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Contents lists available at ScienceDirect

Air Medical Journal

journal homepage: <http://www.airmedicaljournal.com/>

ISSN 1049-3867
 Air Medical Journal
 Volume 38, Number 6, December 2019
 Pages 359-400

Review Article

Review of Literature for Air Medical Evacuation High-Level Containment Transport



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A B S T R A C T

Introduction: Aeromedical evacuation (AE) is a challenging process, further complicated when a patient has a highly hazardous communicable disease (HHCD). We conducted a review of the literature to evaluate the processes and procedures utilized for safe AE high-level containment transport (AE-HLCT) of patients with HHCDs.
Methods: A literature search was performed in PubMed/MEDLINE (from 1966 through January 2019). Authors screened abstracts for inclusion criteria and full articles were reviewed if the abstract was deemed to contain information related to the aim.

Results: Our search criteria yielded 14 publications and were separated based upon publication dates, with the natural break point being the beginning of the 2013-2016 Ebola virus disease epidemic. Best practices and recommendations from identified articles are subdivided into pre-flight preparations, inflight operations, and post-flight procedures.

Conclusions: Limited peer-reviewed literature exists on AE-HLCT, including important aspects related to healthcare worker fatigue, alertness, shift scheduling, and clinical care performance. This hinders the sharing of best practices to inform evacuations and equip teams for future outbreaks. Despite the successful use of different aircraft and technologies, the unique nature of the mission opens the opportunity for greater coordination and development of consensus standards for AE-HLCT operations.

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Acknowledgment: The opinions and assertions contained herein are the private views of the authors and not to be construed as official or reflecting the views of the U.S. Air Force or Department of Defense. We would like to acknowledge the U.S. Air Force Air Mobility Command Transport Isolation System research Initiative, contract number TO-0064-P2; the National Institute of Environmental Health Sciences Worker Training Program Ebola Biosafety and Infectious Disease Response Training UH4 Information, grant number UH4 ES027055-01; and the Assistant Secretary of Preparedness and Response National Ebola Training and

Education Program, contract EP-U3R-15- 003t. While these funded programs did not contribute to the development and distribution of this literature review analysis, the programs did highlight the need.

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Air medical evacuation (AE) is a challenging process, further complicated when a patient has a highly hazardous communicable disease (HHCD). The ease of air travel, tourism, and expansion of international commerce exposes all regions of the world to these diseases.¹ The preference is to treat patients with HHCDs on-site, rather than transport from the outbreak area²; however, high-level containment transport (HLCT) evacuations may be preferred when 1) there is an incapacity of the local infrastructure to provide care, 2) there is a potential detrimental effect to local health care workers (HCWs) (ie, the patient is a colleague),³ 3) the outbreak is in an active war or conflict zone, 4) it is a policy decision (to increase volunteerism), or 5) there are local or national political concerns. Regardless, successful AE HLCTs of patients with HHCDs requires a discussion on risks, benefits, planning, training, and resources.

The 2013 to 2016 Ebola virus disease (EVD) epidemic prompted multiple AE HLCTs; at least 10 nations conducted AE HLCTs for at least 33 patients with EVD within the country and internationally.⁴⁻⁷ The AE-HLCTs were conducted by single-patient isolation transports. Since that epidemic, multiple groups have developed AE HLCT systems enabling simultaneous isolation and care of multiple patients; these include the US Department of State Containerized Bio-Containment System and the US Department of Defense (DoD) Transport Isolation System.

The US Centers for Disease Control and Prevention issued AE guidance for EVD in 2015.⁸ Although portions of the guidance were broadly applicable, it was EVD specific, lacked discussion of logistical challenges, and did not include experiences from recently conducted AE HLCTs.² No AE HLCTs during the epidemic had secondary transmissions although they were conducted differently by each organization. Some evacuation procedures were preestablished and drilled, whereas others were based on situational needs.

AE HLCT has increased since it was introduced in the 1970s, but no literature review comparing approaches has been published. A 2000 literature review⁹ queried the intersection of key words “biological warfare” and “aeromedical evacuation” or “transportation of patients” and yielded a single citation; today, that same search yields 4 results.¹⁰⁻¹³ This study’s purpose is to provide a more comprehensive evaluation of the processes and procedures used for safe AE HLCTs of patients with HHCDs in preflight, in-flight, and postflight environments.

