Original Research

Severe Acute Respiratory Syndrome Coronavirus 2 Pandemic: Chilean Air Force Experience in the Air Transport of Critically Ill Patients—The First 100 Cases

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A B S T R A C T

Objective: Critical care air transport has played an important role during the coronavirus disease 2019 (COVID-19) pandemic. The goal of this article is to analyze results and lessons learned from the evacuation of the first 100 COVID-19 patients transported between medical facilities in Chile.
Methods: We reviewed prospective data of patients who were referred for air transport between March 27, 2020, and July 9, 2020.
Results: Of 115 referred patients, 100 were transported by air. All patients were intubated and mechanically ventilated. Hypertension, diabetes, and obesity were the most commonly observed comorbidities. Our service did not experience any major problems in patient care en route or among the crewmembers. We did not observe any severe acute respiratory syndrome coronavirus 2 infections among our flight team members during the study period. Twelve (12%) patients died at their destination intensive care unit, whereas the remaining 88 patients (88%) returned to their primary hospitals after recovery.
Conclusions: Air transport of mechanically ventilated patients with COVID-19 infection has been shown to be a safe way of transport, with no in-flight deaths and an in-hospital mortality of 12%, which compares favorably with the in-hospital mortality of similar patients who did not undergo air transport.

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On March 18, 2020, Chile declared a national catastrophe because of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic. At that time, there was a total of 191,122 infected people worldwide, 265 of whom were reported in Chile.[1] One of the strategies defined by the Chilean government to fight the pandemic was to maintain the availability of critical care beds across the whole territory of Chile. The distance between the northernmost and southernmost cities is 5,040 km, making the evacuation of some patients extremely complex in those places that did not have enough bed capacity. To remedy this problem, the Chilean government tasked the Chilean Air Force to undertake the evacuation of patients from places with low numbers or 0 intensive care unit (ICU) beds to areas with ICU bed availability. One of the main concerns regarding the performance of this plan was the unknown physiological, physical, and psychological effects that air medical evacuation might have on the outcome of these patients. Even without the complexities of the highly transmissible disease and the need for patient isolation, it is already well established that the transport of critically ill or injured patients being mechanically ventilated can lead to a higher risk of complications.[2-5] In this article, we report our results and conclusions from the air transport of ventilated coronavirus disease 2019 (COVID-19) patients.

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Methods

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. This article has the ethical approval from an appropriate institutional review board (internal protocol code 272107) of the Chilean Air Force Hospital.

A prospective register of patients with severe respiratory failure due to COVID-19 undergoing air transport was performed. Of these patients, the first 100 evacuated patients were studied. The transports undergoing study were performed from March 27, 2020, through July 9, 2020. All the air evacuations were supervised by Chilean Air Force critical care transport teams. The aircraft used in the evacuation were the Lockheed C-130 Hercules (fixed wing tactical transport) and the MH-60 Black Hawk (medevac helicopter). Control and prevention measures against the SARS-CoV-2 contagion were performed according to a standard established by the Chilean Air Force and the Ministry of Health.[6] Compartments and crew/patient distributions in the C-130 aircraft and the MH-60 helicopter are shown in Figures 1 and 2. Patients were chosen for air evacuation[2,7-9] based on the Chilean Air Force Task Force definition provided in Table 1.

The Air Force critical care team is composed of 2 medical doctors (1 of them with the specialty of intensive care or anesthesiology), 1 registered nurse (flight nurse), and 2 nurse assistants. This team is responsible for the care of 2 patients.

The null hypothesis of this study was that the final outcome of patients undergoing air transport was not different from those who did not undergo air transport. Individual patient isolation chambers were used for each evacuation. The model of the isolation chamber was the IsoArk N 36-6, B93096 (Beth-El Industries, Zikhron Yaaqov, Israel). The main characteristics of the patient isolation chamber

device were 1) quick setup, 2) complete side and top opening for easy patient access, 3) robust and lightweight structure, 4) fully collapsible unit, 5) integrated glove portals, 6) integrated utility portals, 7) double high-efficiency particulate air filter, 8) autonomy of 10 hours, and (9) a total weight of 30 kg. The chamber meets the North Atlantic Treaty Organization standard. The isolation chamber in use is shown in Figure 3.

