Oxygen Management During Collective Aeromedical Evacuation of 36 COVID-19 Patients With ARDS

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ABSTRACT

Objective:

The ongoing coronavirus disease-2019 pandemic leads to the saturation of critical care facilities worldwide. Collective aeromedical evacuations (MEDEVACS) might help rebalance the demand and supply of health care. If interhospital transport of patients suffering from ARDS is relatively common, little is known about the specific challenges of collective medevac. Oxygen management in such context is crucial. We describe our experience with a focus on this resource.

Methods:

We retrospectively analyzed the first six collective medevac performed during the coronavirus disease-2019 pandemic by the French Military Health Service from March 17 to April 3, 2020. Oxygen management was compliant with international guidelines as well as aeronautical constraints and monitored throughout the flights. Presumed high O_2 consumers were scheduled to board the last and disembark the first.

Results:

Thirty-six mechanically ventilated patients were successfully transported within Europe. The duration of onboard ventilation was 185 minutes (145-198.5 minutes), including the flight, the boarding and disembarking periods. Oxygen intake was 1,650 L per patient per flight (1,350-1,950 L patient per flight) and 564 L per patient per hour (482-675 L per patient^{-1} per hour) and surpassed our anticipation. As anticipated, presumed high O_2 consumers had a reduced ventilation duration onboard. The estimations of oxygen consumptions were frequently overshot, and only two hypoxemia episodes occurred.

Conclusion:

Oxygen consumption was higher than expected, despite anticipation and predefined oxygen management measures, and encourages to a great caution in the processing of such collective medevac missions.

INTRODUCTION

The coronavirus disease-2019 (COVID-19) outbreak has been declared pandemic by the WHO on March 11, 2020.[1] The virus induces severe pneumonia frequently associated with ARDS requiring extended hospitalization in intensive care units (ICU).[2,3] This led to a gradual saturation of critical care capacities in France, especially in the Grand Est region.[4] As part of the management of this crisis, the French government ordered interhospital transfers from overloaded facilities to less-affected ones. For this, the French Military Health Service (FMHS) activated the a program called Module de Réanimation pour Patients à Haute Elongation d'Evacuation (MoRPHEE). This program was initially designed for the airborne medical evacuation (medevac) of multiple casualties from war zone to tertiary hospitals in France[5] and offers the opportunity to transport up to 12 victims, including up to 6 patients under mechanical ventilation.

There is increasing evidence on interhospital transfer of ARDS patients, but these transfers have always been conducted for single patients.[6,7] Every interhospital or intrahospital transfer is known to be a risk period for the critically ill patient.[8,9] In the case of ARDS patients, interhospital transfers have been shown to be associated with minor deterioration of the patients' condition; however, the risks are to be balanced with the expected benefits, such as the opportunity for the patient to access to specialized facilities such as extracorporeal membrane oxygenation (ECMO).[8]

Thus, the unique ongoing pandemic led to carry out collective MEDEVACS with ARDS patients. Despite short flights (mainly within French national territory), the medical

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management could last for several hours because of the boarding and disembarking phases and the handovers from team to team. The oxygen availability onboard was therefore a constant concern.

The main objective of this study was to describe oxygen management during the collective evacuations of these severely hypoxemic patients.

METHODS

Study Design and Setting

This was a retrospective analysis of the first six collective aero-MEDEVACS performed with MoRPHEE during the COVID-19 pandemic.

Collective MoRPHEE MEDEVACS were originally conceived by the French Air Force and the FMHS to repatriate severely injured war casualties. The system based on mission-tailored "plug-and-play" modules was settled into a non-dedicated aircraft, an Airbus A330 Multi Role Tanker Transport. Six intensive care modules were available onboard for the following facilities: mechanical ventilation (LTV 1200 ventilator, CareFusion, Yorba Linda, CA), continuous monitoring, drug infusion, echography, and arterial blood gas analysis.[9] The medical crews were trained to perform MEDEVACS; each team was composed of three ICU doctors, two flight surgeons, three anesthetist nurses, three flight nurses, and two critical care nurses.[10] Because of the contagious risks linked to the COVID-19, the teams were reinforced by four experts of two specialized units of the FMHS, and the French Air Force (the specific management of the biological risk during flights will not be discussed in this publication).

