Critical COVID-19 patient evacuation on an amphibious assault ship: feasibility and safety. A case series

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ABSTRACT

Introduction An amphibious assault ship was deployed on 22 March in Corsica to carry out medical evacuation of 12 critical patients infected with COVID-19. The ship has on-board hospital capacity and is the first time that an amphibious assault ship is engaged in this particular condition. The aim is to evaluate the feasibility and safety of prolonged medical evacuation of critical patients with COVID-19.

Methods We included 12 patients with confirmed COVID-19 infection: six ventilated patients with acute respiratory distress syndrome and six non-ventilated patients with hypoxaemia. Transfer on an amphibious assault ship lasted 20 hours. We collected patients' medical records: age, comorbidities, COVID-19 history and diagnosis, ventilation supply and ventilator settings, and blood gas results. We calculated oxygen consumption (OC).

Results All patients had a medical history. The median delay from onset of symptoms to hospitalisation was 8 (7–10) days. The median Sequential Organ Failure Assessment score on admission was 3 (2–5). There was no significant increase in oxygen during ship transport and no major respiratory complication. There was no significant increase in arterial oxygen pressure to fractional inspired oxygen ratio among ventilated patients during ship transport. Among ventilated patients, the median calculated OC was 255 L (222–281) by hours and 5270 L (4908–5616) during all ship transport. Among non-ventilated patients, the median calculated OC was 120 L (120–480) by hours and 2400 L (2400–9600) during all ship transport.

Conclusion The present work contributes to assessing the feasibility and safety condition of critical COVID-19 evacuation on an amphibious assault ship during an extended transport. The ship needs to prepare a plan and a specialised intensive team and conduct patient screening for prolonged interhospital transfers.

Key messages

- Critical COVID-19 evacuation on an amphibious assault ship is feasible and safe.
- The ship needs to prepare a plan and a specialised intensive team and conduct patient screening for prolonged interhospital transfers.

INTRODUCTION

The COVID-19 outbreak started in Wuhan, Hubei Province, China in December 2019 and has now extended across the globe with >400 000 cases and 17 000 deaths as of 22 March 2020. The WHO has declared COVID-19 a pandemic.[1] The Wuhan experience and most recently the Italian experience prove that the health system can be quickly overwhelmed, especially intensive care units (ICUs).[2 3] Healthcare had to redesign its logistical and departmental structure to respond to influx of patients with COVID-19 with acute hypoxaemic distress. In the current COVID-19 pandemic, like any natural disasters or other kinds of mass casualties, local healthcare capacity can become overwhelmed, necessitating a request for external assistance at the national level.[4]

On 22 March 2020, there were more than 16 000 cases in France, of which more than 2000 patients require intensive care support.[5] Intensive care capacities were about 5000 beds,[6] and a significant health system reorganisation was needed to increase these capacities. Unfortunately, an uneven regional distribution exists between these capacities and the number of cases. The local health agency (ARS), as a regional medical coordinator, ensures the availability of intensive care beds to guarantee citizens' health and coordinates interhospital transfers. Corsica is one example with a weak intensive care bed to residents ratio of 5:100 000,[6] and its capacity is already overwhelmed. Corsica is an island 165 km from the French continental coast, complicating interhospital transfers of several critical patients.

The French government decided to deploy medical military abilities to manage this situation. An amphibious assault ship was deployed on 22 March in Corsica to carry out medical evacuation of 12 critical patients infected with COVID-19 and transfer them to Marseille Hospital's critical care units. It is one of the three French '*Marine Nationale*' amphibious assault ships, and is a command ship with projection capacities (helicopters, troops and vehicles) and an on-board hospital capacity used to care for the war-wounded. It is the first time that an amphibious assault ship is engaged in this particular condition.

The aim is to evaluate the feasibility and safety of prolonged medical evacuation of critical patients with COVID-19.

MATERIALS AND METHODS

This is a retrospective case series of 12 critical patients with COVID-19 who had medical evacuation on a military amphibious assault ship.

The requirement for informed consent was waived because the study was observational and the family members were in quarantine.