Methods

A literature search was performed in PubMed/MEDLINE (from 1966 through January 2019) with the following terms: 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 “contagious” OR “communicable” OR “Middle East respiratory syndrome (MERS)” OR “SARS” OR “smallpox”, and 3) “mobile” OR “transport” AND “high-level isolation” OR “high containment”. Authors screened abstracts for the following inclusion criteria: peer-reviewed literature, written in English, and described AE HLCT of persons with an HHCD. Diseases considered highly hazardous were identified based on the following definition by the European Network for Highly Infectious Diseases: “an infection that is easily transmissible from person to person; life-threatening; presents a serious hazard in the health-care setting and the community; and requires specific control measures (e.g., high-level isolation).”¹⁴ This definition is understood to include various viral hemorrhagic fevers, severe acute respiratory syndrome (SARS), and other easily transmissible emerging infectious diseases. Articles were reviewed if the abstract contained information related to the aim, with those focused exclusively on ground transport or AE of non-HHCD patients excluded.

Results and Discussion

The search terms yielded 101 publications; 14 met the inclusion criteria and were included in the study (Tables 1 and 2). The articles were separated based on publication dates, with the natural break point being the 2013 to 2016 EVD epidemic. Thoms et al² discussed drawing on the operational experience from Phoenix Air Corporation, a private organization that began AE HLCTs in 2007 when it developed the Aeromedical Biological Containment System. The US Department of State, United Nations, and other governments used that single-patient transport system for AE HLCTs of patients with EVD in 2013 to 2016.¹⁵ Although Phoenix Air Corporation’s AE HLCT experience is widely known, details of their procedures and policies were not published in peer-reviewed literature and were not available. Planning for and executing AE HLCTs must account for multiple variables; our review is organized around “preflight, in-flight, and postflight” environments.

Preflight

Types of Diseases

A broad spectrum of diseases was covered in the reviewed articles, including airborne diseases,¹⁶ biological warfare agents,^{9,10,17} and viral hemorrhagic fevers. Articles published before 2014 targeted many diseases (Table 1), whereas articles published after 2014 (Table 2) focused almost exclusively on EVD. Pre-2014 articles included considerations for airborne isolation, whereas post-2014 articles stressed contact isolation associated with EVD.

Decision-making Process

The reviewed articles understated the considerable collaborations involved in AE HLCT decision making because most only vaguely mentioned frequent discussions and multiagency requests must occur before transport.¹⁷⁻¹⁹ Nicol et al¹⁹ did indicate that the decision to evacuate patients is a “complex process that considers the clinical, public health, and political contexts.” Although no article identified a decision-making rubric for deploying AE HLCT assets, several discussed factors involved in the decision-making process (eg, recommendations by domestic and international agencies). Lotz and Raffin²⁰ indicated their transport met recommendations set by the World Health Organization for medical evacuation of patients with high infectious risk (36–48 hours). Thoms et al² noted that “. . . U.S. military policy is to treat highly infectious patients ‘in place’, and avoid unnecessary evacuation to the U.S.” but acknowledged instances in which transport would occur, such as index cases or for political considerations. Given the current emphasis on military participation in nation-building efforts, it is unlikely that adequate resources for “treatment in place” will be present during future outbreaks. As such, the military may become increasingly reliant on AE HLCTs.

Patient stability and survivability were noted as principal factors in the decision to conduct an AE HLCT; a patient moved before the onset of severe disease manifestations is preferable and, at times, a requirement for transport because of limited isolation units.^{5,6,17,19-21} AE HLCT places additional stressors associated with altitude on the patient that impact their physical condition (eg, hypoxia and claustrophobia).^{2,6,19,21,22} Articles identified a lack of local facilities with resources and capabilities as a reason for domestic or international evacuation.^{2,6,22} Volunteers supporting humanitarian endeavors overseas are often assured that they will be repatriated should they become ill, as was the case during the 2013 to 2016 EVD epidemic when at least 24 EVD-infected HCWs/volunteers were evacuated to their home countries.⁷

Table 1
Summary of Air Medical Evacuation High-Level Containment Transport Literature Published Before 2014

First Author Year Country (Military or Civilian)	Preflight							In-flight						Postflight				
	Types of Diseases	Decision to Air Medical Evacuate	Training/Drills	Regulations and Legal limitation	Communication Plan	Layout/Space Assessment	Other Preparations	Personnel	Personnel 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
Christopher 1999 United States (military)	X	X	X					X	X	X	X			X				
Lamb 2006 United Kingdom (military)	X	X	X					X	X	X	X	X					X	X
Lotz 2012 France/Sweden (civilian)	X	X					X	X	X			X		X			X	
Marklund 2002 United States (military)	X							X			X							
Schilling 2009 Germany/Sweden/Italy/Europe (civilian and military)	X		X	X			X	X	X	X				X				
Tsai 2004 Taiwan (civilian)	X							X	X	X				X	X			X
Wilson 1987 United States (military)	X								X	X								
Withers 2000 United States (military)	X			X			X	X	X					X				
Withers 2003 United States (military)	X			X			X	X	X					X				

X indicates the subject was included in the article.

