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.

Key messages

- ⇒ MEROPE system transforms the A400M tactical military aircraft into a 'flying ICU'.
- ⇒ Collective aero-MEDEVACs have been performed with the MEROPE system to transfer patients presenting SARS-CoV-2-related acute respiratory distress syndrome under mechanical ventilation.
- ⇒ Twenty-two patients have been transported during seven flights; they were all selected according to rigorous selection criteria for their safety.
- ⇒ Thanks to the continuous medical care during flight and the organisation of this original MEROPE system, transfer of these critical patients was performed safely.
- ⇒ Biohazard was controlled with the application of national guidelines and the creation of the specific ALCYONE system to avoid SARS-CoV-2 crew contamination.

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, her name was an appropriate choice to identify the system created to transform the military tactical ATLAS Airbus A400M military transport aircraft into a flying intensive care unit. The ATLAS aircraft has been deployed in France since 2013. It is used for logistical support by the French Army in all theatres of operation.

The COVID-19 pandemic challenged all of France's healthcare systems, acutely from the beginning of 2020 and then on a chronic basis throughout the year.[1] Numerous initiatives were launched to serve the influx of patients (ie, intensive care bed creation, creation of military intensive care hospitals and inter-regional medical evacuations to avoid local saturation).[2–4] These strategies relied on, among others, the French Army and the French Military Health Service.[5 6]

To carry out these medical evacuations (MEDEVACs), a variety of means of transport were used: ambulances, trains, helicopters and planes—some of which belonged to the French Army. One of the challenges of this crisis has been to manage a significant number of patients with acute respiratory distress syndrome (ARDS)[7] requiring intensive care and with life-threatening prognoses, making these MEDEVACs high-risk patient transfers for the patients. A previous 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 Elongation d'Evacuation* (MoRPHEE; Intensive care module for high elongation evacuation patients) system.[6 8]

To allow the use of the ATLAS A400M for collective MEDEVACs, the *ModulE de Réanimation pour les OPErations* (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 a '*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, Corpuls, 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

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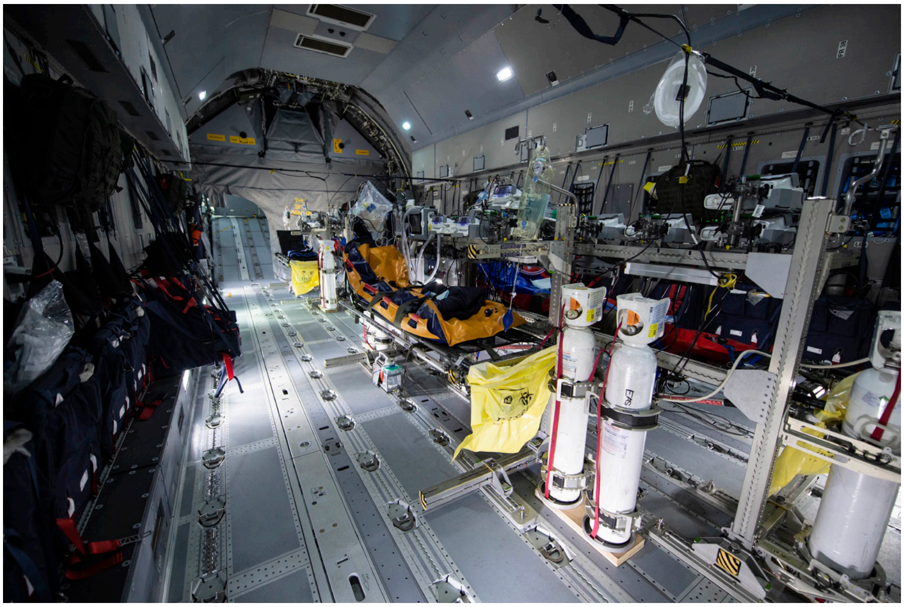

Figure 1 Modules of the MEROPE system. Photo credits: French Army Ministry.

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 exclusion 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 pharmacologically paralysed. Non-invasive 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 comorbidities were hypertension and obesity. The median body mass index (BMI) was 29 (26–33). All patients were under mechanical ventilation. The patients' pre-flight characteristics are detailed in Table 1.

All patients were sedated and pharmacologically 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 dobutamine). In-flight FiO_2 (60% (50–70)) was higher than pre-flight FiO_2 (50% (45–50)), $p<0.001$. In contrast, positive 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 evolution 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

Table 1 Patient's characteristics the day before the flight

Characteristics	All patients (n=22)
Age, median (IQR)	69 (63–73)
Male gender, n (%)	20 (91)
BMI, kg/m^2, median (IQR)	29 (26–33)
Comorbidities	
Charlson score, median (IQR)	4 (2–4)
Diabetes, n (%)	5 (23)
Hypertension, n (%)	13 (59)
Obesity (BMI >30), n (%)	10 (45)
SOFA score, median (IQR)	3 (3–6)
SOFA Respiratory score, median (IQR)	3 (3–3)
SOFA Cardiovascular score, median (IQR)	0 (0–0)
Days since symptoms beginning, median (IQR)	17 (13–19)
Days since ICU admission, median (IQR)	8 (6–16)
Days since mechanical invasive ventilation, median (IQR)	6 (4–11)
Treatments before flight	
Tidal volume, mL/kg, median (IQR)	6.2 (6.0–6.4)
PEEP, mm Hg, median (IQR)	10 (8–12)
FiO_2, %, median (IQR)	50 (45–50)
Neuromuscular blockade, n (%)	13 (60)
Corticosteroid treatment, n (%)	23 (100)
Pneumonia, n (%)	9 (41)
Prone positioning, n (%)	17 (74)
Number of prone position sessions, median (IQR)	1 (1–3)

BMI, body mass index; FiO_2, O_2 inspired fraction; ICU, intensive care unit; PEEP, positive end-expiratory pressure; SOFA, Sequential Organ Failure Assessment score.

