ORIGINAL RESEARCH

Collective Air Medical Evacuation: The French Tool

Marc Borne, MD, Jean P. Tourtier, MD, Solange Ramsang, MD, Laurent Grasser, MD, and Bruno Pats, MD

Introduction

The cornerstone of the current concept of military medical operations is the function, fit, and form of the provision of en route care. The life-saving capability of far-forward surgery creates the need for a new and unique ability: to move stabilized, but not necessarily stable, patients. The current system of en route care serves as a primary and indispensable portion of the continuum of critical care.[1-3] Without the capability of moving patients, the ability to do far forward surgery would be meaningless.[4,5]

In France, during the mid-1990s, several means allowed the medicalization of Airbus A 310 for collective air medical evacuation (MEDEVAC). They were based on the use of health-conveying lots sized for care within an aircraft carrying 30 wounded people, including four on a respirator. The necessity of developing a new route care system first became apparent in the 2000s, as a result of the analysis of lack of capabilities during the first Gulf War, the terrorist attack in Karachi, and the combat in Cote d'Ivoire.[6,7] The evolution of resuscitation techniques, the modernization of conveying material, and the increasing severity of patients transported forced a need to update. This led the health service and the French Air Force to reflect on their capacity to transport over long distances several seriously injured people in the same aircraft. A project (named MORPHEE: MOdule de Réanimation Pour Haute Elongation d'Evacuation, or Resuscitation Module for High Elongation Evacuation) was developed to design a collective MEDEVAC system based on mission-tailored "plug and play" modules, easily and quickly installable aboard a nondedicated aircraft. The final goal was to provide the level of care of an intensive care unit, while meeting the constraints of aeronautical and aviation regulations. We shall describe and discuss the critical choices that led to the MORPHEE system: aircraft, number of injured that could be supported, and the material and human organization.

Military Hospital Val-De-Grace, Department of Anesthesia and Intensive Care, Paris, France

Address for correspondence:
Jean-Pierre Tourtier, MD, HIA Val-de-Grâce, Secrétariat De Réanimation, 74 Boulevard Port Royal, 75005 Paris, France, jeanpierre.tourtier@free.fr

1067-991X/$36.00
Copyright 2012 Air Medical Journal Associates
doi:10.1016/j.amj.2011.09.002

Methods

Choice of Aircraft

The selection criteria were the presence of such an aircraft in the French Air Force, sufficient number to be continuously available, and finally a long-range power to intervene in all theaters of operation where France is militarily involved. The aircraft should not be solely dedicated to MEDEVAC missions, but rather could occasionally be used.

Choice of the Number of Injured That Could Be Supported

An epidemiological analysis was performed. All medical evacuations conducted in the last 10 years were studied, to assess the number of patients to be transported.

Material Organization

The organization had to be modular to be installed or uninstalled quickly and easily on the plane and adapt to a specific mission. It seemed necessary to receive patients, with or without ventilatory support. In addition, the modules had to integrate the storage of drugs and equipment and allow for their preparation before treatments. Conducting laboratory tests and storage of blood products was necessary.

Human Organization

The composition of the conveying team had to be determined. In addition, specific training of medical personnel was established.

Results

Choice of Aircraft

The C135FR strategic tanker was chosen as a suitable vector. Eleven aircrafts were modified to accommodate the medical solution. These aircrafts have a cargo capacity and a high range, and they are permanently available. Their autonomy of 10 hours of flight can cover all theaters of operations in which the French military are actually involved. The creation of genuine medical calls, especially with the availability of air oxygen cylinders in Guyana and Djibouti, also increases the medical range of the aircraft.

Choosing the Number of Injured That Could Be Supported

In light of previous missions, the maximum target was the transport of 12 seriously injured patients.[8] Now, for one or

Figure 1. Intensive Care Module

Figure 2. Light Care Modules

two injuries, the Falcons currently operating perfectly fulfill the mission needs. Consequently, MORPHEE should enable the transport of 3 to 12 wounded.

Material Organization

The technical platform MORPHEE consists of two types of modules for the transportation of patients and a module of servitude. The "patient transportation" modules were made by the Austrian society Air Ambulance Technology, which specializes in the development of medical aircraft. The first type of module, Module Seriously Injured or Intensive Care Module (ICM), allows the management of a patient on a respirator (Fig. 1). The second type of module, Module Slight Injury or Light Care Module (LCM), allows the support of two lightly wounded patients (Fig. 2).