Training/Drills

No reviewed articles detailed the types, duration, requirements, or frequency of training. Biselli et al²² noted training includes personal protective equipment (PPE), patient management on ground and in-flight, and equipment decontamination, whereas Christopher and Eitzen,¹⁷ referring to training at United States Army Medical Research Institute of Infectious Diseases (USAMRIID), stated that “team members practice these skills on each other during . . . training exercise.” On-ground training at USAMRIID, when it had AE HLCT capability, occurred twice monthly, whereas flight training aboard a C-130 aircraft took place quarterly (L. Marklund, Written communication, December 2017). Clayton,²³ using a Canadian system similar to USAMRIID’s, further advocated medical crew knowledge on patient management and care techniques, hypobaric medicine, and equipment familiarization. Schilling et al²¹ discussed the importance of PPE training and detailed the timing of Italy’s Aeromedical Isolation Team trainings, indicating military portions of their team are trained every 15 days. Likewise, Nicol et al¹⁹ noted that the UK’s Royal Air Force Deployable Air Isolator Team convenes

monthly for retraining on PPE and the patient isolator used for transports. A study by Lamb,²⁴ which detailed a 2006 Royal Air Force mission, remarked on the benefit of in-flight, just-in-time training that occurred on the flight to the patient, while also stating that the mission resulted in routine air transport isolator exercises. As with many fields, it is difficult to determine applicable training and exercise needs for AE HLCT. Organizations work internally (considering equipment, mission, and personnel) to determine the appropriate training and delivery to maintain competency.

Regulations and Legal Limitations

The regulations and legal limitations associated with the AE HLCT were not fully explored in any reviewed article. Two articles mentioned the need to adhere to organizational policies,^{2,6} 1 noted a requirement to obtain consent from governments for transports⁵ and one stated AE HLCT teams routinely seek diplomatic clearance when flying over other nations,¹⁹ but none discussed applicable federal or international regulations. Withers and Christopher^{9,10} discussed the

Table 2
Summary of Air Medical Evacuation High-Level Containment Transport Published After 2014

First Author Year Country (Military or Civilian)	Preflight						In-flight						Postflight					
	Types of Diseases	Decision to Air Medical Evacuate	Training/Drills	Regulations and Legal Limitation	Communication Plan	Layout/Space Assessment	Other Preparations	Personnel	Personnel 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
Biselli 2015 Italy (military)	X	X	X			X	X	X	X	X								
Dindart 2017 Guinea (civilian)	X	X				X	X	X	X	X				X			X	
Ewington 2016 United Kingdom (military)	X	X	X		X	X	X		X	X	X		X	X	X	X		
Nicol 2019 United Kingdom (military)	X	X	X	X		X	X	X	X	X	X	X		X	X	X		
Thoms 2015 United States (military)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X

X indicates the subject was included in the article.

need for regulations to address the unpredictable reaction of the international community in a HHCD event but primarily focused on the Biological Weapons and Toxin Convention protocol. Schilling et al²¹ discussed the need for flight certification to ensure materials are deemed safe to fly. Withers⁹ and Adams et al¹¹ detailed preference for long-range capable aircrafts to limit refueling stops. All US military aircraft used in AE HLCT missions are capable of midair refueling and are able to eliminate stops for fuel and/or extend flights to avoid the airspace of hostile or reluctant nations.

Communication Plan

Four studies mentioned the importance of effective communication and coordination among partners, but none discussed details of communication plans.^{5,6,17,20} Seven articles did identify organizations that would be contacted to initiate a transport, albeit at a high level.^{5,10,16,17,19,20,22} Thoms et al² detailed crew predeparture briefings. The article by Christopher and Eitzen¹⁷ was the only one to detail communication plans with the patient in-flight, namely, 2-way radios between team members and patients.

