M., Peek, G., Pellegrino, V., Pesenti, A., Ranieri, M., Slutsky, A., Vuylsteke, A., International ECMO Network (ECMONet), 2014. Position paper for the organization of extracorporeal membrane oxygenation programs for acute respiratory failure in adult patients. Am J Respir Crit Care Med 190, 488–496. https://doi.org/10.1164/rccm.201404-0630CP

Combes, A., Hajage, D., Capellier, G., Demoule, A., Lavoué, S., Guervilly, C., Da Silva, D., Zafrani, L., Tirot, P., Veber, B., Maury, E., Levy, B., Cohen, Y., Richard, C., Kalfon, P., Bouadma, L., Mehdaoui, H., Beduneau, G., Lebreton, G., Brochard, L., Ferguson, N.D., Fan, E., Slutsky, A.S., Brodie, D., Mercat, A., EOLIA Trial Group, REVA, and ECMONet, 2018. Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome. N Engl J Med 378, 1965–1975. https://doi.org/10.1056/NEJMoa1800385

Combes, A., Peek, G.J., Hajage, D., Hardy, P., Abrams, D., Schmidt, M., Dechartres, A., Elbourne, D., 2020. ECMO for severe ARDS: systematic review and individual patient data meta-analysis. Intensive Care Med 46, 2048–2057. https://doi.org/10.1007/s00134-020-06248-3

Cucinotta, D., Vanelli, M., 2020. WHO Declares COVID-19 a Pandemic. Acta Biomed 91, 157–160. https://doi.org/10.23750/abm.v91i1.9397

Elli, S., Mattiussi, E., Bambi, S., Tupputi, S., San Fratello, S., De Nunzio, A., D'Auria, S., Rona, R., Fumagalli, R., Lucchini, A., 2020. Changing the syringe pump: A challenging procedure in critically ill patients. J Vasc Access 21, 868–874. https://doi.org/10.1177/1129729820909024

Foti, G., Giannini, A., Bottino, N., Castelli, G.P., Cecconi, M., Grasselli, G., Guatteri, L., Latronico, N., Langer, T., Monti, G., Muttini, S., Pesenti, A., Radrizzani, D., Ranucci, M., Russotto, V., Fumagalli, R., COVID-19 Lombardy ICU Network, 2020. Management of critically ill patients with COVID-19: suggestions and instructions from the coordination of intensive care units of Lombardy. Minerva Anestesiol 86, 1234–1245. https://doi.org/10.23736/S0375-9393.20.14762-X

Gajkowski, E.F., Herrera, G., Hatton, L., Velia Antonini, M., Vercaemst, L., Cooley, E., 2022. ELSO Guidelines for Adult and Pediatric Extracorporeal Membrane Oxygenation Circuits. ASAIO Journal 68, 133–152. https://doi.org/10.1097/MAT.0000000000001630

Giani, M., Lucchini, A., Magni, G., Villa, S., Rona, R., Fumagalli, R., Foti, G., 2022a. How to avoid rapid carbon dioxide changes at the start of veno-venous extracorporeal membrane oxygenation: Role of end-tidal CO2 monitoring. Perfusion 2676591221079508. https://doi.org/10.1177/02676591221079508

Giani, M., Rezoagli, E., Guervilly, C., Rilinger, J., Duburcq, T., Petit, M., Textoris, L., Garcia, B., Wengenmayer, T., Grasselli, G., Pesenti, A., Combes, A., Foti, G., Schmidt, M., 2022b. Prone positioning during venovenous extracorporeal membrane oxygenation for acute respiratory distress syndrome: a pooled individual patient data analysis. Crit Care 26, 8. https://doi.org/10.1186/s13054-021-03879-w

Giani, M., Seminati, D., Lucchini, A., Foti, G., Pagni, F., 2020. Exuberant Plasmocytosis in Bronchoalveolar Lavage Specimen of the First Patient Requiring Extracorporeal Membrane Oxygenation for SARS-CoV-2 in Europe. J Thorac Oncol 15, e65–e66. https://doi.org/10.1016/j.jtho.2020.03.008

