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Review Article

An Updated Review of Literature for Air Medical Evacuation High-Level Containment Transport During the Coronavirus Disease 2019 Pandemic

Jocelyn J. Herstein, PhD, MPH [1,2,*], Claire E. Figi, BS [3], Aurora B. Le, PhD, MPH, CPH [4], Elizabeth L. Beam, PhD, RN [2,5], James V. Lawler, MD, MPH [2,6], Elizabeth R. Schnaubelt, MD [2,6,7], Gary W. Carter, [8], John J. Lowe, PhD [1,2], Shawn G. Gibbs, PhD, MBA, CIH [9]

[1] Department of Environmental, Agricultural, and Occupational Health, University of Nebraska Medical Center, College of Public Health, Omaha, NE
[2] Global Center for Health Security, Omaha, NE
[3] Department of Epidemiology and Biostatistics, School of Public Health, Texas A&M University, College Station, TX
[4] Department of Environmental Health Sciences, School of Public Health, University of Michigan, Ann Arbor, MI
[5] College of Nursing, University of Nebraska Medical Center, Omaha, NE
[6] Department of Internal Medicine, University of Nebraska Medical Center College of Medicine, Omaha, NE
[7] United States Air Force School of Aerospace Medicine, Dayton, OH
[8] National Strategic Research Institute, Omaha, NE
[9] Department of Environmental and Occupational Health, School of Public Health, Texas A&M University, College Station, TX

A B S T R A C T

Objective: In 2019, our team conducted a literature review of air medical evacuation high-level containment transport (AE-HLCT) of patients infected with high-consequence pathogens. Since that publication, the coronavirus disease 2019 (COVID-19) pandemic has resulted in numerous air medical evacuations. We re-examined the new literature associated with AE-HLCTs to determine new innovations developed as a result of the pandemic.
Methods: A literature search was performed in PubMed/MEDLINE from February 2019 to October 2021. The authors screened abstracts for the inclusion criteria and reviewed full articles if the abstract was relevant to the aim.
Results: Our search criteria yielded 19 publications. Many of the early transports of patients with COVID-19 used established protocols for AE-HLCT, which were built from the most recent transports of patients with Ebola virus disease. Innovations from the identified articles are subdivided into preflight considerations, inflight operations, and postflight operations.
Conclusion: Lessons gleaned from AE-HLCTs of patients with COVID-19 in the early weeks of the pandemic, when little was known about transmission or the severity of the novel disease, have advanced the field of AE-HLCT. Teams that had never conducted such transports now have experience and processes. However, more research into AE-HLCT is needed, including research related to single-patient portable isolation units as well as containerized/multipatient transportation systems.

The treatment and handling of patients with highly hazardous communicable diseases (HHCDs) takes a great deal of coordination and attention to detail, which is amplified during an air medical evacuation (AE). The combination of these 2 tasks can drastically increase the risk of infection to health care and transport workers as well as potentially endanger the departure and receiving communities. Although there are myriad reasons in which an AE high-level containment transport (HLCT) would be required to take place (eg, a military or governmental request, the distance to a facility with high-level isolation capabilities, and challenges to ground transport), it

*Address for correspondence: Jocelyn J. Herstein, PhD, MPH, University of Nebraska Medical Center, 985110 Nebraska Medical Center, Omaha, NE 68198.
E-mail address: jocelyn.herstein@unmc.edu (J.J. Herstein).

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must always be done with the utmost attention to detail and the best available policies and procedures.

In 2019, our team published a commentary calling for guidelines and greater global cooperation surrounding the policies and procedures associated with AE-HLCT.[1] We believed then as we do now that the best way to ensure the safety of all personnel and communities involved in transporting patients with HHCDs is through open communication regarding the success and failures of these events, working toward the development of standards and consensus guidelines with safety for all (patient, workers, and community) at the forefront. Later that same year, we also published a review of the peer-reviewed literature associated with AE-HLCT,[2] which showed a dearth of research within the field and limited case study publications. The intention was to combine the publicly available information into a single source for use by the AE community to establish best practices and for scholars to expand on to push the field of AE-HLCT forward.

Since that publication, the coronavirus disease 2019 (COVID-19) pandemic has resulted in numerous AEs of patients with COVID-19, including mass evacuation of passengers of the Diamond Princess cruise ship, some of whom tested positive before transport.[3] Although COVID-19 is no longer considered an HHCD, there is no doubt that early in the pandemic, when few cases were confirmed in the United States and information was evolving quickly, it was initially treated as an HHCD, particularly around early ground transports and AEs.[4] As a result of these transports, we believed it was important to re-examine the new literature associated with AEs of patients with HHCDs to determine what new innovations may have developed as a result of the COVID-19 pandemic and the increased number of AE-HLCTs that were conducted.