Before boarding and immediately after landing, the following hemodynamic data, ventilator parameters, temperature, and sedation information were recorded:

1. Hemodynamics: mean, systolic, and diastolic blood pressure; heart rate and rhythm; and vasoactive medication strength and dosage details
2. Ventilation: ventilator mode, respiratory rate, inspired fraction of oxygen, positive end-expiratory pressure (PEEP), tidal volume, and saturation (Spo_2)
3. Sedation: sedation agitation scale, type and doses of sedative drugs, and neuromuscular blocking agents

Statistics were determined with median and interquartile range for continuous variables and number and percentages for categoric variables. The 30-day mortality was established as the main parameter to be evaluated, and data were obtained from the Chilean National Public Register Office.

Results

A total of 115 patients were presented to the Chilean Air Force critical care air transport team for transport to areas with availability of ICU beds. Of those, 9 patients did not meet the criteria for evacuation during the first assessment performed by the air medical
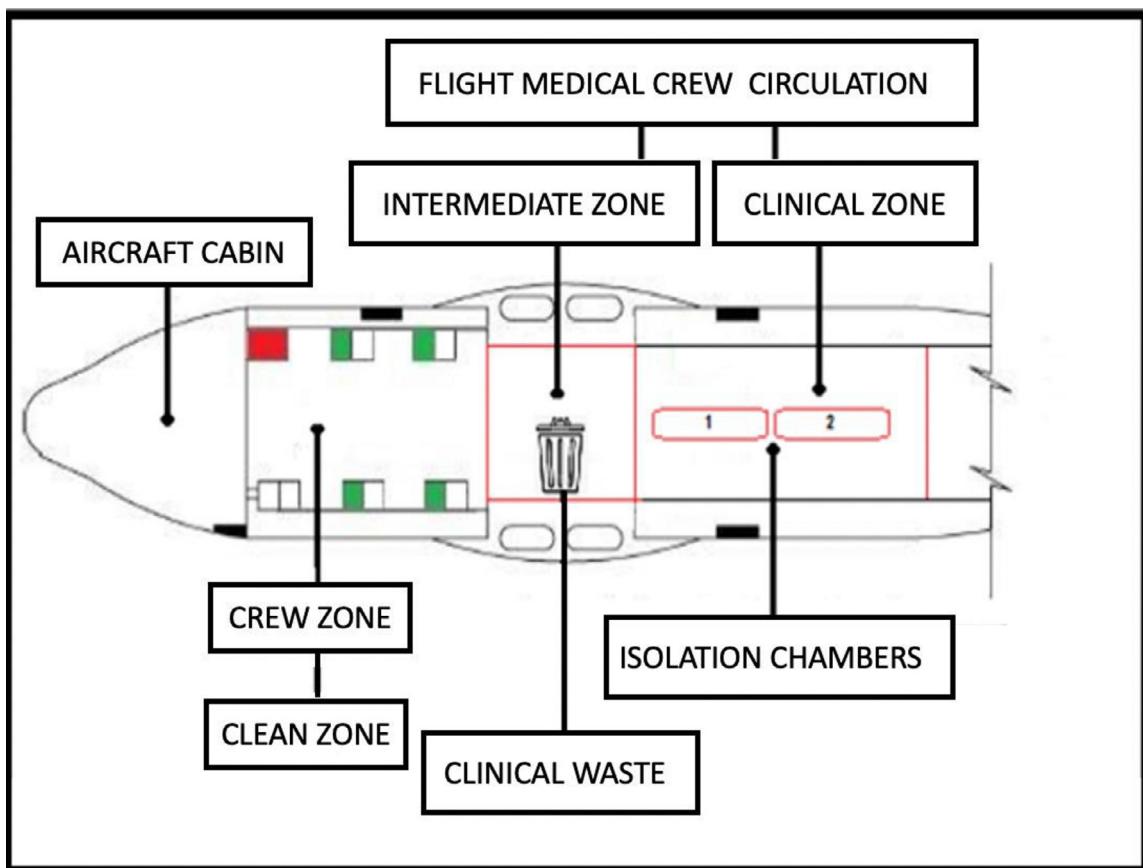