The amphibious assault ship: medical organisation

This medical ability is organised for war-wounded care and minor medical or surgical emergency. Usually, there are no permanent ICU beds. The on-board hospital has to be improved and redesigned as an ICU. Hospitalisation capacity has to be reduced to 14 critical care beds. An isolated area, divided into three spaces, was designated for contagious patients with COVID-19, with one airlock entrance for dressing personal protective equipment (PPE) and one airlock exit for undressing. The first space could admit four to five ventilated patients, another space for two to three ventilated patients, and the last for six non-ventilated patients with hypoxaemia. Patients with hypoxaemia, who needed ventilation support, could be transferred to the first or second space. Specialised material equipment was upgraded with 2–14 transport ventilators (eight Monnal T60, two Elisée 250 and four Elisée 350), 5–14 patient monitors (Propaq) and two blood gas transport analysers (i-STAT). Inhaled nitric oxide (iNO) was available, but we did not need to use it. Extracorporeal life support was the only ultra-specialised care that we could not perform. The usual medical team (one general physician and two nurses) was reinforced by a civil-military intensivist team (five anaesthetist-intensivist physicians, one intensivist, two residents, one emergency physician, one bacteriologist physician, four anaesthetist nurses, six intensivist nurses, one radiological manipulator and one laboratory assistant). All civilian and military medical teams were intensivist teams that were trained at the hospital in managing patients with COVID-19. The clinician to patient ratio was 1:4. There was a shift rotation every four hours. PPE consisted of goggle protection, long-sleeved water-resistant gowns and gloves, filtering facepiece FFP2, apron, and head and shoe cover. The available oxygen supply was limited to 250 000 L divided into 50 L in 25 oxygen bottles at 200 bar pressure (total oxygen supply=25 bottles×50 L×200 bars). Three portable oxygen concentrators (SeQual Integra 10-OM) were available.

Population

We included 12 patients with COVID-19 infection confirmed by a positive test on severe acute respiratory syndrome coronavirus 2 real-time PCR of throat swab specimen. All patients were civilians. Patients were at the Ajaccio Hospital Center: six ventilated patients with acute respiratory distress syndrome (ARDS)[7 8] and six patients with hypoxaemia, defined by oxygen saturation <90% without oxygen supplementation.[9] Exclusion criteria were haemodynamic instability with more than 2 mg/hour of norepinephrine, and arterial oxygen pressure to fractional inspired oxygen ratio of <100 or continuous haemofiltration indication. ICU has 12 places already blocked in this COVID-19 pandemic situation, so the French government, in collaboration with the Marseille Hospital public assistance and '*service de santé des armées*', organised a medical evacuation on an amphibious assault ship.

The total transfer (set-up, transport and evacuation) delay was approximately 20 hours.

Table 1 Characteristics of patients with COVID-19

Characteristics	Patients (N=12)
Age, years, median (IQR)	65 (62–67)
Sex, male, n (%)	9 (75)
Body mass index, kg/m^2, median (IQR)	28 (27–29)
Chronic medical illness, n (%)	
Hypertension	5 (42)
Diabetes	4 (33)
Coronary heart disease	1 (8)
Chronic obstructive pulmonary disease	2 (16)
Obstructive sleep apnoea syndrome	4 (33)
Immunocompromised	1 (8)
Symptoms delay, days, n (%)	8 (7–10)
Ventilation, n (%)	
Invasive	6 (50)
Non-rebreather mask	2 (16)
Nasal oxygen	4 (33)
Prone position	1 (8)
Oxygen concentrator	1 (8)
SOFA score, median (IQR)	3 (2–5)

SOFA, Sequential Organ Failure Assessment.

Data collected

We collected patients' medical records: age, comorbidities, COVID-19 history and diagnosis, ventilation supply and ventilator settings, and blood gas results. Reported data were arterial carbon dioxide ($PaCO_2$), arterial oxygen pressure (PaO_2), fractional inspired oxygen concentration (FiO_2), PaO_2 to FiO_2 ratio, arterial potential hydrogen (pH), tidal volume, RR, measured minute ventilation (VE), plateau pressure, positive end-expiratory pressure, driving pressure and static respiratory system compliance.