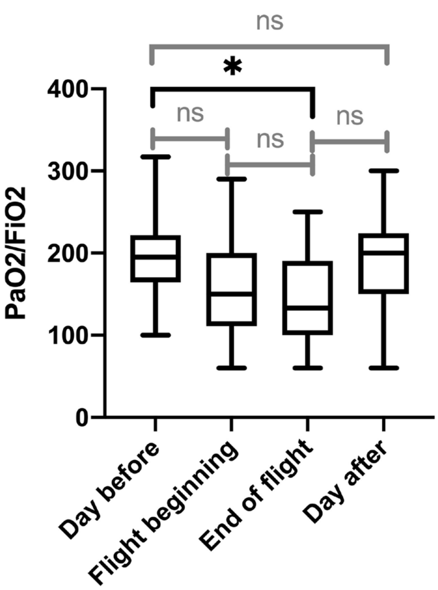

Figure 2 PaO_2/FiO_2 ratio evolution from the day before to the day after the flight. *p<0.05. Multiple comparisons were performed using the Kruskal-Wallis test.

considered severe or life-threatening. There were eight respiratory events (seven patients), including two cases of respiratory acidosis and six of desaturation (peripheral capillary oxygen saturation <92%) resolved with recruitment manoeuvres; two haemodynamic events (hypotension in two patients); and five other events (in five patients): three cases of hyperglycaemia >10 mmol/L, one case of hypothermia <36°C and one case of hypokalaemia <3.5 mmol/L. Median 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.

Table 2 En route characteristics and short-term outcomes

Characteristics	All patients (n=22)
FiO_2, %, median (IQR)	60 (50–70)
PEEP, mm Hg, median (IQR)	10 (8–12)
Tidal volume, mL/kg, median (IQR)	6.2 (6.0–6.4)
PaO_2/FiO_2 during flight	132 (116–197)
SOFA score, median (IQR)	3 (3–6)
SOFA Respiratory score, median (IQR)	3 (3–3)
SOFA Cardiovascular score, median (IQR)	0 (0–3)
Event requiring medical intervention, n (%)	12 (55)
Life-threatening event, n (%)	0
Respiratory event, n (%)	7 (32)
Cardiovascular event, n (%)	2 (9)
Other event, n (%)	5 (23)
O_2 consumption, L/hour, median (IQR)	341 (290–444)
Short-term outcomes	
Mechanical ventilation on day 1, n (%)	22 (100)
Alive on day 1, n (%)	22 (100)
Mechanical ventilation on day 7, n (%)	12 (55)
Alive on day 7, n (%)	21 (95)

FiO_2, O_2 inspired fraction; PEEP, positive end-expiratory pressure; SOFA, Sequential Organ Failure Assessment score.

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[12–15] and few studies have described the transfer procedures.[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 PaO_2/FiO_2 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

Table 3 Flight's characteristics

Flight number	Departure	Arrival	Length (km)	Flight duration (min)	Duration of medicalisation (min)	PPE wearing time (hh:mm)	Patients number	ALCYONE
1	Cayenne	Pointe-à-Pitre	1610	150	219	9:00	2	Yes
2	Cayenne	Fort de France	1438	125	193	9:00	2	Yes
3	Cayenne	Pointe-à-Pitre	1610	150	213	9:00	2	Yes
4	Avignon	Brest	869	100	233	6:30	4	No
5	Lyon	Nantes	516	70	205	6:30	4	No
6	Lyon	Villacoublay	390	60	225	3:15	4	No
7	Lyon	Brest	763	90	215	6:15	4	No

All flights took place on French territory.
PPE, personal protective equipments.

and the intensive medical care available in flight. There are critical times, particularly for respiratory function, for patients with ARDS during extra-hospital transportation: 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 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/m^2), 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 aircrew (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 MEROPE 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.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Disclaimer The opinions expressed in here are the private views of the authors and are not to be considered as official or as reflecting the views of the French Military Health Service.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval Local ethics committee (Comité d'Ethique de la Recherche en Anesthésie et Réanimation): number IRB 00010254.

Provenance and peer review Not commissioned; externally peer reviewed.

To cite Martinez T, Simon K, Lely L, *et al*. *BMJ Mil Health* 2023;**169**:443–447.

Received 27 April 2021
Accepted 7 June 2021
Published Online First 9 July 2021

BMJ Mil Health 2023;**169**:443–447.
doi:10.1136/bmjmilitary-2021-001876

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