Methods

A literature review[5] was performed using PubMed/MEDLINE and Google Scholar with a date range of February 2019 through October 2021. The search took place in November 2021. This date range was selected so as not to capture articles from our previous literature search[2] but to focus on the innovations that have taken place since and new best practices that have been published. The search terms used were as follows: 1) “aeromedical isolation,” 2) “aeromedical evacuation” OR “transportation of patients” OR “air ambulance” OR “HEMS” OR “Helicopter” AND “ebola” OR “lassa” OR “viral hemorrhagic” OR “highly infectious” OR “highly hazardous” OR “high-consequence infectious disease” OR “contagious” OR “communicable” OR “Middle East respiratory syndrome (MERS)” OR “SARS” OR “smallpox” OR “VHF” OR “Crimean-Congo Hemorrhagic Fever,” 3) “aeromedical evacuation” AND “transportation of patients” AND “SARS-CoV-2” OR “COVID-19” OR “2019-nCoV” OR “Wuhan virus,” and 4) “mobile” OR “transport” AND “isolation” OR “containment” AND “patient” AND “ebola” OR “lassa” OR “viral hemorrhagic” OR “highly infectious” OR “highly hazardous” OR “high-consequence infectious disease” OR “contagious” OR “communicable” OR “Middle East respiratory syndrome (MERS)” OR “SARS” OR “smallpox” OR “VHF” OR “Crimean-Congo Hemorrhagic Fever.” The authors selected articles published in 2019 or later and screened abstracts for the following criteria: peer-reviewed literature, articles written in English, and articles that described AE-HLCT of persons with COVID-19 or HHCDs (Fig. 1).

Results and Discussion

Our methodology identified 19 publications meeting the inclusion criteria (Fig. 1, Table 1). As with our previous article,[2] we broke down the synthesis into preflight, in-flight, and postflight environments. This was done to allow for an easier comparison between the 2 articles and for practitioners to use both articles in a similar fashion.

As expected, many of the early transports of patients with COVID-19 used established protocols for HHCDs, which were built from the most recent transports of patients with Ebola virus disease (EVD). Early in the pandemic when severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was a novel pathogen and the world knew very little about it, following the established AE protocols for patients with HHCD was proper; however, as the pandemic expanded and more information on SARS-CoV-2 was established (eg, its transmission route and severity of disease), protocols were naturally adjusted. In this article, we focused on new innovations implemented and described in the literature that were not previously discussed in our other work.[1,2]

Preflight

Types of Diseases and Transports

Articles published since 2019 primarily focused on COVID-19; 3 articles (all published prepandemic) exclusively focused on EVD transport,[6-8] 3 discussed AEs of both COVID-19 and other HHCD cases,[9-11] and 13 focused solely on COVID-19 transport.[12-24] This represents an increased focus on respiratory pathogens since our previous review. This is understandable because EVD and other viral hemorrhagic fevers, which are transmitted primarily via contact or droplets, had been the previous driver of AE-HLCTs; however, even in the early days of the COVID-19 pandemic before studies confirmed it to be true, there was concern that the virus was potentially airborne.[25,26]

As a novel disease, the published guidelines and recommendations on the safe AE transport of patients with suspected or confirmed COVID-19 were lacking, leading many organizations to refer to approaches and experience from AE-HLCTs (eg, EVD).[9,24] In the authors’ awareness, the first air transport of persons with known SARS-CoV-2 infection occurred on February 17, 2020, when evacuees from the cruise ship Diamond Princess were flown from Japan to the United States.[3] The reader should keep in mind that at the time experts had limited understanding of COVID-19’s mechanisms of transmission, propensity for asymptomatic transmission, infection fatality rate, and sequelae of infection. Although engineering and administrative controls and personal protective equipment (PPE) were able to mitigate the risk to flight medical team members, more limited measures were available to reduce the risk to other passengers, and the ability to provide more than basic first aid care was severely restricted.[3] As the COVID-19 pandemic expanded, the rapid surge in the need for AE transports of patients with COVID-19 resulted in programs around the world conducting AEs and attempting to implement strict infection prevention and control measures.

Although not reflected in the literature, the increased operations tempo of AE-HLCTs at the beginning of the COVID-19 pandemic likely resulted in many organizations conducting AE-HLCTs that had never done such a transport and likely did not have significant preplanning for such operations. This is further exacerbated by the complexities of moving more than 1 patient when many of the examples they had to draw from were for single AE-HLCT. Standardized and available procedures from previous AE-HLCT experience would likely have been very beneficial to those who found themselves needing to conduct an AE-HLCT for the first time; however, there was, and remains, a lack of publicly available AE-HLCT guidelines or recommendations.[1]

As noted, the COVID-19 pandemic created the challenge of moving multiple patients in a single transport; before the COVID-19 pandemic, most articles describing AE-HLCT focused on single-patient transports,[2] with a few exceptions of multipatient/containerized models for transport such as the Transport Isolation System or Containerized Biocontainment Care System.[27,28] As AE needs during the early months of the COVID-19 pandemic quickly surpassed the availability of single units, several articles described the collective