Grasselli, G., Pesenti, A., Marcolin, R., Patroniti, N., Isgró, S., Tagliabue, P., Lucchini, A., Fumagalli, R., 2010. Percutaneous vascular cannulation for extracorporeal life support (ECLS): a modified technique. Int J Artif Organs 33, 553–557. https://doi.org/10.1177/039139881003300806

Grasselli, G., Zangrillo, A., Zanella, A., Antonelli, M., Cabrini, L., Castelli, A., Cereda, D., Coluccello, A., Foti, G., Fumagalli, R., Iotti, G., Latronico, N., Lorini, L., Merler, S., Natalini, G., Piatti, A., Ranieri, M.V., Scandroglio, A.M., Storti, E., Cecconi, M., Pesenti, A., COVID-19 Lombardy ICU Network, 2020. Baseline Characteristics and Outcomes of 1591 Patients Infected With SARS-CoV-2 Admitted to ICUs of the Lombardy Region, Italy. JAMA 323, 1574–1581. https://doi.org/10.1001/jama.2020.5394

Harish, M.M., Janarthanan, S., Siddiqui, S.S., Chaudhary, H.K., Prabu, N.R., Divatia, J.V., Kulkarni, A.P., 2016. Complications and benefits of intrahospital transport of adult Intensive Care Unit patients. Indian J Crit Care Med 20, 448–452. https://doi.org/10.4103/0972-5229.188190

Isgrò, S., Patroniti, N., Bombino, M., Marcolin, R., Zanella, A., Milan, M., Foti, G., Pesenti, A., 2011. Extracorporeal membrane oxygenation for interhospital transfer of severe acute respiratory distress syndrome patients: 5-year experience. Int J Artif Organs 34, 1052–1060. https://doi.org/10.5301/ijao.5000011

Labib, A., August, E., Agerstrand, C., Frenckner, B., Laufenberg, D., Lavandosky, G., Fajardo, C., Gluck, J.A., Brodie, D., 2022. Extracorporeal Life Support Organization Guideline for Transport and Retrieval of Adult and Pediatric Patients with ECMO Support. ASAIO J 68, 447–455. https://doi.org/10.1097/MAT.0000000000001653

Lebreton, G., Schmidt, M., Ponnaiah, M., Folliguet, T., Para, M., Guihaire, J., Lansac, E., Sage, E., Cholley, B., Mégarbane, B., Cronier, P., Zarka, J., Da Silva, D., Besset, S., Morichau-Beauchant, T., Lacombat, I., Mongardon, N., Richard, C., Duranteau, J., Cerf, C., Saiydoun, G., Sonneville, R., Chiche, J.-D., Nataf, P., Longrois, D., Combes, A., Leprince, P., Paris ECMO-COVID-19 investigators, 2021. Extracorporeal membrane oxygenation network organisation and clinical outcomes during the COVID-19 pandemic in Greater Paris, France: a multicentre cohort study. Lancet Respir Med 9, 851–862. https://doi.org/10.1016/S2213-2600(21)00096-5

Lucchini, A., De Felippis, C., Elli, S., Gariboldi, R., Vimercati, S., Tundo, P., Bondi, H., Costa, M.C., 2014. Mobile ECMO team for inter-hospital transportation of patients with ARDS: a retrospective case series. Heart Lung Vessel 6, 262–273.

Lucchini, A., Elli, S., De Felippis, C., Greco, C., Mulas, A., Ricucci, P., Fumagalli, R., Foti, G., 2019. The evaluation of nursing workload within an Italian ECMO Centre: A retrospective observational study. Intensive and Critical Care Nursing 55. https://doi.org/10.1016/j.iccn.2019.07.008

Lucchini, A., Elli, S., Piovera, D., Grossulè, M., Giannini, L., Cannizzo, L., Crosignani, A., Rona, R., Foti, G., Giani, M., 2021. Management of vascular access for extracorporeal life support: A cohort study. J Vasc Access 11297298211056756. https://doi.org/10.1177/11297298211056755

Murata, M., Nakagawa, N., Kawasaki, T., Yasuo, S., Yoshida, T., Ando, K., Okamori, S., Okada, Y., 2022. Adverse events during intrahospital transport of critically ill patients: A systematic review and meta-analysis. Am J Emerg Med 52, 13–19. https://doi.org/10.1016/j.ajem.2021.11.021