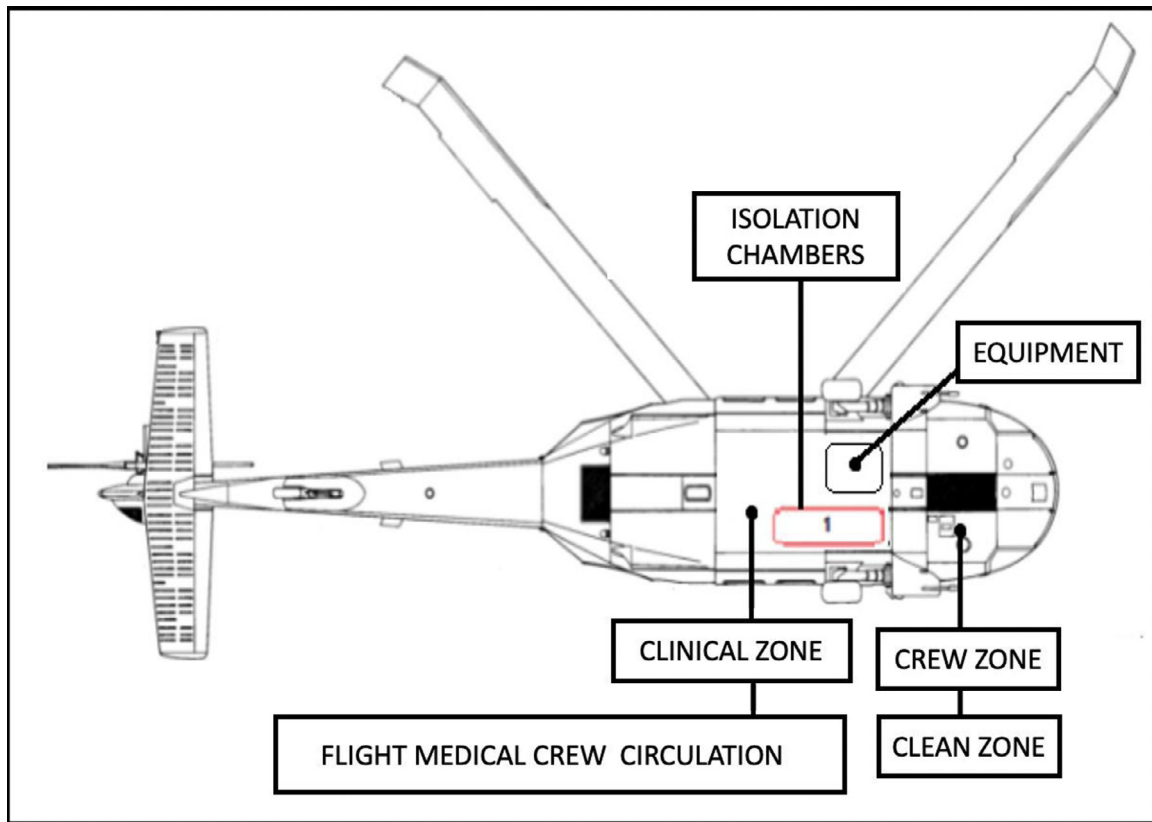**Figure 1.** Zone distribution in Lockheed Hercules C-130.

Figure 2. Zone distribution in Black Hawk UH-60 helicopter.

evaluation team at their respective hospitals, and a further 6 patients were rejected just before boarding at the aircraft parking areas. Half of the patients were rejected for clinical reasons, including hemodynamic instability (2 patients) and unexpected critical respiratory failure (1 patient). The other 3 patients were unable to be transported because of problems in the negative pressure isolation chamber.

Of the patients proposed for evacuation, 32 (28%) were women, and 83 (72%) were men, with ages ranging between 26 and 83 years (average = 67 years). Before undertaking the evacuation, 74 patients (64.3%) were in already in an ICU, 36 (31.4%) were in an emergency department bed, and 5 (4.3%) were in an operating room that was being used to manage ventilated patients. All patients were receiving mechanical ventilation at the time of referral.

Table 1
Patient Critical Care Air Transport Absolute and Relative Rejection Criteria (Chilean Air Force Task Force Definition)

Absolute Criteria	Relative Criteria
Hemodynamic Instability	Noradrenaline < 0.3 μg/kg/min
$Pao_2/Fio_2 < 100$	$Pao_2/Fio_2 < 130$
Undrained pneumothorax	Pneumothorax with pleural drainage
Pneumomediastinum	Tracheostomy
HGB/PLT< 7/50,000	High-risk PTE
Unresolved pneumoencephalon	Traumatic brain injury between day 3 and 6
Digestive tract surgery < 1 week	Severe digestive bloating
Thrombolysis < 2 weeks	IAP > 15 APP < 60 mm Hg
Massive PET	AIM < 5 days
Unstable spinal cord trauma	Need for 3 sedatives for SAS1
Unresolved dialysis urgency	
Abdominal compartment syndrome	

AIM = acute myocardial infraction; Fio_2 = fraction of inspired oxygen; HGB = Heamoglobin; PET = Pulmonary Thromboembolism; PLT = Platelets; PTE = Pulmonary Thromboembolism; SAS1 = sedation agitation scale.