Medical Equipment of the Intensive Care Modules (ICM)

Patient safety is based on the technical platform available. The challenge was to position the module with all equipment essential to the treatment of a critically ill patient type multitrauma. Ventilator assistance is based primarily on the use of an electric respirator Pulmonetic LTV1000 (Pulmonetic Systems Inc., Colton, CA). In the event of total power failure, a pneumatic respirator, Dräger Oxylog 2000, takes over (Dräger Medical, Lübeck, Germany). The issue of oxygen is completely integrated in the module. The entire oxygen system of the module has been certified medical CE (Community European). Oxygen is delivered from cylinders of oxygen gas of the health service to aviation standards. Medical physiological parameters are collected by a multiparametric monitor including the monitoring of two invasive pressures and capnometry. Each patient has two infusion pumps and a pilot three syringe pumps for the controlled delivery of therapeutics. For the thermal comfort of patients, three forced air heaters of the type Bair Hugger (Arizant Inc., MN) are embedded. Given their power consumption, the number has been voluntarily restricted. Two electrical outlets are not used on each module and are designed to power optional equipment (for measuring intracranial pressure, for example).

The lighting has been settled to provide each patient a light intensity level of 1,000 Lux. The stretchers were the subject of special attention. Equipped with casters, they can move the wounded by rolling. Reversible, they can be fixed in the module head forward or backward as indicated. Multi-position, they offer a wide variety of installations for patient comfort. Finally, these stretchers provide a special base and an aviation harness restraint with four inking points.

Medical Equipment of the LCMs

The LCMs are designed to transport two patients with less serious injuries. However, each patient can be put on a drip and given oxygen during the flight. Each module has a device for monitoring vital signs and an infusion pump and two syringe pumps. Accessibility to lower and higher places is satisfactory. The reversibility of stretchers helps to override issues of lateralization of infusions. If the transport condition of a patient requires it, the light care modules include a stretcher removable top. The stretcher top can be adjusted to liberate space for the care of an injured patient with intermediate severity. To always respect the harmony between care activity and medical team, two versions were approved:

- Version 1: six intensive care modules for transportation of six patients on ventilatory support
- Version 2: four ICM and four LCM to carry 12 wounded patients

The Module Servitude

If each module offers many storage spaces (8 drawers), the management of 12 patients during 10 hours of flight requires the carriage of reserves (Fig. 3). In addition, specific furniture was designed. A work plan with a floor area of 1.4 m^2, with a strong light and a power supply, allows the preparation of therapeutics. Approximately 40 drawers hold equipment and infusion therapy.

Furniture is installed to be available on both sides. This includes a refrigerator for blood products and certain drugs and compartments for electrical equipment: ultrasound portable device, mini-laboratory, electrocardiogram, and

Figure 3. The module servitude

Figure 4. In-flight echography

defibrillator with an external electro-systolic drive system. In the other furniture can be placed a folding table and two mini-carts (trolleys), to have a crash cart or a cart of care at the bedside of the patient.

Moreover, because the MORPHEE material is needed infrequently but must respond urgently when activated, supplies and equipment must be in a constant state of readiness, which can be challenging. Equipment that is seldom used must be inspected regularly for normal function, battery charge, and expiration dates.

Human Organization

The medical team includes 11 to 12 persons. This is a mixed team composed of medical and paramedical staff from hospitals, medical services unit, and air conveyors. It consists of two anesthetist-resuscitators, two aviation physicians, three anesthetist nurses, two air conveyors, and two nurses of the Air Force. A 12th place is reserved for a specialist (neurosurgeon, psychiatrist, cardiologist) or a liaison officer as part of a mission for the benefit of another nation. The team is sized to ensure its ability in taking charge of approximately 6 to 12 injured people during approximately 10 hours for a mission lasting a total of 30 to 50 hours. Designed to reproduce the conditions for monitoring a patient in an intensive care unit (ICU), the composition of the conveying team was studied to ensure the continuum of care throughout the flight: efficient technical level (Fig. 4). Training consists of a 2-day introductory course at the Istres air base. It is both theoretical and practical, including sessions with trained actors, and culminates in a flight. In the months before deployment, a refresher day is organized to ensure operational readiness. The permanence of resources is essential.