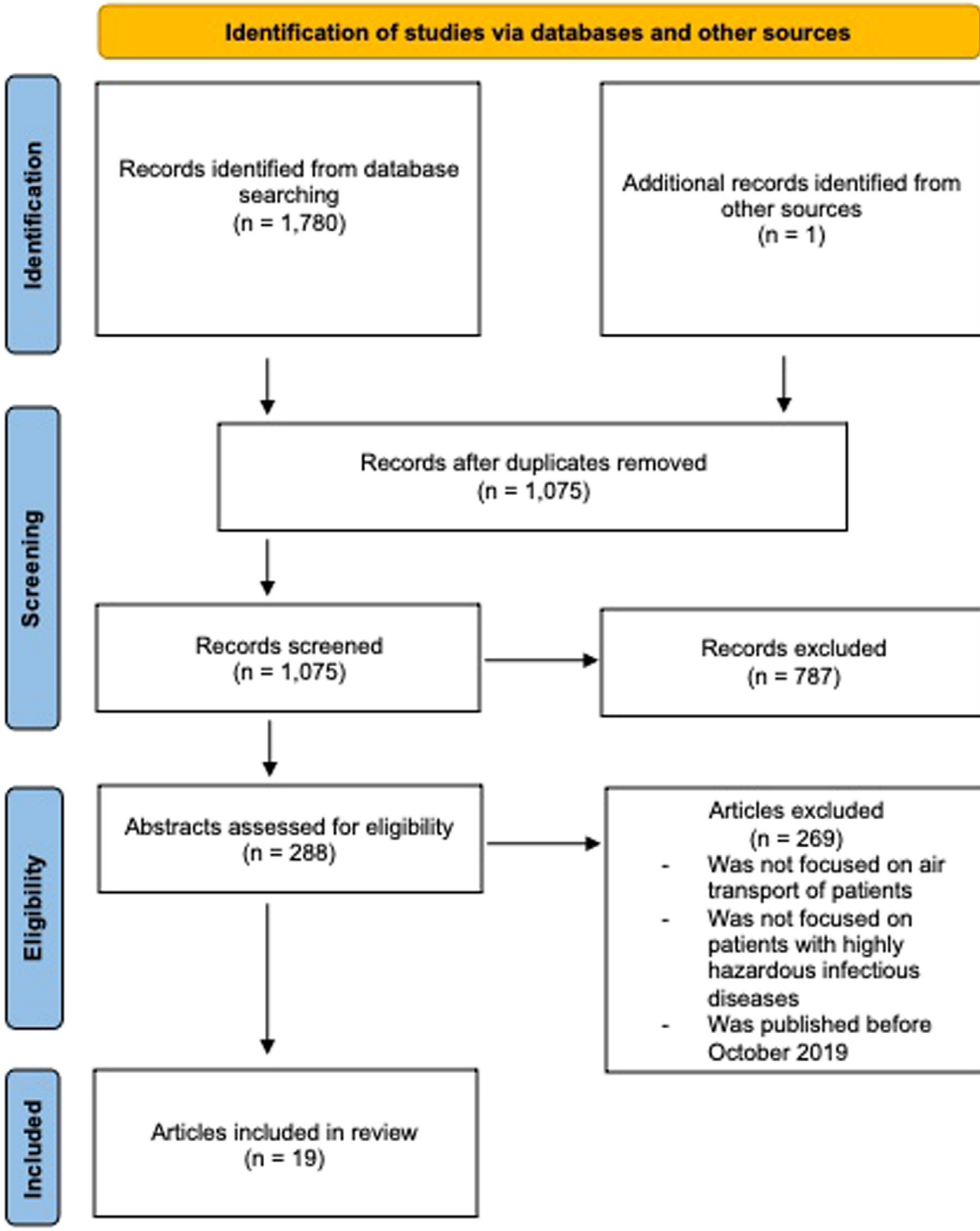

Figure 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses chart for AE-HLCT literature review.

evacuation of multiple patients, including groups with high-risk exposures[13] or AE-HLCTs of multiple critically ill patients to neighboring countries or regions to alleviate shortages (eg, ventilators, intensive care beds, or health care worker shortages) in regions with hospitals stretched beyond capacity.[19,22]

Decision-Making Process

Early in the COVID-19 pandemic, when knowledge and information on SARS-CoV-2 transmission or severity were lacking, AE programs had to make decisions on how to safely provide care while protecting their teams. This included the decision on whether to provide transportation for patients with suspected or confirmed COVID-19 at all, how to protect their crews given supply chain shortages of critical PPE components, and what infection prevention and control measures needed to be put in place for any transport regardless of a patient's COVID-19 status given the potential that any patient could have an asymptomatic infection.