Layout/Space Assessment

Ewington et al⁶ and Thoms et al² detailed the space layout within the C17 aircraft that both evacuations used, including placement and securing of the isolation unit. Thoms et al² detailed “aircraft containment zones” for patient areas within the aircraft where HCWs and crew could move within the aircraft and procedures and level of PPE that HCWs and crew would need for each zone. Nicol et al¹⁹ also demarcated clean and dirty zones for confirmed patients and established a corridor for access to toilets and eating spaces for exposed, asymptomatic cases. Zone designation lends the ability to transport multiple patients at different stages of disease progression for the same disease or, more likely, to transport both suspected and

confirmed patients. In the 1974 air medical transportation of a Lassa fever patient from Nigeria to Germany, the following zones were established: a containment zone where the patient was located, a crew zone where PPE was not worn, and a neutral zone between the 2 that was also available for plane-related emergency procedures.²⁵

Withers and Christopher^{9,10} stated that military “flight nurses know that cabin airflow is ‘top to bottom, front to back’ on the C-9A Nightingale; therefore, contagious patients are placed as far aft and as low as possible.” Withers and Christopher^{9,10} also noted particular considerations (eg, high-efficiency particulate air systems, air exchanges/hour, and negative pressure zones) are made on the ventilation systems within each aircraft for potential dispersion of aerosolized microbes from a contagious patient that is either uncontained in an isolation unit or may have been unknowingly contagious.

In-flight

Personnel

The professional training level of AE HLCT personnel varied (Table 3). The articles by Thoms et al² and Nicol et al¹⁹ were the only ones that explicitly noted the care team could be augmented with additional support to ensure adequate staff levels for the full flight dependent on the number of patients transported and, in the case of Thoms et al,² for flight duration; however, no details were provided on the targeted staffing-to-patient ratio or the flight duration that would demand augmented staff.

Although a critical issue, the time personnel spent in PPE is not extensively discussed. Schilling et al²¹ noted a portable anteroom is used for PPE donning and doffing when flights exceeded 4 hours. Lamb²⁴ noted the AE HLCT team worked shifts consisting of 1 nurse and 1 paramedic, enabling the rest of the team to eat, sleep, and rest. Other articles lacked analysis and recommendations for HCW fatigue

Table 3

Summary of the Number of In-flight Personnel per Flight and Aircraft Type From Each Air Medical Evacuation High-Level Containment Transport Article

First Author, Year	Aircraft Model	Physician	Nurse	Flight Crew	Other
Published after 2014					
Biselli, 2015	Lockheed C130, Alenia C27, KC-767 ^a ~8 h	3	6	NS	NS
Dindart, 2017	Unspecified helicopter, ^b Cessna 208 Caravan 2-h helicopter, 4-h plane	1	1	2	NS
Ewington, 2016	Boeing C17 ~8-h	3	6-9	NS	5
Nicol, 2019	Lockheed C130, Boeing C17 ~8-10 h	2	NS	NS	12 total
Thomas, 2015	Boeing C17 ~8-h	2	3	NS	4
Published before 2014					
Christopher 1999	Unspecified helicopter, C-130, C-141	1	1	NS	6
Lamb 2006	NS	1	5	NS	6
Lotz 2012	Falcon 50	1	1	NS	NS
Marklund, 2002	Chinook helicopter, C-130	1	1	NS	4-6
Schilling, 2009	C-130	2	2-4	NS	2-3
Tsai, 2004	Fokker 50	2	0	NS	1
Wilson, 1987	NS	NS	NS	NS	NS
Withers, 2000	Conducts a historical overview of many different transport operations	NA	NA	NA	NA
Withers, 2003	Conducts a historical overview of many different transport operations	NA	NA	NA	NA

NA = not applicable; NS = number not stated in article; Other = included flight medical technicians, respiratory technician, personnel for decontamination, security, maintenance.

^a For all aircraft, an air transport isolator is used.^b Only used for the evacuation of the first patient; patients 2-4 were evacuated by a Cessna 208.

and shift rotation during longer transports. PPE can be cumbersome and trigger HCW physiological and psychological distress—even in environmentally controlled biocontainment facilities²⁶—and may be exacerbated at altitude. Appropriate work-rest cycles; considerations to time in PPE; and fatigue, alertness, and clinical performance monitoring are important during AE HLCT. The objective analysis of these factors is necessary to maximize performance and safety.