We calculated oxygen consumption (OC) considering the measured VE or oxygen flow (non-ventilated patient) and FiO_2 used (OC by hour=oxygen flow or VE L/min×60 min×FiO_2). The total OC was calculated by adding up the OC of each patient. We collected the actual OC on the ship (total oxygen supply less total OC measured from the oxygen bottles).

We calculated the Sequential Organ Failure Assessment (SOFA) score on admission.

Statistical analysis

Data that were not normally distributed are expressed as median and IQR (25th–75th percentile). Nominal variables are reported as number and proportion (%).

RESULTS

Patients' characteristics

Patients' characteristics are presented in Table 1. Twelve patients (nine male (75%); median age 65 (62–67)) were included: six ventilated patients with ARDS and six patients with hypoxaemia. The median delay from onset of symptoms to hospitalisation in ICU was 8 (7–10) days. All patients had a medical history: obesity (body mass index (BMI) >30 kg/m^2), n=2 (16%); overweight (BMI 25–30 kg/m^2), n=6 (50%); hypertension, n=5 (42%); diabetes, n=4 (33%); coronary heart disease, n=1 (8%); chronic obstructive pulmonary disease, n=2 (16%); obstructive sleep apnoea syndrome, n=4 (33%); and immunocompromised, n=1 (8%). The median SOFA score on admission was 3 (2–5). Among non-ventilated patients (n=6), two had a non-rebreather mask with oxygen flow between 10 and 15 L/min, and four had

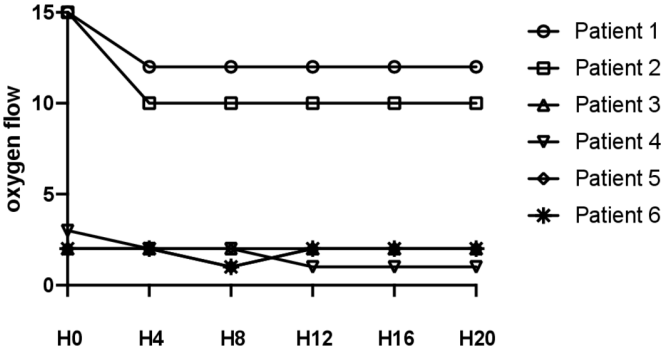

Figure 1 Non-ventilated oxygen flow between admission and arrival.

nasal oxygen with oxygen flow between 1 and 3 L/min. There was no significant increase in oxygen during ship transport (Figure 1). One ventilated patient required prone positioning to improve oxygenation during ship transport.

Oxygen consumption

The calculated OCs are presented in Table 2. Among ventilated patients, the median calculated OC was 255 L (222–281) by hours and 5270 L (4908–5616) during all ship transport. Among non-ventilated patients, the median calculated OC was 120 L (120–480) by hours and 2400 L (2400–9600) during all ship transport. One non-ventilated patient had 10 L oxygen mask supplied by an oxygen concentrator, which resulted in a calculated oxygen economy of 12 000 L. The total calculated OC during transport was 70 260 L. The total measured OC was 50 000 L.

Oxygenation, ventilator variables and medical events

Among non-ventilated patients (n=6) (Table 3), only blood gases collected from Ajaccio Hospital were available. The median PaO_2 was 73 mm Hg (66–79) and the median $PaCO_2$ was 35 mm Hg (35–37). The median pH was 7.44 (7.42–7.45).

Blood gas results and ventilator settings for ventilated patients are presented in Table 4. There was no major respiratory complication, except for one endotracheal tube obstruction requiring gentle suction.

The PaO_2 to FiO_2 ratio evolution between admission and arrival is presented in Figure 2. One patient presented transient atrial fibrillation requiring amiodarone. Two patients needed an increase in norepinephrine requirements. Antibiotic therapy was started in one patient for septic shock with major metabolic acidosis.

DISCUSSION

This retrospective analysis of 12 critical patients with COVID-19 describes the feasibility and safety of a prolonged medical evacuation. It is, to our knowledge, the first published medical experience in this exceptional condition.

