Collective aeromedical evacuations of SARS-CoV-2-related ARDS patients in a military tactical plane: a retrospective descriptive study

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ABSTRACT
After the appearance of the COVID-19 pandemic in France, MEROPe system was created to transform the military tactical ATLAS A400M aircraft into a flying intensive care unit. Collective aeromedical evacuations (aero-MEDEVAC) of patients suffering from SARS-CoV-2-related acute respiratory distress syndrome was performed from June to December 2020. A total of 22 patients were transported during seven missions. All aero-MEDEVAC was performed in safe conditions for patients and crew. No life-threatening conditions occurred during flight. Biohazard controls were applied according to French guidelines and prevented crew contamination. Thanks to rigorous selection criteria and continuous in-flight medical care, the safe transportation of these patients was possible. To the best of our knowledge, this is the first description of collective aero-MEDEVAC of these kinds of patients using a tactical military aircraft. We here describe the patient’s characteristics and the flight’s challenges.

INTRODUCTION
Merope was the daughter of Atlas and Pleione in ancient Greek mythology. She was one of the seven Pleiades who were transformed into doves in the myth. Thus, was one of the seven Pleiades who were transformed into doves in the myth. Thus, Merope was the daughter of Atlas and Pleione. This study described the first use of military collective aeromedical transportation of patients in a pandemic context, using an Airbus A330 Multi-Role Tanker Transport plane equipped with the Module de Réanimation pour Patient à Haute Élongation d’Evacuation (MoRPHEE; Intensive care module for high elongation evacuation patients) system.

To allow the use of the ATLAS A400M for collective MEDEVACs, the Module de Réanimation pour les OPérations (MEROPE; Critical care module for operations) system was created in 2020. Like the MoRPHEE system, it transforms the aircraft into a flying intensive care unit, allowing the transport of four supine patients under intensive care.

Since June 2020, MEROPE has been deployed several times to perform aeromedical transportations of patients with SARS-CoV-2-related ARDS. This study describes the medical organisation and results of these flights.

**MEROPe SYSTEM**
The MEROPE system turns a multipurpose tactical transport and logistics aircraft into ‘flying ICU’. It is composed of four intensive care modules, each allowing the management of one intensive care unit patient. It complies with international aviation security rules. This system allows the transportation of patients for medium to long distances, even in tactical conditions in combat zones.

Each module (Figure 1) is made up of a transport ventilator (Monnal T60, Air Liquide Medical System, Antony, France), continuous monitoring system (Corpuls 3, Corpsul, Kaufering, Germany) and drug infusion pumps (four electric syringe pumps, Injectomat Agilia, Fresenius Kabi, Sevres, France; one Alaris GW pump, CareFusion, Rolle, Switzerland). In addition, there is an ultrasound system (Edge II, Sonosite, Bothell, Washington, USA) and a blood analysis system (epoc, Siemens, Zurich, Switzerland).

The medical crew for the MEROPE system included one intensivist, two emergency physicians with aeromedical...
specialty, two nurse anaesthetists, two
general nurses and two flight nurses. All
crew were trained for aero-MEDEVACs.

PATIENT’S CHARACTERISTICS
Participants selection
All transported patients were included if
they had no exclusion criteria. The exclu-
sion criteria were age under 18 years or
classification as a protected adult. Patients
were selected the day before the flight by
the hospital physicians who were in charge
of them. Only stabilised patients with
moderate ARDS severity were selected to
mitigate the risk of decompensation due
to aero-MEDEVAC. The selection criteria
were as follows: confirmed SARS-CoV-2
infection, PaO$_2$/FiO$_2$ > 120, bodyweight
< 130 kg, no prone position in the 24
hours prior to the flight and moderate
infusion rate of catecholamines (< 0.5 µg/
kg/min). All patients under mechanical
ventilation had to be sedated and phy-
armacologically paralysed. Non-
vasive mechanical ventilation was not available
onboard. Preferably, patients had either
respiratory failure only or mild associated
organ failures.

Clinical data
From June to December 2020, 22
patients were evacuated by the MEROPE
system during seven aero-MEDEVAC
missions.

All patients met the criteria for ARDS
following a SARS-CoV-2 infection that
was qualified as severe for one patient
(5%), moderate for 13 patients (59%)
and mild for eight patients (36%). The
patients transported were 91% male,
with a median age of 69 years (63–73).
The median Charlson comorbidity
score was 4 (2–4). The main comorbid-
ities were hypertension and obesity. The
median body mass index (BMI) was 29
(26–33). All patients were under me-
chanical ventilation. The patients’ pre-
flight characteristics are detailed in Table 1.

All patients were sedated and phar-
macologically paralysed during the flight
following the instructions given to the
medical teams in the upstream intensive
care units. Seven (32%) patients had
haemodynamic failure (six patients on
norepinephrine and one patient on dobu-
tamine). In-flight FiO$_2$ (60% (50–70))
was higher than pre-flight FiO$_2$ (50% 
(45–50)), p < 0.001. In contrast, posi-
tive end-expiratory pressure and tidal
volume remained stable (p = 0.46 and
0.98, respectively). Arterial blood gases
were analysed during the flight at least
once for all patients and twice for 12
(55%) of them (at the beginning and end
of the flight). Figure 2 shows the evolu-
tion of the PaO$_2$/FiO$_2$ ratios. PaO$_2$/FiO$_2$
ratios decreased slightly during the flight,
with a significant difference between
the day before and the end of the flight
(p = 0.024). This result may have been
affected by the fact that patients who
received two arterial blood tests during
the flight were the most critical patients.
All PaO$_2$/FiO$_2$ ratios returned to baseline
the day after the flight.