PPE

Every article mentioned the importance of proper PPE use, but few detailed PPE ensembles, and none described donning and doffing procedures. Ewington et al⁶ noted that decontamination procedures were overseen by a designated and trained PPE monitor but lacked details on the PPE level or type. Dindart et al⁵ stated their personnel used “full PPE” with no details provided; however, based on article images, it appears they used the World Health Organization–recommended PPE (goggles, procedure masks, fluid-resistant hood, fluid-resistant coveralls, gloves, and boots).²⁷ Thoms et al² described their use of “coveralls, multiple pairs of surgical gloves, rubber outer boots and a powered air purifying respirator (PAPR) system to prevent skin exposure”; Christopher and Eitzen¹⁷ and Withers and Christopher¹⁰ described similar configurations. Schilling et al²¹ discussed the physical stress of working in a respirator but did not specify type; however, images indicate a PPE configuration similar to Thoms et al.² Nicol et al¹⁹ repeatedly noted that once sealed, patient care during transport with the Trexlar Air Transport Isolator (T-ATI) does not require staff to wear PPE. Although Lamb²⁴ did not specify in-flight use, PPE similar to that described in the article by Dindart et al⁵ was used for personnel that helped transport the patient onto the aircraft.

Types of Isolation Units

Most articles indicated that a portable isolation unit, such as the air transport isolators used by the Italian Air Force and British military (previously used by USAMRIID), the T-ATI currently used by the British military, the Vickers Aircraft Transport Isolator (previously used by USAMRIID), or the Human Stretcher Transit Isolator-Total Containment (Oxford) Limited (HSTI-TCOL) used domestically in Guinea, were operated in-flight.^{1,5,16,19,21,22,24} The HSTI-TCOL was

described in detail with significant limitations, including the inability to restrain the patient during turbulence or place items (eg, medicine, devices) into the unit once the patient is enclosed.⁵

Although these portable units were described in varying levels of detail, each offered complete enclosure for a single patient, barrier protection for the HCWs, and high-efficiency particulate air–filtered negative pressure air.^{17,18,20} Most depended on batteries with a 6-hour life,⁵ whereas others had the ability to use the aircraft’s electrical system.^{2,6} Experiments showed that portable isolation chambers may leak or rupture when exposed to an explosive decompression²⁸; therefore, contingency procedures should be in place.

Sweden and Italy use a combined ground and air transport whereby a specially designed and equipped ambulance is driven inside of a C-130.²¹ The patient remains in the ambulance in-flight; essentially, the ambulance becomes an isolation unit. This combination reduces loading time and the likelihood of aircraft contamination. The British military uses a dedicated road transport vehicle for the T-ATI positioned at the receiving air base for seamless transport to the destination facility.¹⁹

A major limitation of transport systems was the inability to house multiple patients. Newer systems currently in validation seek to alleviate this limitation. The Transport Isolation System is a DoD containment modality designed and approved for loading onto C-17 and C-130 military aircraft; each system (aluminum frame with clear plastic liner that maintains a negative pressure isolation environment) is capable of moving multiple patients simultaneously, and 2 such systems can be accommodated on the larger C-17 platform. The Containerized Bio-Containment System is a US State Department–sponsored platform similar to a hard-sided shipping container with viewing ports and a negative-pressure isolation environment. It has the capability to transport 4 patients simultaneously with space for multiple caregivers and is designed to be loaded onto the C-17 (not yet approved by the US Air Force) or the Boeing 747 airframe.^{29,30}

Procedures/Capabilities In-flight

Care provided during AE HLCTs will not be equivalent to that available at a dedicated health care facility. However, several articles detailed the ability to provide a wide range of medical procedures

in-flight (eg, endotracheal incubation and defibrillation)^{2,6,18,19}; other articles implied in-flight procedures were limited to monitoring.³ The type of isolation unit limits capabilities in-flight; for example, the HSTI-TCOL detailed in the study by Dindart et al⁵ is a sealed pod and enables only limited interventions (eg, intravenous rehydration and antiemetics).

Waste Handling

In reviewing articles and operational experiences for EVD,³¹ we found a lack of consideration and planning for liquid and solid waste. There is a general underestimation of the volumes of both produced in-flight and an unclear understanding of the rules and regulations that govern waste during each transport phase.

Lotz and Raffin²⁰ and Ewington et al⁶ indicated waste generated by the patient in-flight were kept within the isolation unit but segregated from the patient. Upon transport completion, the isolation unit was enveloped, and all associated waste destroyed^{6,20}; however, methods for packaging, transporting, and subsequent waste destruction were not described. Thoms et al² stated a transportable lavatory would be included on the aircraft and used to capture liquid waste but did not discuss the handling and storage of solid wastes generated in-flight (eg, PPE). Nicol et al¹⁹ noted waste can be minimized in-flight by using containers with absorbent powder or solidifying agents but did not detail the process. Lamb²⁴ discussed the process of double bagging PPE used for patient receipt with the intention to dispose with waste generated in-flight but did not elaborate. Dindart et al⁵ indicated that waste generated in-flight would be collected and incinerated postflight; however, no details were provided. Withers and Christopher^{9,10} discussed criteria for a decontaminating compound (eg, effective within a short time, in low concentrations with low human toxicity, stable shelf life, and compatible with aircraft materials). This stressed the importance of the compound compatibility with aircraft materials.