Pan, A., Peddle, M., Auger, P., Parfeniuk, D., MacDonald, R.D., 2022. Interfacility Transport of Mechanically Ventilated Patients with Suspected COVID-19 in the Prone Position. Prehosp Emerg Care 1–6. https://doi.org/10.1080/10903127.2022.2036882

Patroniti, N., Zangrillo, A., Pappalardo, F., Peris, A., Cianchi, G., Braschi, A., Iotti, G.A., Arcadipane, A., Panarello, G., Ranieri, V.M., Terragni, P., Antonelli, M., Gattinoni, L., Oleari, F., Pesenti, A., 2011. The Italian ECMO network experience during the 2009 influenza A(H1N1) pandemic: preparation for severe respiratory emergency outbreaks. Intensive Care Med 37, 1447–1457. https://doi.org/10.1007/s00134-011-2301-6

Peek, G.J., Mugford, M., Tiruvoipati, R., Wilson, A., Allen, E., Thalanany, M.M., Hibbert, C.L., Truesdale, A., Clemens, F., Cooper, N., Firmin, R.K., Elbourne, D., CESAR trial collaboration, 2009. Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial. Lancet 374, 1351–1363. https://doi.org/10.1016/S0140-6736(09)61069-2

Poiroux, L., Le Roy, C., Ramelet, A.-S., Le Brazic, M., Messager, L., Gressent, A., Alcourt, Y., Haubertin, C., Hamel, J.-F., Piquilloud, L., Mercat, A., 2020. Minimising haemodynamic lability during changeover of syringes infusing norepinephrine in adult critical care patients: a multicentre randomised controlled trial. Br J Anaesth 125, 622–628. https://doi.org/10.1016/j.bja.2020.06.041

Ramanathan, K., Shekar, K., Ling, R.R., Barbaro, R.P., Wong, S.N., Tan, C.S., Rochwerg, B., Fernando, S.M., Takeda, S., MacLaren, G., Fan, E., Brodie, D., 2021. Extracorporeal membrane oxygenation for COVID-19: a systematic review and meta-analysis. Crit Care 25, 211. https://doi.org/10.1186/s13054-021-03634-1

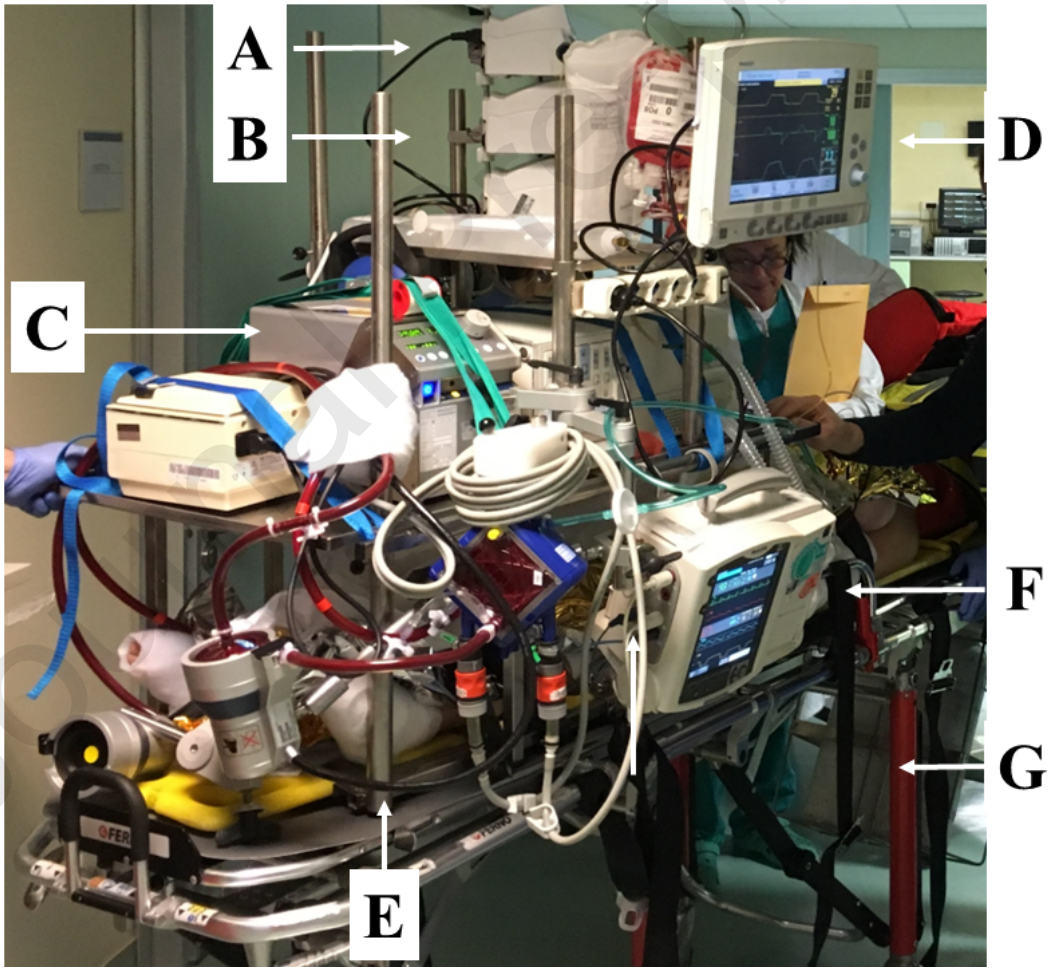
Seethala, R.R., Frakes, M.A., Cocchi, M.N., Cohen, J.E., Dargin, J., Friedman, F., Grant, C., Kaye, A., Wilcox, S.R., 2020. Feasibility and Safety of Prone Position Transport for Severe Hypoxemic Respiratory Failure Due to Coronavirus Disease 2019. Crit Care Explor 2, e0293. https://doi.org/10.1097/CCE.0000000000000293