Ventilation was conducted as follows. In order to facilitate the ventilator support during the flight and to limit the risk of tracheal tube disconnection and viral contamination of the cabin, the patients' current healthcare teams were encouraged to maintain any ongoing sedation, to induce muscle relaxation, and to use closed-suction devices. A protective ventilation strategy using a low tidal volume and high positive end-expiratory pressure was established in order to prevent alveolar collapse and hypoxaemia, and to minimize the risk of ventilator-induced lung injury. Medical crew was encouraged to gradually lower the inspired oxygen fraction (FiO_2) with respect to the following oxygenation objectives: $SpO_2 > 90\%$, partial pressure of oxygen (PaO_2) of 55 to 80 mmHg in line with international standards.[11–13] However, during the takeoff and the landing, regarded as high-risk period during which the access to the patient is limited, FiO_2 was raised to 100%.

Oxygen was managed based on the following hypothesis: tidal volume (V_t), 450 mL; respiratory rate (RR), 25 per minute; and FiO_2, 50%. We anticipated that the average O_2 needs of our patients would be 337.5 L h^{-1} and with a safety margin of 50%, about 500 L h^{-1}. The maximal oxygen need was estimated to 900 L h^{-1} with the following hypotheses: V_t, 500 mL; RR, 30 per minute; FiO_2 100%, 1. Onboard allocated O_2 volume for each patient was three cylinders (15 L, 200 bars), being 9,000 L, broadly exceeding the estimated requirements.

The patients' boarding and disembarking plans were decided according to clinical severity and the expected oxygen needs. Presumed high O_2 consumers were the last to be boarded and the first to be offloaded, in order to limit the time spent onboard and subsequent oxygen consumption.

The study was approved by the Ethics Committee of the French Society of Intensive Care and Anesthesiology and was registered to the French Data Protection Authority (Commission Nationale d'Informatique et Libertés) under the number MR 0509270320.

Selection of Participants

All consecutive transported patients were eligible. Six patients were selected the day before each flight in coordination with the treating ICU according to the following criteria: confirmed severe acute respiratory syndrome coronavirus 2 pneumonia requiring invasive mechanical ventilation, body weight < 120 kg, PaO_2/FiO_2 ratio >120 mmHg, absence of ongoing prone position ventilation, and moderate infusion rates of catecholamine (norepinephrine infusion rate <0.5 μg kg^{-1} min^{-1}). Exclusion criteria were as follows: age <18 years, handicap, or consent withdrawal by the patient or relatives after written information was provided. Two presumed high O_2 consumers were identified before each medevac based on a clinical judgment according to relevant aspects such as high minute ventilation, low PaO_2/FiO_2 ratio, and presence of other organ failure.

Measures

Data were extracted from the medical records using a standardized data collection form and from the missions detailed reporting. During the flight, patients were continually monitored, and both physiological and biological data were recorded, as well as ventilator settings and O_2 consumption. Ventilator settings and arterial blood gas analysis were collected after a stabilization period of 10 minutes after the takeoff. In order to reduce potential bias, data collection was conducted immediately after the flights. Data were anonymized and compiled on a spreadsheet (Excel, version 16.35, Microsoft, Redmond, Washington, USA).

ARDS was defined and graded according to the Berlin definition.[14] Predicted body weight was calculated according to the ARDS Network–predicted body weight calculator.[13]

Outcomes

The ventilator support duration onboard was recorded from the onset to the closure of the patients ventilator. Oxygen intake was measured by tracking the content of oxygen cylinders.

Hypoxemia episodes were defined as an SpO_2 <90% over at least 5 minutes.

TABLE I. Characteristics of Onboard Ventilation Settings and Patients' Oxygenation

Variables	$N = 36$
Ventilator settings, median (IQR)	
Tidal volume/predicted body weight, mL kg^{-1}	6.5 (6.2−7.0)
Respiratory rate, per minute	25 (22−26)
Inspired oxygen fraction, %	55 (50−60)
Positive end-expiratory pressure, cmH_2O	13 (12−14)
Duration of onboard mechanical ventilation, median (IQR), minutes	185 (145−198.5)
Patient-centered issues	
PaO_2/FiO_2 ratio, median (IQR), mmHg ($n = 30$)	143 (119−185)
Hypoxemia episodes ($SpO_2 < 90\%$ over at least 5 minutes), *n*.	2
Oxygen intake	
Hourly, median (IQR), L per patient per h	564 (482−675)
Per flight, median (IQR), L per patient	1,650 (1,350−1,950)

Abbreviation: IQR, interquartile range.

Analysis

Continuous and categorical variables were respectively presented as median (first-third quartiles) and *n* (%). Descriptive statistics were provided, and the comparison of O_2 consumption among presumed high O_2 consumers and others was done using a non-parametric test (Wilcoxon test).