Three articles published decision-making frameworks for AE of patients with COVID-19.[10,14,16] Bredmose et al[14] detailed a decision support tool for the development of guidelines for helicopter transport, whereas Hilbert-Carius et al[16] included decision trees used by several organizations to evaluate the safe transfer of a COVID-19

Table 1
A Summary of Air Medical Evacuation High-Level Containment Transport

	Preflight										In Flight							Postflight			
First Author, Year Country (Military or Civilian)	Disease Type, COVID-19	Disease Type, Other	Decision to Air Medical Transport	Training/ Drills	Regulations and Legal Limitation	Communication Plan	Rotary Wing Aircraft	Fixed Wing Aircraft	Layout/ Space Assessment	Other Preparations	Personnel	Personal Protective Equipment	Type of Isolation Units	Procedures/ Capabilities In Flight	Liquid and Solid Waste Handling	Death In Flight	Other Contingency Procedures	Decontamination	Equipment Reuse	Waste Disposal	Personnel Monitoring
Albrecht, 2020 Switzerland/Europe (civilian)	X	X		X			X	X		X	X	X	X	X		X					
Berry, 2021 United States (civilian)	X		X	X			X	X	X	X	X	X	X	X				X			
Bleeg, 2019 Denmark (military)		X	X			X		X	X	X	X	X	X								
Borges, 2020 Brazil (military)	X		X	X				X	X	X	X	X									X
Bredmose, 2020 Norway/Scotland/ Finland/Germany/Australia (civilian)	X		X	X		X	X		X	X	X	X	X	X			X	X			X
de Wit, 2021 Denmark (civilian)	X						X	X	X	X		X									
Garibaldi, 2019 United States (civilian/military)		X	X		X	X		X	X	X		X	X				X	X			
Hilbert-Carius, 2020 Europe (civilian)	X		X	X			X	X		X		X	X	X				X			
King, 2019 United States (military)		X		X				X	X		X		X								
Koch, 2021 France (military)	X		X					X	X	X	X	X	X				X	X			X
Lemay, 2020 Canada (civilian)	X					X		X	X	X		X		X			X				
Martin, 2020 United States (civilian)	X	X	X	X	X	X		X	X	X	X	X		X			X	X			
Martinez, 2021 France (military)	X		X	X				X	X	X	X	X	X	X			X				X
Meng, 2021 United States (civilian)	X			X			X		X	X		X		X							X
Peddle, 2020 Canada (civilian)	X	X		X			X	X		X	X	X									
Reynolds, 2021 United States (military)	X			X				X			X		X								

Table 1 (*Continued*)

First Author, Year Country (Military or Civilian)	Preflight										In Flight							Postflight			
	Disease Type, COVID-19	Disease Type, Other	Decision to Air Medical Transport	Training/ Drills	Regulations and Legal Limitation	Communication Plan	Rotary Wing Aircraft	Fixed Wing Aircraft	Layout/ Space Assessment	Other Preparations	Personnel	Personal Protective Equipment	Type of Isolation Units	Procedures/ Capabilities In Flight	Liquid and Solid Waste Handling	Death In Flight	Other Contingency Procedures	Decontamination	Equipment Reuse	Waste Disposal	Personnel Monitoring
Sammito, 2021 France/Germany (military)	X		X					X		X	X		X	X							
Schwabe, 2020 Germany (civilian)	X		X	X		X		X	X	X	X		X	X			X	X			
Spoelder, 2021 Netherlands (civilian)	X			X	X	X	X		X	X	X	X		X			X				X

X indicates the subject was included in the article.

mission. Martin[10] posited 5 overarching questions for programs to consider in justifying transport decisions and then prove they have the highly skilled personnel and appropriate equipment to be considered competent for such high-risk transports. The questions included suitability of the aircraft for special transport, critical care capabilities in flight, patient isolation capabilities, communication strategies, and willingness of employees to undertake such missions; if answers caused doubts or concerns, the clear decision was the program could not safely undertake COVID-19 transports.[10] These were important frameworks for these organizations to share with their peers confronting similar questions at that time, and such frameworks have an important role in the future of AE-HLCT.

Albrecht et al[9] published a table (as of April 5, 2020) with transport concepts for patients with COVID-19 in several European countries, including for helicopter emergency medical services (HEMS) and fixed wing aircraft. Because of the many unknowns, most European countries early in the pandemic preferred ground-based transportation of confirmed cases. Only air rescue providers in Germany, Netherlands, Switzerland, Norway, and Italy were intentionally operating transports of patients with COVID-19 in helicopters, and only Switzerland, Germany, and France were conducting fixed wing transports in Europe at that time.[9,22] (In the United States, the Department of Defense's Transport Isolation System was first used on April 8, 2020, for COVID-19 patient movement on a fixed wing aircraft.[21])

In a May 2020 survey to HEMS providers, 85% of HEMS organizations would transport patients with suspected or confirmed COVID-19; of the 15% that would not, 70% felt they did not have the ability to adequately protect their pilots from infection, 50% listed increased downtime because of decontamination as an issue, and 20% noted they did not have an adequate supply of PPE to safely provide care.[12] Similarly, another survey conducted from May to August 2020 of the American College of Emergency Physicians Air Medical Section found that 89% of respondents would transport patients infected with COVID-19.[20] HEMS AE-HLCT is an important component of AE-HLCT that is underexplored in the literature because much of the previous focus of AE-HLCT has been for long-distance transports from countries where a HHCD exposure or infection occurs to a higher-resource isolation unit outside of the region. However, HEMS AE-HLCT deserves greater consideration; although it may add additional complexities, the benefits bridging the gap between ground transport and fixed wing transport are clear. Air transport via HEMS is considered the preferred mode of transport for patients with time-critical conditions because of the ability to provide medical interventions en route and better posttransfer survival rates.[16] Particularly during the pandemic, HEMS AE-HLCT allowed for more localized, shorter-distance transports.