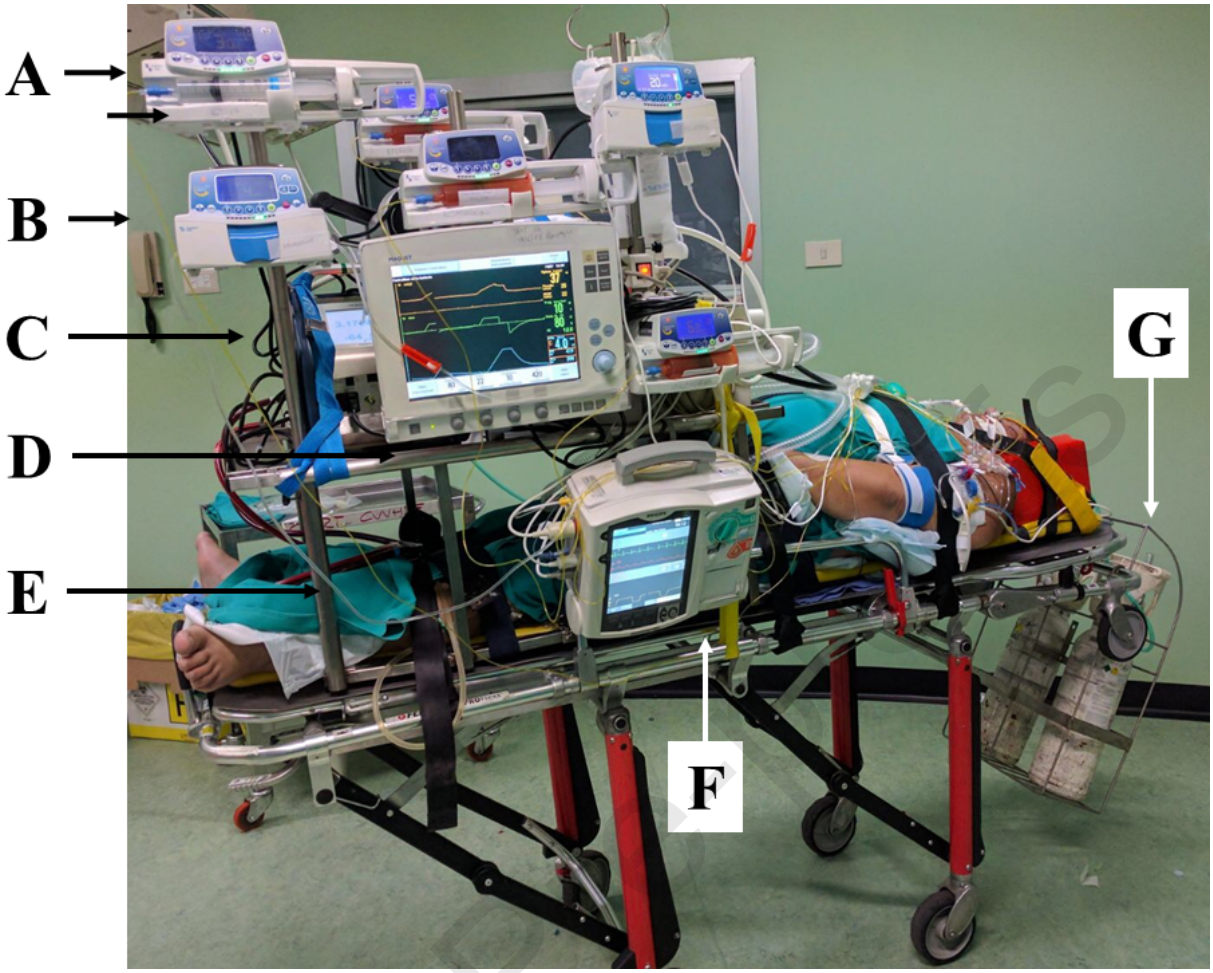
Shimoda, T., Sekino, M., Higashijima, U., Matsumoto, S., Sato, S., Yano, R., Egashira, T., Araki, H., Naoya, I., Miki, S., Koyanagi, R., Hayashi, M., Kurihara, S., Hara, T., 2021. Removal of a catheter mount and heat-and-moisture exchanger improves hypercapnia in patients with acute respiratory distress syndrome. Medicine (Baltimore) 100, e27199. https://doi.org/10.1097/MD.0000000000027199