RESULTS

Main Results

Onboard Ventilation Settings and Patients' Oxygenation

During six collective aero-medevac performed on March 18, 21, 24, 27, 31 and April 3, 2020, 36 civilian patients were evacuated. The ventilator support duration onboard was 185 minutes (145-198.5 minutes). Ventilator settings recorded during the flight after an initial stabilization period are described in Table I. Oxygenation parameters were as follows: PaO2, 80.5 mmHg (70.5-109 mmHg) ($n = 30$); PaO_2/FiO_2 ratio, 143 mmHg (119-185 mmHg) ($n = 30$); SpO_2, 96% (94-99.5%). Hypoxemia episodes (SpO_2 <90% over at least 5 minutes) occurred in two patients, and no other serious respiratory adverse event occurred. Oxygen targets were frequently surpassed, as observed at steady state on the SpO_2 monitoring with 14 patients (39%) having an SpO_2 of 98% or more, or on blood gas analysis with 18 of 30 patients (60%) having a PaO_2 >80 mmHg.

Oxygen Consumption

Oxygen intake was 1,650 L per patient per flight (1,350-1, 950 L per patient per flight) and 564 L per patient per hour (482-675 L per patient per hour). A broad majority of the patients ($n = 25$, 69%) needed 500 L h^{-1} or more, four of them (11%) needed 900 L h^{-1} or more, which were the standard and maximal needs that we anticipated.

On the first flight, the overall O_2 consumption on the plane was 13,650 L. It could be decreased during subsequent flights to 11,025, 8,100, 9,600, 11,100, and 9459 L, respectively.

Before each medevac, two presumed high O_2 consumers (high minute ventilation, low PaO_2/FiO_2 ratio) were identified. The boarding plan was set up in order to limit the duration of their management onboard, which could be achieved at each medevac. Their hourly O_2 intake was 691 L h^{-1} (548-803 L h^{-1}) and did not significantly differ from the intake of the non-presumed high O2 consumers, 529 L h^{-1} (462-619 L h^{-1}) ($P = 0.07$).

Characteristics of the Study Subjects

During the six collective aero-MEDEVACS, 36 civilian patients were evacuated. All of them could be included. Originating hospitals were located in Mulhouse ($n = 16$), Colmar ($n = 8$), Metz ($n = 10$), and Thionville ($n = 2$). The patients were transferred into ICU located in Bordeaux ($n = 12$), Toulouse ($n = 6$), Brest ($n = 4$), Marseille ($n = 3$), Toulon ($n = 3$), Quimper ($n = 2$), France, and Kiel ($n = 3$) and Lübeck ($n = 3$), Germany.

The baseline patients' characteristics were as follows: the male-to-female sex ratio was 2, age was 64 years (58-72 years), ranging from 49 to 78 years. The most common comorbidities were obesity ($n = 17$, 47%) and diabetes ($n = 13$, 36%).

The majority of the patients required vasopressor ($n = 22$, 61%). All of them were under mechanical ventilation, and among 35 patients with recorded pre-transport PaO_2/FiO_2 ratio, 23 (66%) suffered from moderate ARDS. The duration of previous ventilator support was 4 days (3-5.25 days). Five patients required previous prone position and one patient was weaned from ECMO 2 days before the transfer.

Characteristics of the Aero-medivac Missions

The six flights lasted between 52 and 77 minutes (distances between airports ranging from 700 to 1080 km). The cabin altitude was approximatively set between 4,900 (1 500 m) and 8,800 ft (2,700 m). For each medevac, the collective boarding or disembarking durations ranged from 60 to 100 minutes, with approximately 15-25 minutes of handling per patient. Transfers characteristics are summarized in Table II.

TABLE II. Characteristics of the Six Aeromedical Evacuation Missions

Medevac mission	1	2	3	4	5	6
Patients, *n*	6	6	6	6	6	6
Distance, km	700	830	1080	830	610	770
Boarding duration, minutes	88	60	75	53	59	68
Flight duration, minutes	52	70	73	62	77	75
Disembarking duration, minutes	60	67	85	64	100	74

DISCUSSION

We report the oxygenation strategy and oxygen management of 36 ARDS patients during the six collective aero-medevac missions performed in France during the COVID-19 pandemic. All patients suffered from mild to moderate ARDS and required invasive ventilator support onboard, during 185 minutes (145−198.5 minutes). This duration broadly surpassed the duration of the flights (71 minutes [62−75 minutes]) because of the boarding and disembarking periods. Oxygen intake was 1,650 L per patient per flight (1,350−1,950 L per patient per flight) and 564 L per patient per hour (482−675 L per patient per hour).