Before the pandemic, AE-HLCT was focused on patients with high-risk exposures to or confirmed infection with an HHCD and had dedicated transport groups for that level of care. The pandemic changed this paradigm; any patient, regardless of the reason for AE, had the potential to be presymptomatic or asymptomatic with COVID-19. This emphasized the need for preventative protection of all crew involved in AEs during the pandemic and the importance of having a risk-averse approach at that time.[10] Indeed, even HEMS programs in the United States that did not plan to take COVID-19–positive patients protected crew with PPE in case of an asymptomatic patient.[12] Several articles emphasized the importance of this prevention to ensure service continuity[10,12,14] because unprotected exposure to a patient with COVID-19 early in the pandemic could lead to weeks of quarantine that could impact staffing and create shortages of personnel to sustain operations. Martin[10] advocated for a risk-averse approach to standard health care guidelines when AE-specific guidelines were lacking, citing the more confined, challenging, and high-risk environments of AE environments compared with conventional hospital settings.

Rotary Wing and Fixed Wing Aircraft

Several COVID-19−related articles describe COVID-19 transports in rotary wing aircraft[9,12,14,20,24]; this is in contrast to most of the articles reviewed in the first literature review[2] in which fixed wing aircraft were more commonly used for AE-HLCTs. This difference is likely caused by the widespread community transmission of COVID-19 in Europe and North America and the need for shorter-distance transports compared with the more contained nature of previous HHCD outbreaks in those areas and the focus of AE-HLCT from the region of HHCD exposure or infection to specialized HHCD units in the United States or Europe. Rotary wing aircraft have particularly limited cabin space and air circulation, posing specific challenges with reducing transmission to crewmembers.[12,20] However, they also were readily and effectively used to redistribute cases regionally where demand for intensive care unit beds exceeded capacity.[24] Articles that described collective evacuation[13,17,19,22] and those that discussed containerized systems[7,8,15,21] focused on fixed wing aircraft. Long-distance flights for COVID-19 transports (overseas flights or between European countries) were also more likely to use fixed wing aircraft.[16]

Layout/Space Assessment

Airflow in aircraft vary by airframe.[7] In a C-130, cabin air is vented out through the cockpit (a problematic direction from an infectious disease standpoint), although there are ventilation systems and updates that can alter this.[7] Several studies tested airflow in both fixed wing and rotary wing aircrafts.[15,29] De Wit et al[15] conducted a study on stationary aircraft to determine the safest positioning of clinicians and suspected or confirmed patients with COVID-19 during the flight and the risk of exposure to aircrew in the cockpit. Physical barriers between the cockpit and cabin in both types of aircraft were found to provide a degree of protection from the nonclinical crew, but such barriers could become an issue during an emergency landing or other in-flight emergency.[15] However, in mid-2020, just 35% of the respondents from the American College of Emergency Physicians Air Medical Section reported that the airframe permitted complete separation of the cockpit from the patient care compartment.[20] Spoelder et al[24] considered a separation sheet between the cockpit and the cabin in helicopter transports but elected not to include it because it would interfere with the direction of the small constant movement of air from the cockpit to the cabin and out through the cabin air exhaust ducts. Clearly, if one decides to erect a barrier within an aircraft, it must be done with consideration of emergency evacuation routes, fire protocols, and so on to determine its appropriateness for the aircraft and the AE-HLCT.

In Flight

PPE

Most articles that used PPE for COVID-19 included filtering facepiece respirators (eg, N95 or FFP2/3), goggles or face shields, gloves, and a protective gown.[9,11,12,16,20] In rotary wing aircraft, most programs required pilots to wear an N95 respirator[12,20]; however, some US HEMS organizations that did not plan to transport patients with COVID-19 early in the pandemic referred to difficulties in protecting pilots and issues with pilots wearing an N95 respirator (eg, possibly causing goggles to fog and a reduction in the ability to communicate) as the primary reasons for that decision.[12] The significant strains in the PPE supply chain at the time were discussed in several reviewed articles.[11,12,16] Peddle and Smith[11] recognized the need to ensure an adequate supply of PPE (0-120 days) and created a PPE utilization flow chart for all medical and crewmembers and each transport phase (eg, patient arrival, assessment, transport, destination arrival, and decontamination) for both fixed wing and rotary wing aircraft.