There are two significant differences in the management of these patients compared with military patients. One, military patients are young and healthy and never present severe lung infections. Respiratory distress is related to thoracic trauma following war injuries, and as a result requires more trauma management than medical treatment. The second difference is operational safety. Evacuation of military patients is carried out in war-affected countries, unlike this mission which has occurred on national territory.

As mentioned in several studies,[4 10 11] we report the same characteristics and comorbidities of patients with COVID-19: age more than 60 years old, weight problems, hypertension, diabetes, chronic obstructive pulmonary disease and obstructive sleep apnoea syndrome.[10] Also, we noted the same median delay from onset of symptoms of about one week before the hypoxaemic clinical presentation.[10] We decided to transfer six non-ventilated patients with hypoxaemia because they had clinical and radiological predictive factors for severe respiratory failure.[11–13] Among ventilated patients, two patients presented mild ARDS and four patients presented moderate ARDS.[14]

The main challenge was to quickly improve the on-board hospital used to take care of trauma patients and those with

Table 2 Oxygen consumption of ventilated and non-ventilated patients

	Ventilated patients (n=6)	Non-ventilated patients (n=6)
Oxygen consumption calculated, L, median (IQR)		
By hours	255 (222–281)	120 (120–480)
During transport (20 hours)	5270 (4908–5616)	2400 (2400–9600)
Total	70 260	

Table 3 Blood gas results of non-ventilated patients

Non-ventilated patients (n=6)	At Ajaccio Hospital
Saturation (%)	94 (94–95)
Oxygen flow (L/min)	2 (2–8)
pH (mm Hg)	7.44 (7.42–7.45)
PaO_2 (mm Hg)	73 (66–79)
$PaCO_2$ (mm Hg)	35 (35–37)

$PaCO_2$, arterial carbon dioxide; PaO_2, arterial oxygen pressure; pH, arterial potential hydrogen.

Table 4 Ventilator settings and blood gas results of ventilated patients

Ventilated patients (n=6)	Ship admission	During transport	On arrival
Saturation, (%), median (IQR)	97 (95–97)	96 (95–98)	96 (94–98)
Ventilator settings, median (IQR)			
VT (mL/kg PBW)	6.3 (5.7–7.1)	6.4 (5.8–6.6)	6.4 (6.2–6.6)
PEEP (cmH_2O)	12 (11–12)	11 (10–12)	11 (10–12)
RR (beat/min)	24 (23–24)	25 (22–26)	23 (21–26)
FiO_2 (%)	58 (51–60)	40 (36–40)	38 (35–40)
Pplat (cmH_2O)	23 (20–23)	22 (20–23)	23 (20–24)
Driving pressure (cmH_2O)	11 (9–12)	9 (9–14)	10 (9–14)
Cst (mL/cmH_2O)	42 (32–53)	46 (34–53)	47 (34–53)
VE (L/min)	9.5 (9.4–11.6)	10.1 (9.5–11.3)	9.8 (9.5–11.7)
PaO_2 to FiO_2 ratio, median (IQR)	139 (116–180)	199 (166–216)	187 (152–211)
$PaCO_2$ (mm Hg), median (IQR)	39 (37–40)	42 (38–43)	42 (41–43)
pH, median (IQR)	7.36 (7.32–7.43)	7.38 (7.27–7.44)	7.36 (7.32–7.43)

Cst, static respiratory system compliance; FiO_2, fractional inspired oxygen; $PaCO_2$, arterial carbon dioxide; PaO_2, arterial oxygen pressure; PEEP, positive end-expiratory pressure; pH, arterial potential hydrogen; Pplat, plateau pressure; VE, minute ventilation; VT, tidal volume.