Death In-flight and Other Contingency Procedures

Only Nicol et al¹⁹ mentioned the existence of a mortuary protocol if the patient were to pass away in-flight, stating only that a death in-flight is “managed with standard procedures, which vary depending on the jurisdiction of the flight.” In the case of a death in-flight, a decision would have to be made to either continue to the destination or return to the departure origin based on factors such as distance traveled, available fuel, political considerations, and other patients awaiting transport. Although such a decision would be made in communication with decision makers on the ground, preliminary discussions of this contingency would be beneficial.

Several potential in-flight emergency scenarios were discussed. Ewington et al⁶ acknowledged the potential of an isolation unit breach and noted the medical engineer would conduct repairs immediately. In discussing emergency evacuation procedures, Thoms et al² noted crew would don patients in PPE to reduce exposure and minimize contact with rescuers or nonmission personnel.

Postflight

Postflight details were limited in most reviewed articles.

Decontamination and Equipment Reuse

Dindart et al⁵ stated “the plane is decontaminated using a chlorine solution at every point of contact between the pod and the plane, which take about 15 min.” Thoms et al² indicated that a dilution of disinfectant solution Calla 1452 (Zip-Chem Products, Morgan Hill, CA) and Sani-Wipes (Disposables International, Incorporated, Orangeburg, NY) were available during the transport. It also stated that postflight “medical crewmembers and/or equipment will be decontaminated per current policy”; however, there were no policy

details.² Lotz and Raffin²⁰ indicated that “disinfection of the cabin of the aircraft and medical equipment with Nocolyse (OxyPharm; Champigny-sur-Marne, France) spray (hydrogen peroxide, catalyst, biosurfactant)” is conducted after mission conclusion. Schilling et al²¹ detailed the use of formaldehyde fumigation as the final decontamination posttransport and indicated that Sweden used a nonflammable peracetic acid for decontamination of the staff. Nicol et al¹⁹ stated the T-ATI system was fumigated with vaporized hydrogen peroxide and the frame decontaminated and returned for reuse after 7 days. Tsai et al¹⁶ detailed the use of bleach solution spray on the isolation unit and PPE before air transport of patients with SARS, and the use of water spray and desiccation on the isolation unit upon transport completion. Wilson and Driscoll¹ also reported the use of bleach for surface decontamination before boarding the aircraft.

Posttransport decontamination of aircraft differed. Efficacy is the primary intention; however, decontamination agents must also comply with aircraft material compatibility. The viability and stability of pathogens differ; therefore, decontamination methods may be adapted based on the HHCD. Lufthansa Technik, a German laboratory, found 3 disinfectant components effective against HHCDs while also aircraft compatible (alcohol, formaldehyde, and hydrogen peroxide) and detailed standard operating procedures for aircraft disinfection.³² More research and information on regulations are needed to support safe aircraft decontamination.

Waste Disposal

Waste disposal details were lacking. Two articles indicated waste was incinerated^{5,20} but did not specify how it was packaged or transported before incineration. Likewise, Nicol et al¹⁹ noted the isolator envelope is autoclaved on-site and disposed of as regulated clinical waste after decontamination but did not provide additional details. In the United States, the terminal disposal of Category A waste (of which EVD and many other HHCDs are classified) is costly and requires specific packaging and a vendor with a Department of Transportation special permit to move and process the waste. All transporting organizations should have written protocols and procedures for the terminal disposal of category A waste and, when necessary, preidentify a certified vendor if the waste is not able to be autoclaved, incinerated, or deactivated on-site to downgrade the hazardous materials classification.

Personnel Monitoring

Thoms et al² mentioned only that an infectious disease physician might screen medical personnel postflight. Tsai et al¹⁶ indicated that personnel performed twice daily temperature monitoring for 10 days after a SARS transport. Lamb²⁴ noted that personnel were monitored for only 48 hours after returning to the United Kingdom because the transported patient later tested negative for Lassa fever and positive for malaria. As with monitoring of HCWs providing care in high-level containment facilities, postmission monitoring of crew and HCWs should be included in written protocols to minimize the opportunity for further transmission.