Type of Isolation Units

Twelve articles discussed various types of systems, including single-patient isolation units (PIUs) and larger containerized/multipatient systems that provide a portable isolation facility large enough for both the patient (or multiple patients) and medical staff wearing PPE (eg, the Transport Isolation System and the Containerized Biocontainment Care System).[6-9,12,14,16,17,19,21-23] Our previous literature review described many of these sytems.[2]

Containerized/multipatient systems were primarily discussed in articles prepandemic, apart from the Transport Isolation System, which can be used on either the C-17 or C-130 aircraft.[8,21] The first operational flight performed using the Transport Isolation System, rapidly developed for EVD by the US Air Force in 2014, was conducted in April 2020 to medically evacuate 3 government contractors that tested positive with COVID-19 from Afghanistan to Ramstein Air Base in Germany.[21] Between April and July 2020, the Transport Isolation System was used 18 times for AEs of patients with COVID-19. Bleeg[6] described another containerized system developed and conceived by Denmark for EVD transport. The system is used on a C-130 aircraft and has separate modules for patient care and medical crew respite. Medical teams are donned in P4 insultation suits while in the module with the patient. The system, which has a tricolored concept of red, yellow, and green zones, has a capacity of 1 to 2 patients with EVD but can accommodate 12 routine patients or 3 critically ill patients.[6]

Since the publication of our last article, the EpiShuttle[30] (EpiGuard AS, Oslo, Norway), a reusable PIU, was developed; 4 of the articles discussed its use as a PIU for a COVID-19 transport.[9,14,16,23] Additionally, Switzerland's Rega also developed a similar unit, referred to as the Rega PIU.[9] Both have been tested and approved for rotary and fixed wing aircrafts,[9,23] and the use of these PIUs was reported on both types of aircraft. During a described transport, the EpiShuttle was fixed on a stretcher module for security during transport, and standard air ambulance equipment, including advanced monitoring, ventilator, suction and infusion pumps, and portable ultrasound, and an array of medications were available on board.[23]

There are costs and benefits to consider with both containerized/multipatient systems and PIUs. Albrecht et al[9] argued that containerized/multipatient systems do not offer an additional benefit for COVID-19. The use of full PPE during the transport of COVID-19 cases, particularly when AEs last several hours, can be exhausting and physically stressful for medical teams, which can lead to medical errors.[9,16,24] For long-lasting missions, PIUs offer benefit to allow medical teams to deliver care during the transport without the use of PPE and were increasingly used by teams as the COVID-19 pandemic progressed.[16] However, although medical providers do wear full PPE while caring for patients in containerized/multipatient systems, each system allows for medical crew to doff out of PPE during transport to allow for rest periods.[7,8,21] These larger systems served important roles during COVID-19 patient movement.[21]

Containerized/multipatient systems require larger airframes, which might be a limiting factor, especially in a global pandemic when there is high demand for AE transports and most transports were conducted by private air ambulance providers without access to large aircraft.[23] As such, particularly in Europe, there was a shift to PIU solutions.[9,23] (In the United States, only 4% of US HEMS respondents reported the use of an isolation pod/containment device when transporting known COVID-19 cases.[20]) PIUs can also better facilitate easier transfers between aircraft and ground ambulances and vice versa, particularly versions like the EpiShuttle, which are becoming increasingly smaller and readily fit into various transportation vehicles.[9,16] Moreover, the use of a PIU enables both air and ground teams to be protected without the need for N95 respirators and other PPE, which can be reserved during times of shortages for frontline health care teams. However, it should be noted that PIUs themselves are costly; soft-shelled models like the IsoPod are around US $5,000, whereas hard-shelled models like the EpiShuttle cost around US $40,000.[31] That price is not inclusive of consumable filters and disinfection procedures. However, they are reusable. Given the high costs of PIUs and the limited number of larger containment systems designed for multipatient AE-HLCT, further research and efforts are needed to find solutions for HHCD transport in lower-resource settings.[23]

Collective Evacuation

Collective evacuations are a unique consideration that were not reviewed in our previous article.[2] In the first few weeks of the pandemic, collective evacuation flights were conducted to return nationals to their home countries from Wuhan, China, although these flights did not include known infected patients. Later flights responding in other countries with early outbreaks of COVID-19 may have moved known cases, including the Diamond Princess evacuation. Collective evacuation flights also allowed for regional redistribution of patients, avoiding saturation of intensive care unit beds from a system perspective by transferring intensive care patients to neighboring countries or regions with greater bed capacity. The documented experiences of organizations that conducted collective evacuation of confirmed and/or suspected cases of COVID-19[13,17,19,22] add to the body of literature, which before COVID-19 was severely lacking, on considerations and challenges of multiple-patient AE-HLCTs from 4 to 6 critically ill patients at a time to potentially hundreds of exposed or positive cases on a single transport.

Articles that discussed collective evacuation described the aircraft being configured around zones to contain infectious patients to a single area and minimize exposure risks to those outside of that zone (eg, a clean/cold zone for medical crew rest, a warm zone for equipment storage and medical team preparation, and a dirty/hot zone for patients in which all crewmembers wore PPE). Martinez et al[19] noted that nonmedical aircrew required for flight were contained in the cargo bay, given PPE and just-in-time training, and supervised by the medical director or biosecurity team to ensure adherence to infection prevention and control measures.