During the flights, 12 patients required
medical interventions to manage 15
medical events (constituting 100% of the
events). Three of them presented with
two medical events. None of these were

Figure 1   Modules of the MEROPE system. Photo credits: French Army Ministry.
oxygen consumption was 341 (290–444) L/hour.

Table 2 shows patient characteristics during the flights and their outcomes on the following days. Two patients (9%) required prone positioning on the day of the flight after being admitted to the downstream intensive care unit. All patients were still under mechanical ventilation and alive on the day after the flight. One week later, 12 patients were still under mechanical ventilation, and one patient had died.

**FLIGHT’S CHARACTERISTICS**

**Flight’s characteristics**

Table 3 presents the flight characteristics. All seven flights were performed in the French national territory even if the first three flights took place between overseas territories.

**Infection prevention and control**

Because of the biological risk linked to the transportation of patients infected with SARS-COV-2, the entire crew wore personal protective equipment (PPE) according to the procedures defined in the French guidelines and validated by the Armed Forces Research Institute.9 All members of the medical crew were trained in these procedures. From the moment the patients entered the aircraft cargo bay, it was considered fully contaminated, even after unloading the patients, until a decontamination procedure took place after the return flight. PPE was therefore maintained without interruption. Wearing PPE for several hours caused dehydration and had a significant impact on crew fatigue (Table 3). That is why, when the mission was particularly long, a system called ALCYONE (Abri Léger et Collectif de reconditionnement physiologique du personNEL; Light and collective shelter for the physiological reconditioning of crew) was implemented to create a green zone in the cargo bay, allowing the crew to carry out physiological reconditioning (eating, drinking, etc). This system consists of a temporary room with vinyl walls and an airlock. Its air is filtered and renewed to create a safe zone. Protective equipment can be removed and thrown into the airlock, and then new equipment is worn into the cargo bay. To assist and secure the medical crew when the ALCYONE system was used, specialised military staff who were biohazard experts participated in the mission and ensured compliance with hygiene rules to reduce the risk of transmission of SARS-CoV-2. None of the crew members contracted COVID-19 during these missions.

**DISCUSSION**

The French Army, with the MEROPE system, safely performed collective aero-MEDEVAC of patients with ARDS under invasive mechanical ventilation. This is the first description of collective evacuation in a military tactical A400M aircraft. Patient characteristics were consistent with those reported in the literature for patients with COVID-19 requiring invasive mechanical ventilation.10 11 Although a few authors have proposed recommendations for the medicalised transfer of patients with COVID-19 during these missions.6 16 In our study, the characteristics of the patients were consistent with those reported in the handful of previous studies of medical evacuations.6 17 18 Compared with ARDS developed in war casualties, our patients were transported later than the onset of lung disease and with a more severe respiratory condition (the median PaO2/FiO2 was about 240 during aero-MEDEVAC of war casualties’ patients). They were older and had more comorbidities.19

Illness severity during the flights was at a level that would be expected for patients meeting our selection criteria. Even though transportation is recognised as high risk,20 21 we believe that no patients were endangered during these transports. This was possible because of the strict selection of patients.
and the intensive medical care available in flight. There are critical times, particularly for respiratory function, for patients with ARDS during extra-hospital transport: during the road transport before the flight, during the flight itself and during road transport to the hospital. Transfers between medical teams, with changes in position, ventilator disconnections and changes in ventilatory modes, all contribute to atelectasis. Two modes, all contribute to atelectasis. Two patients required prone positioning after the flight, on the same day, because of worsening respiratory failure. These two patients had the most advanced obesity (BMI 40 and 39 kg/m²), putting them at greater risk for lung collapse, although the risk cannot be statistically analysed due to the limited number of patients. Nevertheless, our weight-related selection criterion appears to have been a key factor in the safety of flights. Additionally, systematic sedation and neuromuscular blockade of the patients prevented complications such as patient–ventilator asynchrony or patient agitation. This was also critical for flight safety.

Another feature of this military tactical aircraft is that non-medical aircrews (loadmasters) are required in the cargo bay; they are also exposed to the biological risk inherent in transporting patients with SARS-CoV-2. They were given the same PPE as the medical crew and received training in its use before the flight. Their safety and the application of hygiene rules were the responsibility of the medical director or the biosecurity team if the team was present. The application of these measures was effective as no case of COVID-19 transmission to the crew was observed during the seven missions.

CONCLUSION

This is the first description of the collective aero-MEDEVAC of SARS-CoV-2-related ARDS patients experience onboard a tactical military aircraft. Thanks to rigorous selection criteria and continuous in-flight medical care, the safe transportation of these patients was possible. This study documents collective medical evacuations using the MEROPÉ system and illustrates the commitment of the French Army to the national management of the pandemic. In sharing our experience, we hope to facilitate the organisation of similar missions by other medical teams.

Contributors TM, MB and LR conceived the study and designed the trial. TM supervised the conduct of the trial and data collection. TM, KS, LL, CND, ML, PA, JL, SS, ON, MB and LR undertook recruitment of patients and managed the data. TM provided statistical advice on study design and analysed the data; TM drafted the manuscript, and KS, LL, CND, ML, PA, JL, SS, ON, MB and LR contributed substantially to its revision. TM takes responsibility for the paper as a whole.

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