Discussion

During previous conflicts, it was uncommon to move the critically ill patients before they had undergone considerable stabilization at an intratheater medical facility. During the Vietnam conflict, it was common for critically injured soldiers to stay in the theater for an average of 3 weeks before their first strategic evacuation. The contemporary battlefield has adopted a medical model of en route combat casualty care. This progression necessitates the staged treatment and early evacuation of wounded and disease-stricken service members and civilians in medicalized jumbo-jets from the battlefield to more established rearward facilities. In the current theater of operation, the average length of time spent in the theater for the critically injured soldier is less than 30 hours.[9] The capacity to quickly evacuate critically ill patients rearward to more capable and robust medical facilities alleviates the logistic burden of moving the highest medical care to the forward battle zone. The most experienced country in that capacity is the United States. American soldiers are highly exposed in Iraq and Afghanistan. Over the last decade, however, the calculated died-of-wounds rate for soldiers in both countries is the lowest in the history of modern warfare.[10] American exceptional experience, which led to the development of the Critical Care Aeromedical Teams (CCAT), appears as an ideal counterpoint to discuss the various choices we made to construct the MORPHEE system.[11]

Choice of Aircraft

The C-135 airplanes are able to operate from unimproved air fields and in hostile locations. Lighting and environmental control systems are minimal, requiring additional procedures for patient warming and visualization of patient care, and access to patients is limited to 180 degrees.

The operational missions emphasized that practicians complain about the ability to hear lung and heart sounds onboard, because of the extremely noisy environment. The average ambient noise level inside the cabin of a C-135 aircraft approaches 85 dB.[12] Hearing protection is required for all crewmembers. Normal conversation is impossible, and medical team communication is a challenge at all times. Voice amplification/noise reduction headsets that facilitate communication are in development. The noise and darkness seriously handicap physical assessment by air medical transport teams. Noises are associated with vibrations that prevent auscultation.[13-16] Recent electronic stethoscopes seem to increase the ability to access cardiac sounds.[17] The ability to monitor alarm conditions is negated by this environment. The medical team must rely on direct visual observation rather than auditory cues. The C-135 does not have intrinsic onboard oxygen systems, which mandates that oxygen be carried onboard. The electrical system provides 400 Hz AC power through specially configured outlets, limiting its direct usefulness for medical devices. Therefore, MORPHEE must rely on battery power or power provided through an electrical converter. As a summary, the C135 is an old-fashioned aircraft. The vectors of the future in France and in Europe are, respectively, the Airbus 330MRT (multi-role tanker) and the A400M. Hence, all MORPHEE modules were elaborated to be perfectly compatible with these aircrafts.

The United States Air Force CCATs use several aircrafts while providing continuous en route critical care. The C130 Hercules can be used. However, CCATs have the unique opportunity to work on C-17 Globemaster III.[2,18] It has a speed of 450 knots at an altitude of 28,000 feet with an unrefueled range of 2,400 nautical miles and unrestricted range with aerial refueling. This makes it functional for transoceanic missions. It can also use small, unimproved air fields with runways as short as 3,500 feet and 90 feet wide. The C-17 interior is well lit, and the system of litter stanchions provides 360-degree access to critical patients. The aircraft contains built-in systems that provide medical oxygen and 60 Hz AC electric power through standard US outlets. The C-17 can be quickly configured from use as a cargo aircraft to accommodate 36 litter patients. The C-17 Globemaster III is a brilliant aircraft for both tactical and strategic evacuation, and it appears as a luxury plane for collective air medical evacuation.

Choice of the Number of Injured That Could Be Supported

In light of recent missions, the maximum target was the transport of 12 seriously injured patients. Recently, however, there were only a few missions; therefore the confidence interval of the number of injuries could be considerably wider. Moreover, MORPHEE permits one to deal with multiple patients during a mass casualty event, but it is not adapted to disaster medicine. Only one exemplary of the system exists (a second is being built). It could only help to decompress the disaster area of the casualties who are the most vulnerable and who consume the greatest quantity of resources. Whatever, MORPHEE had never been used in such conditions. It contrasts with the experience of CCATs, which were used in real-life experiences dealing with disasters.[19,20]

Material Organization

The system for equipping MORPHEE represents a balance between the desires to duplicate all capabilities of a hospital-based ICU and the practical limitations of the airlift environment. The most interesting point in the MORPHEE concept are the plug-and-play capabilities, with small modules designed to interface into the main unit based on mission needs. The versatility of a solution based on mission-tailored "plug-and-play" modules easily and quickly installable aboard a nondedicated aircraft seems adapted to the French forces' needs.