Procedures/Capabilities In Flight

Several articles included transport experience and considerations for clinical care provided in flight.[9,12,16-20,22,24] These included transports in both HEMS and fixed wing aircraft, the use of PIUs, and collective evaluation of intensive care patients. Albrecht et al[9] described a study showing the achievability of emergency airway management inside the Rega PIU that compared airway management in a PIU with airway management under standard protective measures during an AE; although subjectively more challenging compared with standard measures, there was no difference in success rates.[9] As of early April 2020, 46 intubated patients were transported using the Rega PIU.[9]

Several studies showed moderate- to high-risk aerosol-generating procedures were conducted during HEMS transport of known or suspected patients with COVID-19 without the use of a PIU[12,16,20]; this reinforces the importance of adherence to safe PPE behaviors and other measures. Lemay et al[18] noted that proning, an effective measure for COVID-19 patients with acute respiratory distress syndrome, is impossible in many settings and recommended patients with this condition should be transferred early before facing refractory hypoxemia.

The experiences of French and German armed forces providing intensive care to patients with COVID-19 during collective evacuations in fixed wing aircraft indicated significant resources and interventions were needed to prepare critically ill, mechanically ventilated patients for AE and to stabilize during flight (eg, deepening anesthesia and treating circulatory instability).[19,22] As such, recommendations from these experiences include a maximum of 2 patients per AE team. During HEMS transports of 67 ventilated critical care patients with COVID-19 in the Netherlands, 13 adverse events occurred, including equipment-related events (3 times), crew resource management events (5 times), and unplanned disconnection of tubes (5 times).[24] None of the events resulted in long-term harm to the patients.

Other Contingency Procedures

Cabin decompression at altitude was again cited as a concern, similar to the previous review.[2] Lemay et al[18] noted that if cabin decompression occurs, passengers have to put on oxygen masks, which would involve the medical team removing their respiratory protection; to prevent this situation, EVAQ (Quebec Aeromedical Evacuation Services) opted to fly at a lower altitude, which increased flight durations. Previous concerns with soft-shelled PIUs included leaking internal air during rapid decompression. The Swiss Rega PIU included a built-in air bag that allows for additional air volume expansion to combat potential leakage.[9] The hard-shelled EpiShuttle has been tested for rapid decompression and flotation in case of an emergency landing in water.[23] Contingency preparations and procedures for HHCDs are always important but never more critical than when providing HHCD care in the air. Contingency procedures should be well incorporated as injects into exercises during training. Future articles should discuss and explore procedures for aircraft-related emergency situations, such as fire or a water landing. For example, in a water landing, if personnel are in PPE that includes a suit or boot covers, then it would be important to remove these before entering the water to avoid the very real possibility of drowning.

Postflight

Decontamination

Few articles discussed decontamination after AE of patients with HHCDs or COVID-19. Garibaldi et al[7] described disinfection of the aircraft, with a focus on Lufthansa Technik studies, similar to what was described in our previous literature review.[2] Berry et al[12] described decontamination methods of HEMS transports in the United States in early 2020. The most common method of decontamination was manual surface wiping (95% of surveyed services) followed by germicidal spray (67%).[12] Rarer and less labor-intensive methods of decontamination, including ultraviolet germicidal irradiation, could provide for shorter average downtimes between reservicing of the aircraft; however, few services reported using or having access to ultraviolet germicidal irradiation.[12] With what we now know regarding SARS-CoV-2, a great deal of surface decontamination is likely not required because fomite transmission is not a key transmission pathway.[32,33] However, for future microorganisms that are hardier in the environment or pose a greater fomite transmission risk, these questions of decontamination need to be resolved and done so in a way as not to degrade aircraft material like seals.

No international guidelines exist for the protection of aircraft in a collective evacuation situation, and although the Centers for Disease Control and Prevention and the European Centre for Disease Prevention and Control have recommendations for EVD, they were not adaptable to an airborne disease.[17] Koch et al[17] described manual cleaning and disinfection of all surfaces in the dirty area followed by the application of an aircraft-approved disinfectant by a fogging machine; all 68 environmental samples in the clean zone that they collected during a flight were negative.[17] However, they did not describe the specifics of the disinfectant or considerations for decision making to protect the aircraft.

Albrecht et al[9] and Schwabe et al[23] both discussed the benefit of a PIU model of transport in allowing for quicker reservicing of the aircraft for additional transports, a critical consideration during times of the pandemic surge, and the ability to redistribute patients needing a higher level of care more rapidly. After transports, reusable PIUs (eg, EpiShuttle) can be closed, the outside disinfected, and then transported to another location for a more thorough cleaning and disinfection.[9,23] Schwabe et al[23] did note that after AEs with the EpiShuttle, the aircraft was disinfected with peroxide wipes and a nebulizer.