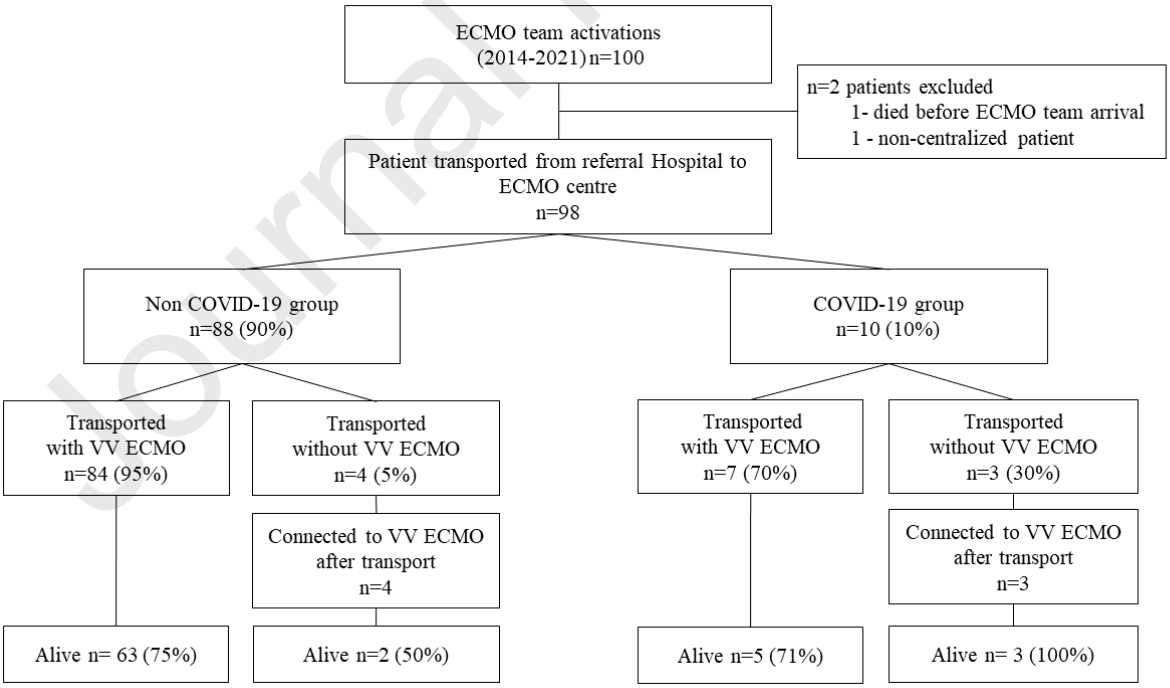
Tonna, J.E., Abrams, D., Brodie, D., Greenwood, J.C., Mateo-Sidron, J.A.R., Usman, A., Fan, E., 2021. Management of Adult Patients Supported with Venovenous Extracorporeal Membrane Oxygenation (VV ECMO): Guideline from the Extracorporeal Life Support Organization (ELSO). ASAIO J 67, 601–610. https://doi.org/10.1097/MAT.0000000000001432