Conclusions

There are limitations to this review. AE of trauma patients and cases of other communicable diseases that are not highly hazardous may offer important considerations for operating procedures that were not included in this review. There also exists an inherent bias in the exclusion of non-English language documents, as well as the lack of access to publicly available non-peer-reviewed resources produced by various organizations. Additionally, our review was conducted specifically searching for “highly hazardous” and “highly infectious” diseases. Other terms are also used, but these were not included in the literature because we were aware that European high-level containment facilities and the majority of federal

documents used the terms “highly infectious” or “highly hazardous communicable” diseases before and during the EVD epidemic. Moreover, this review focuses specifically on AE of patients with HHCDs; clearly, the ground transportation facet is a critical component of the safe movement of such patients and has its own challenges and risks.

Since the EVD epidemic, the US State Department and DoD have developed systems for AE HLCTs of multiple patients of varying levels of HHCD acuity during the same operation. Although AE HLCT during the EVD epidemic was managed within Phoenix Air Corporation’s capabilities, a larger global epidemic may demand scalability. AE HLCT systems advancement with increased space and ability to perform care within the unit enables more advanced patient care procedures than available in single-patient isolation. However, with the improved capability for in-flight care, discussions are needed on what medical procedures should be conducted in-flight, focusing on minimizing aerosol generation. Additionally, post-2014 reviewed articles (Table 2) reflect the increasing staffing demands for patients with EVD; the transport of multiple patients with HHCDs will only enhance the resource-intensive nature of these missions.

AE HLCT poses significant risks to crews. High HHCD mortality rates⁷ and the unstable environment inherent in AEs require policies and procedures to decrease transmission risks and maximize patient management. The designation of high-level isolation facilities in the United States and Europe narrows the list of potential receiving facilities; procedures should be well discussed and thoroughly exercised between transporting organizations and their respective receiving facilities. A future outbreak of a HHCD is likely; advancing the field of AE HLCT is critical.

There is limited peer-reviewed literature available on AE HLCT, including important aspects related to HCW fatigue, alertness, shift scheduling, and clinical care performance. Few experienced teams have published details on their processes, experience, and operations, and this limited breadth of literature hinders the sharing of best practices to inform evacuations and equip teams for future outbreaks.³³ Despite the successful use of different aircraft and technologies, the unique nature of the mission opens the opportunity for greater coordination and the development of consensus standards for AE HLCT operations.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.amj.2019.06.006.