Conclusions

Although COVID-19 is not considered an HHCD and does not warrant the specialized practices inherent to high-level containment, its emergence as a novel disease with limited global knowledge led to protocols and practices used for HHCDs being applied to the transport of patients confirmed or suspected to be infected with it. Unlike previous HHCD outbreaks or epidemics, a single organization did not have the capacity to transport all suspected or confirmed cases of the disease, and there appears to have been far more AE-HLCTs than with any other previously confirmed or suspect HHCD. As such, agencies and organizations responsible for transporting patients with the novel disease—most of which had not previously conducted a HHCD transport—had to rapidly implement plans to safely transport patients and protect AE staff. Although those processes were updated and adapted as more information was learned about COVID-19, the early days of the pandemic led to significant innovations and lessons learned in AE-HLCT.

As an emerging infectious disease, there was a lack of published guidelines on safely transporting patients with COVID-19; as such, many organizations adapted their EVD-related protocols for COVID-19 transports. However, as available guidelines and recommendations on AE-HLCT were, and continue to be, lacking and as the need for COVID-19 transports quickly surpassed the capacity of experienced and designated HHCD organizations, a higher operational tempo for AE-HLCT meant that many groups with likely limited operational planning or exercising for AE-HLCT conducted COVID-19 AEs with minimal existing guidance or available practices to adapt.

Moreover, AE-HLCT before the COVID-19 pandemic was heavily focused on single-patient transports; however, COVID-19 has led to experiences of evacuation of multiple patients to a level that can conceivably be required with an emerging infectious disease event. Although these experiences have generated lessons learned and advanced our knowledge of and practices for multiple patient transports, increased attention and greater exercising, research, and considerations for operationalization of multiple patient transports are warranted. This includes both transports of multiple critically ill patients and transports of tens to hundreds of exposed, suspected, or confirmed patients on, for example, repatriation flights as well as many simultaneous patient transports being conducted and coordinated by different agencies.

The COVID-19 pandemic led to several innovations, including decision support frameworks[10,14,16] and advancements in portable isolation units. The EpiShuttle and Rega PIUs, both developed before the COVID-19 pandemic, were used by diverse groups in Europe, Canada, and Saudi Arabia.[9,14,16,23] Their use during COVID-19 provided data on decontamination methods, reusability and the turnaround time required, and the ability to provide patient care, all of which help to better understand the benefits and drawbacks of hard-sided PIUs for AE-HCLTs. However, questions on hard-sided PIUs still remain, including the impact on skin integrity and the potential development of pressure ulcers in patients if used for extended durations. More research and exercising of these devices are needed to understand their role in AE-HCLTs and to continue to advance these units. In addition, HEMS AE-HLCTs were used much more frequently than described in the literature in our first review. Although limitations with HEMS AE-HLCTs exist, their use was effective during regional redistribution of patients with COVID-19 for time-critical transports and highlighted their use as a critical conduit in AE-HLCTs between ground and fixed wing aircraft.

Despite the literature on AE-HCLTs essentially doubling since our previous literature review in 2019, gaps still exist that remain to be addressed. Optimal decontamination methods for use on aircraft require further investigation, particularly for circumstances when a quick turnaround of the aircraft is needed. Ultraviolet irradiation, a rarer method of disinfection for aircraft that was reported to be used by some HEMS organizations during the COVID-19 pandemic and led to shorter than average downtime,[12] should be explored for its effectiveness and feasibility for AE-HLCT. In addition, little advancement for emergency procedures was published in the literature, and future articles should discuss and provide guidance on procedures for emergency situations during AE-HLCT. Moreover, there appears to be a lack of information sharing and coordination between organizations conducting AE-HLCTs, which was further amplified during the COVID-19 pandemic; however, this could be a result of the peer-reviewed nature of our study. Finally, the pandemic has brought a number of new considerations for AE-HLCT in thinking about challenges of transport of an airborne HHCD; greater collaboration, research, and guidelines are needed for airborne-specific as well as disease-agnostic practices for AE-HLCT.

This review is not without limitations. First, only articles that were available or translated into English were included in this review, thereby potentially limiting representation from other global regions. Second, this was not a systematic literature review but rather an update to a previous literature review; as with the last review,[2] the review was limited to published literature and therefore does not include procedures and policies that air transport teams might have published in lay articles. As such, although the search was comprehensive, it was not exhaustive. Lastly, some AE-HLCT lessons learned and experiences from the first years of COVID-19 are likely still to be published or were published following this review's time frame (eg, an article published in 2022 detailing US Air Force transports using the Transport Isolation System as well as the Negatively Pressurized Conex, which completely replaced the Transport Isolation System[34]). Despite these limitations, this review provides a notable contribution to the literature by providing an update on AE-HLCT that otherwise would have not been synthesized.

In conclusion, the lessons gleaned from the early days of the COVID-19 pandemic have undoubtedly advanced the field of AE-HLCT, and many groups that had previously only exercised their AE-HLCT procedures and plans have now put those processes into practice. Learnings from the COVID-19 pandemic could have enduring changes to the AE-HLCT field, and we may be better prepared for the HHCD event. However, challenges and gaps remain to be addressed in the field, particularly in preparation for emerging respiratory pathogens.

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