To our knowledge, this is the first experience of collective aero-medevac of patients with ARDS. The FHMS has a long history in dealing with aero-medevac of critically ill casualties and has developed a program named MoRPHEE, specifically designed to carry out multi-victim medevac. With large oxygen availability onboard, it seemed to fit the situation. We recently reported the airborne evacuation of ARDS patients from war theater to French mainland territory.[7] Several series of medevac of ARDS patients have been reported, some of them being of high severity and requiring onboard ECMO.[6,15,16] However, in these publications, the patients were transported one by one. The ongoing COVID-19 pandemic led to a unique situation where numerous ARDS patients had to be evacuated from overloaded ICUs. Collective MEDEVACS have specific challenges such as oxygen management, and for this reason we focused this report on this resource.

Even though it did not surpass oxygen availability, with more than two-third of the patients over 500 L h^{-1}, and more than one-tenth of them over 900 L h^{-1}, the O_2 requirements of our patients broadly surpassed our anticipations. One possible explanation is that some of our patients were at the initial stage of the disease, and their condition worsened between the decision of the flight at day 1 and the transport. Yet, four scheduled patients were canceled because of severe ARDS (PaO_2/FiO_2 ratio <100 mmHg) that we figured out could jeopardize the medevac. Therefore, the selection of eligible patients for such a collective medevac is crucial and we emphasize the "Doc-to-Doc" call in addition to the medevac request form.

On the other hand, with only two recorded episodes of hypoxemia, and many SpO_2 or PaO_2 records above the predefined oxygen targets, it is likely that our oxygenation practices were too liberal. Oxygen targets and the risk of hyperoxemia are emerging issues in critically ill patients.[17,18] To the best of our knowledge, neither incidence nor impact of hyperoxemia during interhospital transfers has been explored. Based on our experience, it is hard to be in strict compliance with strict oxygenation targets during medevac flights, and the risk-to-benefit ratio may favor the prevention of hypoxemia in this context.

Based on the medical history, PaO_2/FiO_2 ratio, minute ventilation, and the presence of hemodynamic instability, we identified—the day before each flight—two presumed high O_2 consumers, which was useful on an operational point of view. We indeed could limit the time they spent onboard and their subsequent O_2 consumption, which is crucial in an environment where oxygen availability is limited. Nevertheless, we failed to identify ahead of time some of the highest O_2 consumers. PaO_2/FiO_2 ratio and minute ventilation are certainly the major determinants. Further investigation to identify the factors associated with a high O_2 consumption could be usefull in order to improve O_2 management, but the limited size of our sample prevented us to carry out such analyses.

Beyond oxygen load, this analysis raised some organizational and ethical issues. Organization: the identification of the "presumed" high O_2 consumers were somehow validated during the flights. Anyway, we questioned our classical instruction to set FiO_2 to 100% during the takeoff and the landing, and we chose to test the safety of more restrictive approaches for single-patient MEDEVACS. Ethics: to choose a PaO_2/FiO_2 ratio >120 as an eligibility criteria was a mean to allow safe transportation and avoid severe incidents onboard. We estimated that it was in line with the principle of distributive justice. Indeed, as previously mentioned, the occurrence of time-consuming events in one single patient could jeopardize others. However, this eligibility criteria may have excluded some more hypoxemic patients who could get more benefit from the transport. By now we are inclined to consider a PaO_2/FiO_2 ratio threshold between 80 and 100 if the other patients are not too severe.

Our study has some limitations. The retrospective design exposes to a bias in the data collection. The study population was relatively small. A selection bias was present and even though we included all transported patients, we scheduled the transfer only for moderate risk patients, as we believed that very high-risk patients might jeopardize such collective medevac. Even if the patients' characteristics were similar to other populations of COVID-19 ARDS patients[2] or ARDS medevac patients,[6,8] the results of our study may not be reproducible in all ARDS populations. Finally, the medical team was specifically trained for collective medevac missions,[9] which could also limit the external validity of the study.

In conclusion, we report the oxygenation strategy and oxygen management of 36 ARDS patients during the six collective aero-medevac missions performed in Europe during the COVID-19 pandemic. Oxygen consumption was higher than expected, despite anticipation and predefined oxygen management measures. Management of oxygen in such collective aero-medevac missions should be a permanent concern for the physician.

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CONFLICT OF INTEREST

None declared.

REPRINTS

None.

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