References

- Wilson KE, Driscoll DM. Mobile high-containment isolation: a unique patient care modality. *Am J Infect Control*. 1987;15:120–124.
- Thoms WE, Wilson WT, Grimm K, et al. Long-range transportation of Ebola-exposed patients: an evidence-based protocol. *Am J Infect Dis Microbiol*. 2015;2:19–24.
- Maunder R, Hunter J, Vincent L, et al. The immediate psychological and occupational impact of the 2003 SARS outbreak in a teaching hospital. *CMAJ*. 2003;168:1245–1251.
- Coignard-Biehler H, Isakov A, Stephenson J. Pre-hospital transportation in western countries for ebola patients, comparison of guidelines. *Intensive Care Med*. 2015;41:1472–1476.
- Dindart JM, Peyrouset O, Palich R, et al. Aerial medical evacuation of health workers with suspected Ebola virus disease in Guinea Conakry-interest of a negative pressure isolation pod—a case series. *BMC Emerg Med*. 2017;17:9.
- Ewington I, Nicol E, Adam M, Cox AT, Green AD. Transferring patients with Ebola by land and air: The British military experience. *J R Army Med Corps*. 2016;162:217–221.
- Uyeki TM, Mehta AK, Davey RT, et al. Clinical management of Ebola virus disease in the United States and Europe. *N Engl J Med*. 2016;374:636–646.
- Centers for Disease Control and Prevention (CDC). Guidance on air medical transport (AMT) for patients with Ebola virus disease (EVD). Available at: <https://www.cdc.gov/vhf/ebola/healthcare-us/emergency-services/air-medical-transport.html>. Updated 2015. Accessed January 2, 2018.
- Withers MR. Aeromedical evacuation of patients with contagious infections. In: Hurd WW, Jernigan JG, eds. *Aeromedical Evacuation: Management of Acute and Stabilized Patient*. New York, NY: Springer; 2003:147–159.
- Withers MR, Christopher GW. Aeromedical evacuation of biological warfare casualties: a treatise on infectious diseases on aircraft. *Mil Med*. 2000;165(11 Suppl):1–21.
- Adams HA, Vogt PM, Binscheck T, Lange C. New scenarios in major accidents—use and adaptation of current concepts to ward off damage. *Anesthesiol Intensivmed Notfallmed Schmerzther*. 2002;37:546–553.
- Martin TE. Jubail—an aeromedical staging facility during the gulf conflict: discussion paper. *J R Soc Med*. 1992;85:32–36.
- Bioterrorism readiness plan—a template for healthcare facilities. Association for Professionals in Infection Control and Epidemiology Inc. and Centers for Disease Control and Prevention. *ED Manag*. 1999;11. Suppl 1–16.
- Bannister B, Puro V, Fusco FM, Heptonstall J, Ippolito G, EUNID Working Group. Framework for the design and operation of high-level isolation units: consensus of the European Network of Infectious Diseases. *Lancet Infect Dis*. 2009;9:45–56.
- Esler D. How Phoenix Air entered the Ebola business. Available at: <http://aviation-week.com/bca/how-phoenix-air-entered-ebola-business>. Accessed January 1, 2019.
- Tsai SH, Tsang CM, Wu HR, et al. Transporting patient with suspected SARS. *Emerg Infect Dis*. 2004;10:1325–1326.
- Christopher GW, Eitzen EM Jr. Air evacuation under high-level biosafety containment: the aeromedical isolation team. *Emerg Infect Dis*. 1999;5:241–246.
- Marklund LA. Transporting patients with lethal contagious infections. *Int J Trauma Nurs*. 2002;8:51–53.
- Nicol ED, Mephram S, Naylor J, et al. Aeromedical transfer of patients with viral hemorrhagic fever. *Emerg Infect Dis*. 2019;25:5–14.
- Lotz E, Raffin H. Aeromedical evacuation using an aircraft transit isolator of a patient with Lassa fever. *Aviat Space Environ Med*. 2012;83:527–530.
- Schilling S, Follin P, Jarhall B, et al. European concepts for the domestic transport of highly infectious patients. *Clin Microbiol Infect*. 2009;15:727–733.
- Biselli R, Lastilla M, Arganese F, Ceccarelli N, Tomao E, Manfroni P. The added value of preparedness for aeromedical evacuation of a patient with Ebola. *Eur J Intern Med*. 2015;26:449–450.
- Clayton AJ. Containment aircraft transit isolator. *Aviat Space Environ Med*. 1979;50:1067–1072.
- Lamb D. Evaluation of infection control practices during an AE. *Br J Nurs*. 2007;15:543–547.
- Renemann H. *Transportation by air of a Lassa fever patient in 1974*. AGARD Conference Proceedings No. 169. Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development; 1975.
- Hewlett AL, Varkey JB, Smith PW, Ribner BS. Ebola virus disease: preparedness and infection control lessons learned from two biocontainment units. *Curr Opin Infect Dis*. 2015;28:343–348.
- World Health Organization. *Personal protective equipment in the context of filovirus disease outbreak response*. Geneva, Switzerland: WHO; 2014.
- Albrecht R, Kunz A, Voelckel WG. Airplane transport isolators may lose leak tightness after rapid cabin decompression. *Scand J Trauma Resusc Emerg Med*. 2015;23:16–15.
- Phelps D. Ready for the challenge: Dobbins selected as home for new biocontainment system. <https://www.citamn.af.mil/Features/Article/676297/ready-for-the-challenge-dobbins-selected-as-home-for-new-biocontainment-system/>. September 28, 2016.
- Wade S. Scott airmen train on transport isolation system. Available at: <http://www.af.mil/DesktopModules/ArticleCS/Print.aspx?PortalId=1&ModuleId=850&Article=562739>. Updated 2015. Accessed January 3, 2018.
- Lowe JJ, Gibbs SG, Schwedhelm SS, Nguyen J, Smith PW. Nebraska biocontainment unit perspective on disposal of ebola medical waste. *Am J Infect Control*. 2014;42:1256–1257.
- Klaus J, Gnirs P, Holterhoff S, et al. Disinfection of aircraft: appropriate disinfectants and standard operating procedures for highly infectious diseases. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz*. 2016;59:1544–1548.
- Gibbs SG, Herstein JJ, Le AB, et al. Need for aeromedical evacuation high-level containment transport guidelines. *Emerg Infect Dis*. 2019;25:1033–1034.