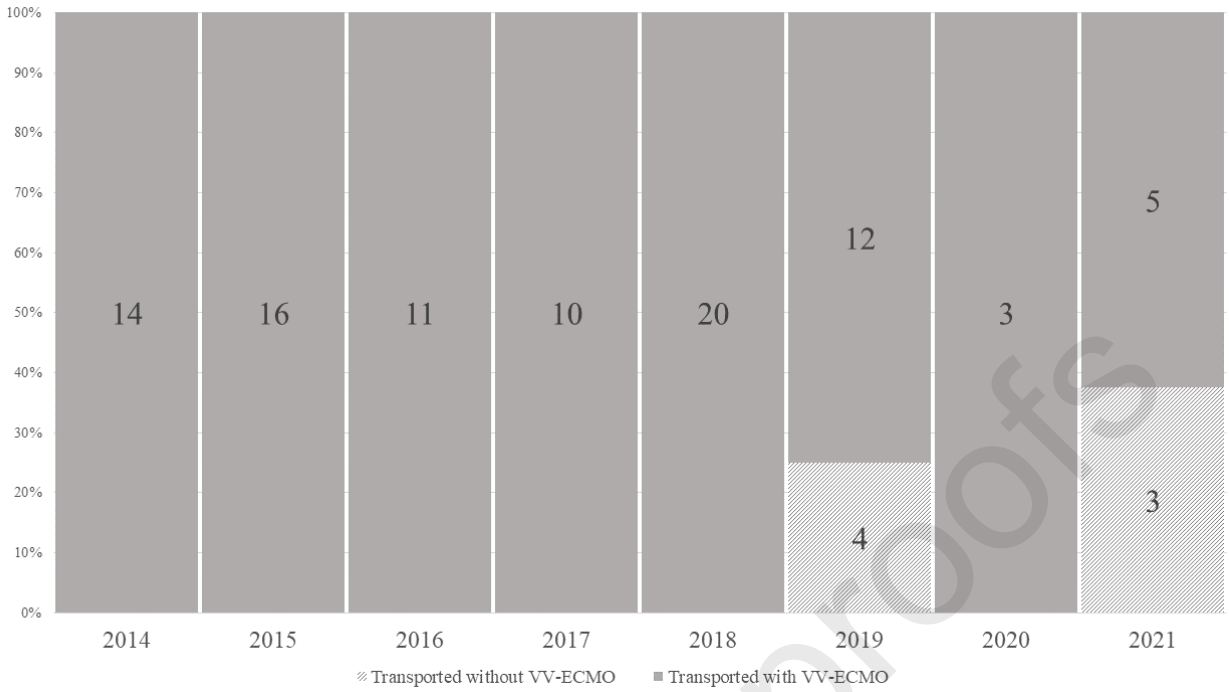
Vieira, J., Frakes, M., Cohen, J., Wilcox, S., 2020. Extracorporeal Membrane Oxygenation in Transport Part 2: Complications and Troubleshooting. Air Med J 39, 124–132. https://doi.org/10.1016/j.amj.2019.09.009

Vinceti, M., Filippini, T., Rothman, K.J., Di Federico, S., Orsini, N., 2021. The association between first and second wave COVID-19 mortality in Italy. BMC Public Health 21, 2069. https://doi.org/10.1186/s12889-021-12126-4