Among all the transported patients, the most common comorbidities were hypertension in 75 (65.3%), diabetes mellitus in 53 (46.9%), obesity in 11 (10.1%), asthma in 7 (6.1%), and cancer in 7 (6.1%). At the time of the evacuation, the number of elapsed days of invasive mechanical ventilation before the flight ranged from 1 to 34 days (average = 8.6 days). The levels of Pao_2/fraction of inspired oxygen (Fio_2) recorded in the hospital at the time of evaluation for the flight ranged between 115 and 317 mm Hg (15.3 and 42.3 kPa) (average = 209 mm Hg [27.9 kPa]). The fraction of inspired oxygen recorded on the aircraft parking area before takeoff and at the time of landing are shown in Table 2.

The ventilator setting for all patients was the assist-control volume mode, with an average PEEP before departing of 10.4 cm H_2O and an average PEEP on arrival of 10.5 cm H_2O. Fio_2 before departing was an average 50% and an average Fio_2 on arrival of 50% Fio_2.

Before boarding, a final assessment was performed. Among the 106 patients who arrived at the aircraft parking area, 100 were accepted for evacuation, whereas 6 patients were not transported (see earlier) and were subsequently returned to their original treating facility.

At the time of the medevac flight, all patients were given ceftriaxone plus azithromycin therapy. Furthermore, 18 patients were receiving antiviral medication (oseltamivir), 38 had ongoing corticosteroid treatment, 36 received therapeutic anticoagulation, and 54 were given prophylactic anticoagulation.

The Sedation-Agitation Scale[10] was used to evaluate the level of sedation. All patients boarded the plane and arrived with Sedation-Agitation Scale levels between I and II. The drugs used for sedation and neuromuscular blocking are shown in Table 3. The mean blood pressure, heart rate, temperature, and Spo_2 data before boarding and during the flight are shown in Table 4.

There were no deaths, no significant medical incidents, and no critical events during any of the medevac flights. Postflight follow-up

Figure 3. Isolation Chamber.

data revealed the 7-, 15-, and 30-day mortality as shown in Table 5. Table 6 shows the clinical characteristics of the patients who died until 30 days after the transport.

The operational flight time to the different destinations, including the Easter Island, is listed in Table 7. Easter Island is a territory of Chile in the southeastern Pacific Ocean 2,182 miles (3,512 km) away from the continent of South America.

With regard to the safety of the flight crew, no SARS-CoV-2 infections were reported during the study period.

Discussion

The Chilean Air Force, as part of the crisis response to the COVID-19 pandemic, provided air transport for patients all over the Chilean territory. The distance between the 2 extreme cities is over 5,000 km (2,600 nautical miles), and Santiago (the capital city) is midway between the 2. The indication for evacuation was the lack of critical care beds in Santiago and not the necessity for better management. During the first wave of the pandemic, because of the geography of

Chile, different areas of the country had significantly different incidence figures. This allowed the transport of patients from places with high incidence to cities where there were vacant critical care beds. This transport model was also developed by private air ambulance carriers who mainly used aircraft with the capacity for only 1 patient.

The Chilean Air Force did not have the task of returning the patients after their full recovery to their primary hospitals. The previously described process was in charge of the Ministry of Health.

In the analysis of the study population, although it may be considered that a selection bias existed, the selection of patients using standard and specific criteria before flight was important. A member of the air evacuation team had the role of visiting and evaluating patients at their referring hospitals. This important step enabled the team to identify those patients who were considered "not fit" for air medical transport. The decision, which was based on specialist air medical knowledge, supported the evaluation performed by the referring critical care physicians who often lack the information and

Table 2
Patients' Fraction of Inspired Oxygen (F_{IO_2}) During the Takeoff and Landing

F_{IO_2} (%)	Takeoff	Landing
< 0.3	0	1
0.3-0.4	35	38
0.41-0.5	34	28
0.51-0.6	20	20
0.61-0.7	8	6
0.71-0.8	2	2
> 0.8	1	5

Table 3
Sedation, Analgesia, and Neuromuscular Block Doses During the Flight

Drug	Median	Interquartile Range
Midazolam (mg/kg/h)	0.3	0.2-0.5
Fentanyl (μg/kg/h)	4	3.5-5.0
Rocuronium (mg/kg/h)	0.6	0.5-0.7

Table 4
Mean Blood Pressure, Heart Rate, Temperature, and Oxygen Saturation (Sp_{O_2}) Before Boarding and During the Flight

Vital SignsMedian and IQR	Before boarding	During the flight
Mean blood pressure	90 (83-96)	90 (80-98)
Heart rate	82 (69-101)	79.5 (67-99)
Temperature	36.6 (36 -37.3)	36.3 (36-37.2)
Sp_{O_2}	97 (95-98)	97 (95-99)

IQR = interquartile range.