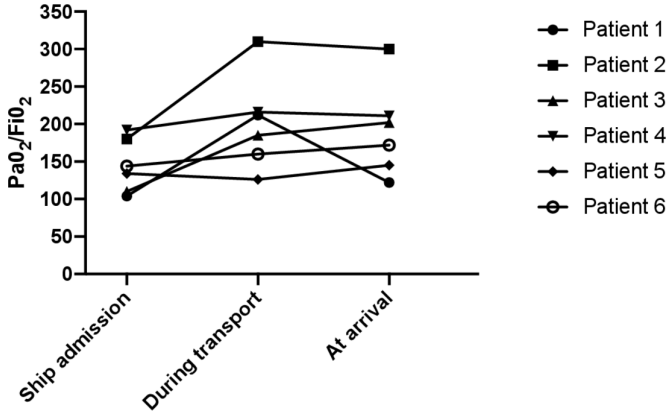

Figure 2 Ventilated patients' PaO_2 to FiO_2 ratio between admission and arrival. FiO_2, fractional inspired oxygen; PaO_2, arterial oxygen pressure.

minor medical or surgical emergency before aeromedical evacuation. We had to redesign areas and management from the beginning to care about many critical respiratory patients with biohazard constraints. This is why the capacity of the hospital had to be reduced from 69 to 14 beds. We also had to create a specialised intensivist civil-military team that could carry out prolonged interhospital critical patient transfer.[15] Compared with usual deployment, we had to improve our ICU bed capacity, particularly in terms of specialised equipment: 2–14 transport ventilators, 5–14 patient monitors, one to two blood gas transport analysers and two iNO bottles.

Patients with ARDS require specific ventilatory management. Following a protective ventilation concept, bundle of care is recommended that includes placing the patient in prone position, providing iNO and monitoring the patient's blood gas.[16] Moreover, transportation of critically ill patients, especially patients with ARDS, can be a challenging task.[17 18] A prolonged transfer could be a risk with severely impaired gas exchange.[18] In our study, risks were anticipated and the medical evacuation was prepared. At first, a specialised intensivist civil-military team was deployed which used to manage patients with COVID-19 ARDS. Military intensive patricians are used to taking care of patients with ARDS in isolated conditions without all hospital capacities.[19] Our data confirmed the medical recommendation application in these unusual conditions. We could respect protective ventilation to ventilated patients and perform a prone position to a patient presenting refractory hypoxaemia.

We have anticipated the risk and we were in constant communication with Corsican patricians to evaluate the risk of patient transport and confirm the feasibility of patient evacuation. Blood gas results confirmed the safety of this evacuation. The PaO_2 to FiO_2 ratio was constant and even improved during ship transport. Only the patient who needed to be in prone position and who we had to return and prepare for Marseille Hospital transportation had decreased PaO_2 to FiO_2 ratio on arrival.

Regarding oxygen supply, it was the primary delay constraint. Oxygen storage was limited to 250 000 L divided into 50 L in 25 oxygen bottles. This capacity was never tested to take care of as many patients with hypoxaemia. When preparing for the mission, we had to calculate the expected OC to secure the interhospital transfer. Thanks to our collected respiratory data, we calculated the total OC that confirmed our forecast and will improve other prolonged medical transfers. We have observed that non-ventilated patients with high oxygen flow consumed the most oxygen. We measured the total effective OC and it was under the total calculated OC. We explain that by concentrator oxygen using and saving oxygen storage. Oxygen concentrators provided to non-ventilated patients were equipped with high oxygen flow. From our military experience, the Elisée 350 turbine transport ventilator with a portable oxygen concentrator can be used as an alternative in an austere environment.[20] In this study, according to our oxygen storage, a four-day transfer delay could be feasible in a safe condition.

This study has several limitations. First, it is a retrospective observational report of 12 patients, with only 6 ventilated patients. Second, outcome data could be interesting to evaluate the impact of prolonged interhospital transfers. Third, further studies are still needed to confirm our results. However, this was an exceptional military deployment and publishing a more robust investigation will be complicated.

CONCLUSION

In conclusion, the present work contributes to assessing the feasibility and safety of critical COVID-19 evacuation on an amphibious assault ship during an extended transport. The ship needs to prepare a plan and a specialised intensive team and conduct patient screening for prolonged interhospital transfers of patients with COVID-19 with acute respiratory failure.

The healthcare system with government management must be able to national adaptation and reorganisation using all available means, both civilian and military.

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Competing interests None declared.

Patient consent for publication Not required.

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