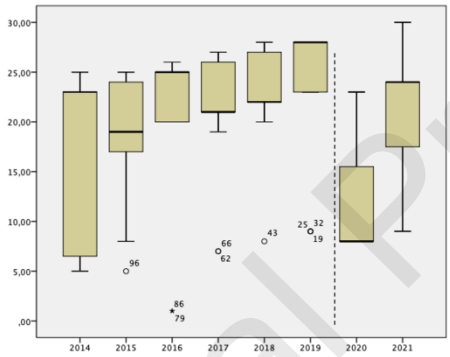



A
B
C
D
E
F
G

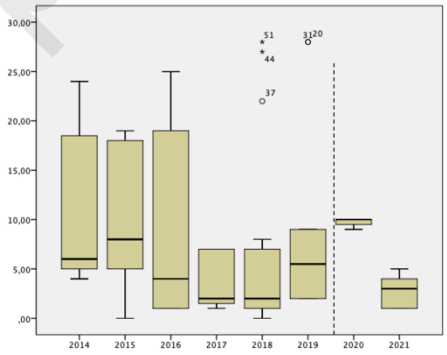

ECMO team activations (2014-2021) n=100
n=2 patients excluded
1- died before ECMO team arrival
1 - non-centralized patient
Patient transported from referral Hospital to ECMO centre n=98
Non COVID-19 group n=88 (90%)
COVID-19 group n=10 (10%)
Transported with VV ECMO n=84 (95%)
Transported without VV ECMO n=4 (5%)
Transported with VV ECMO n=7 (70%)
Transported without VV ECMO n=3 (30%)
Connected to VV ECMO after transport n=4
Connected to VV ECMO after transport n=3
Alive n= 63 (75%)
Alive n=2 (50%)
Alive n=5 (71%)
Alive n= 3 (100%)



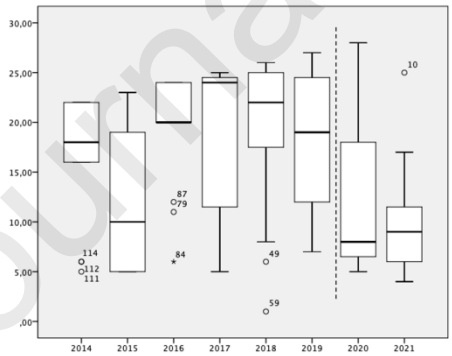
First intensivist



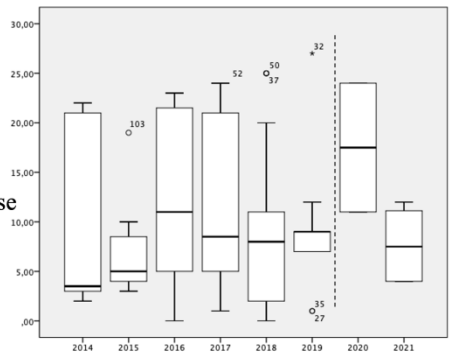
Second intensivist



First Critical Care Nurse



Second Critical Care Nurse



	All patients n=98 (100%)	Transported wi VV-ECMO n=7 (7%)
COVID patients (yes)	10 (11%)	3 (43%)
Mission overall time (hours)	7.0 (6.0-9.0)	2.0 (2.0-7.
Distance from the referral hospital (Km)	66.0 (38.0-119.0)	11 (5-30
Age (Years)	53.0 (43.0-63.0)	57 (44-66
BMI	28.7 (25.0-34.0)	33 (28-36
Weight (Kg)	80.0 (70.0-96.5)	90 (90-10
Ideal Body Weight (Kg)	70.0 (54.5-80.0)	70 (55-80