Table 5
Mortality After Completion of Air Medical Evacuation

Mortality	Number	Cause of Death
0-7 days	1	Respiratory failure/COVID pneumonia
7-15 days	2	Respiratory failure/COVID pneumonia
15-30 days	4	Respiratory failure/COVID pneumonia
> 30 days	5	Respiratory failure/COVID pneumonia
Total deaths	12	

COVID = coronavirus disease 2019.

Table 6
Clinical Characteristics of the Patients Who Died After the Transport

Age	Sex	Operational Flight Time	PEEP	PAFI	Mean Blood Pressure	Number of Vasoactive Medications
52	Male	1-3 h	12	190	85	1
57	Male	1-3 h	7	150	68	0
58	Female	1-3 h	14	200	68	1
58	Male	0-1 h	12	139	78	1
59	Male	1-3 h	5	200	90	1
61	Female	0-1 h	8	198	70	1
62	Male	1-3 h	7	200	78	0
69	Male	1-3 h	12	150	82	1
70	Female	1-3 h	7	250	75	1
70	Male	1-3 h	12	188	103	1
75	Female	0-1 h	8	241	68	1
78	Male	1-3 h	8	200	100	1

PAFI = Pao_2/fraction of inspired oxygen; PEEP = positive end-expiratory pressure.

Table 7
Operational Flight Time

Duration	Distance	Hercules C-130	Black Hawk UH-60
Up to 1 hour	Up to 310 miles	51 patients	5 patients
1-3 hours	310-1,857 miles	41 patients	1 patient
More than 3 hours	More than 1,857 miles	2 patients	0 patients

background to be able to risk assess and accurately evaluate those patients who have a significant probability of developing instability during the flight.

A systematic review and meta-analysis of ICU outcomes in patients with COVID-19 shows that patients undergoing invasive mechanical ventilation and infusion of vasoactive drugs had an ICU mortality rate of approximately 40%. This compares favorably with the postflight mortality observed in our transported patients during their subsequent ICU admission.[11,12]

As suggested earlier, the main limitation of this analysis is the selection bias of the patients who underwent air transport. This may lead to a type II error when we fail to reject the null hypothesis. However, another limitation was the paucity of observations and/or incomplete parameters recorded in some patients during their flight. The lack of a complete record of observation was linked to intracrew variations in clinical performance that complicated the necessity to replace crewmembers in some of the missions.

One of the concerns before starting the transport was the possible adverse effects of the duration of the flights on the outcome of patients. In effect, we conclude that patients who underwent the longest evacuation flights, from or to the extreme ends of Chile, did not have a worse outcome when compared with those who had a shorter flight. This is a highly significant finding that adds to the published current knowledge about the air transport of COVID-19−infected patients.

The requirement to use an isolation chamber created a limitation in the patient selection process. A proportion of our patients had a significant degree of obesity that precluded their carriage in the chamber, thus making them unsuitable for transport. This was 1 of the main problems faced at the time of the evaluation and selection. Because of the standards of best practice published at the time,[13] and, clearly, for safety concerns, we did not attempt to transport patients who could not be properly isolated in the chamber. On the other hand, the use of the chambers and the existence of restricted areas inside the aircraft did limit the number of patients that we were able to evacuate on each flight.

There is evidence that supports the benefits of the prone position during the management of patients with respiratory failure due to COVID-19.[14-19] However, it was impossible to manage prone patients in the isolation chambers used by our team; therefore, we are unable to support these findings. In retrospect, we consider that our evacuation capability would have been enhanced by the employment of a specially designed isolation chamber with the ability to safely manage prone ventilated patients.

The only clinical events observed during flight were neuromechanical coupling problems observed mainly during the takeoff and landing stages of flight. These are triggered by the sudden movement of patients resulting in G-induced biodynamic forces on existing fragile and/or unstable hemodynamics.[20,21]

Conclusion

In conclusion, from our experience and based on the previous results, we have validated our evacuation protocol, which allows us to transport patients all over the country without affecting the patient mortality or affecting the safety of the flight medical crew. These results reassure us that it is feasible to continue with this air transport protocol during the second wave of the pandemic that we are now facing and during any future incidents requiring the urgent transport of ventilated contagious patients by air.

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