Length of ICU stay (referral ICU)	3.0 (1.0-6.0)	5 (1-6)
Mechanical ventilation days before ECMO team activation	2.0 (1.0-5.0)	4 (1-6)
Alive (discharged from hospital)	73 (74%)	5 (71%)
parameters at ECMO team arrival		
pO2/FiO_2	74.0 (61.0-95.0)	94 (92-12
$FiO_{2\ mmHg}$	1.0 (0.9-1.0)	1.0 (0.95-1
$pO_{2\ mmHg}$	70 (56-86)	94 (92-12
pCO_2	54 (49-65)	51 (50-51
pH	7.29 (7.20-7.38)	7.36 (7.33-7
Tidal volume - ml	440 (380-500)	450 (425-4
Tidal volume / Ideal Body Weight (ml/Kg)	5.3 (4.6-6.4)	4.7 (4.2-5.
Respiratory rate	24.0 (20.0-26.8)	24 (18-26
Plateau pressure – cmH_20	28.0 (25.0-30.0)	27 (26-30
PEEP – cmH_20	14.0 (10.0-16.0)	12 (10-14
Driving Pressure – cmH_20	14.7 (12.0 -19.0)	17 (14-20
Heart Rate before ECMO	100 (91-122)	93 (86-10
Arterial Sytolic pressure – mmHg	115 (100-130)	130 (120-1
Arterial Diastolic pressure - mmHg	60 (52-70)	67 (60-75
Norephinefrine before ECMO (yes)	45 (45%)	3 (43%)
Norephinefrine dosage (mcg/Kg/min)	0.100 (0.060-0.300)	0.080 (0.07-
Dopamine infusion before ECMO (yes)	7 (8%)	0 (0%)
Dopamine dosage (mcg/Kg/min)	6.00 (5.00-15.00)	---
NIV before ECMO (yes)	73 (74%)	5 (71%)
Prone position before ECMO (yes)	51 (52%)	3 (43%)
Nitrix Oxide before ECMO (yes)	21 (21%)	1 (14%)
CRRT before ECMO (yes)	15 (15%)	0 (0%)
Protein C Reaction	29.0 (19.7-40.0)	23.5 (13.7-3
White Blood Cells	11350 (6620-21845)	2740 (110-8
Platelets	133000 (77500-197250)	85614 (227-17
Procalcitonin	0.9 (0.50-21.0)	1.42 (1.4-8

Table 1 : Blood gas, ventilation parameters and characteristics of enrolled patients at ECMO team arrival in the referral hospital

		Median (IQR) or n= (%)
Drainage Cannula (site)	*Femoral*	97 (99%)
	Jugular	1 (1%)
Diameter drainage cannula (FR)		23 (23-25)
Reinfusion Cannula (site)	*Femoral*	88 (90%)
	Jugular	10 (10%)
Diameter reinfusion Cannula (FR)		23 (21-23)
Parameters after ECMO start (15 minutes)		
Blood Flow – ml/min		3.5 (3.0 - 3.8)
Gas Flow – ml/min		3.0 (3.0 -4.0)
FiO2 Membrane Lung		1.0 (0.8 - 1.0)
PEEP - cmH_2O		16 (14 - 19)

Plateau Pressure - cmH_2O	27 (24-30)
Driving Pressure - cmH_2O	10 (9-13)
Respiratory rate (minute)	10 (10-10)
Tidal Volume - ml	320 (260-400)
Tidal Volume/ Ideal Body Weight (ml/Kg)	4.15 (3.21-4.7)
FiO_2 natural lung	0.9 (0.7-1)
$pO_{2\ mmHg}$	116 (89-184)
$pCO_{2\ mmHg}$	43 (39-50)
pH	7.41 (7.35-7.44)
Norephinefrine infusion (yes)	59 (64%)
Norephinefrine dosage (mcg/kg/min)	0.1 (0.05 - 0.28)
Dopamine infusion (yes)	8 (9%)
ECMO treatment – key points:	
Alive at hospital discharge	73 (74%)
Intracranial Bleeding (yes)	5 (5%)
Length of ICU stay (ECMO centre)	24 (18-44)
Median ECMO days	14 (9-24)
Mechanical ventilation days (overall)	19 (12-25)
Tracheostomy during ECMO (yes)	40 841%)
Fibro bronchoscopy during ECMO (number of procedures)	5 (2-11)
Prone Position during ECMO (yes)	52 (54%)
CRRT during ECMO (yes)	48 (50%)
Switch to VA ECMO during ICU stay (yes)	3 (4%)
Chest drainage positioning during ECMO (yes)	20 (28%)

Table 2 : Blood gas and ventilation parameters before initiation of ECMO therapy and characteristics of ECMO treatment.

The authors declare no conflicts of interest, corporate involvement, patent holdings, etc.

Data were collected as part of a large observational study on V-V ECMO approved in July 2019 by the local ethics committee (Comitato Etico Brianza, ref. n. 3129). Due to the observational nature of the study, patient consent was waived.