In CCAT, the most fundamental item is a standardized litter made of canvas or nylon with wooden or metal poles, which mounts inside the aircraft on stanchions.[2] The CCATs use a metal bracket that clamps to the litter poles, straddling the patient, with the ventilator, monitor, infusion pump, and suction apparatus secured to its surface. The lack of integrated equipment design results in a tangle of cables and redundant weight and battery sources.

Choice of material is crucial. It must be adapted to both patient care and flight. It should resist a wide range of hypobaric and hygrometric conditions and vibrations, without electromagnetic interferences. To illustrate, mechanical ventilators can suffer in their performance from variations in environmental pressure.[21-25] Criteria exist, however, that can help the user focus on the equipment and potential problems unique to ventilation during air transport. We used a decompression chamber to mimic the hypobaric environment at a range of simulated cabin altitudes of 4,000, 6,670, and 8,000 feet, and assessed the ability of several transport ventilators, built with turbine technology, to deliver to a lung model a tidal volume set at different simulated altitudes, by changing the ambient air pressure using a decompression chamber.[26] Based on that study, the LTV-1000 was chosen. The main ventilator used by CCAT is the Impact Eagle 754 (Impact Instrumentation Inc, West Caldwell, NJ).[27] Rodriquez et al[28] compared, in a simulated hypobaric environment, the performance of the LTV-1000 and Impact Eagle. It appeared, in an SDRA lung model, that the Impact 754 compensated volume output to deliver the set Vt regardless of changes in environmental pressure, whereas the accuracy of the LTV-1000 was inferior. And in the US Air Force Aeromedical Evacuation system, high-frequency percussive ventilation is available in the management of inhalation injury and severe adult respiratory distress syndrome.[29]

Human Organization

Air medical evacuation creates an austere and unique environment that challenges even the most experienced clinician. Successful execution of this care depends on medical knowledge of the principles of resuscitation, the stressors of flight, and the potential for unexpected complications either incurred by the patient's condition or imposed by the environment. MORPHEE members should be experienced and routinely engaged in both critical care and air operations. Because this team is needed infrequently but must respond urgently when activated, this can be a challenge. To illustrate, all members of MORPHEE team working in a military hospital are involved in daily practice in urgent care, but they are not very experienced in the aircraft environment. By contrast, most Air Force physicians do not practice daily emergency care, but they have an expertise in flight. Both of these skill sets are essential to successful missions. Hence, the clinical expertise and air training of the team is actually the most critical point. Training is provided, but it consists of a few days' course. This relatively brief exposure may be insufficient to rebuild atrophied skills.

The CCAT consists of an ICU-capable physician (surgeon, emergency medicine, anesthesia, pulmonary medicine), an ICU-qualified nurse, and a respiratory therapist. CCAT physician recruitment is primarily aimed at physicians who have completed a critical care fellowship. All members go through a CCAT-specific process termed "clinical validation." Personnel selected complete the 12-day CCAT initial course. The course includes operational concepts, flight physiology, flight safety, team equipment, and intensive care knowledge. The next step in the training of a new CCAT member is to participate in a realistic exercise that develops teamwork. Then, when a person is selected for deployment, the 12-day CCAT advanced course must be attended in the 120 days before their departure. The conclusion of the course is a flying mission, with simulated patients. A CCAT team is designed to manage up to three high-acuity ventilator patients or up to six lower-acuity stabilizing patients. To date, the U.S. Air Force estimates that more than 2,500 critically injured soldiers, sailors, and Marines have been transported by the Air Force's CCAT, with an en route mortality rate of well less than 1%. More specialized teams have been developed to cope with complicated burn patients with severe inhalation injuries and complex ventilation (USAISR Burn Flight Team, ALRT).[29,30]

Conclusion

Air medical evacuation is an essential component of French Armed Forces foreign deployment. A platform meeting medical and aeronautical standards was created, based on a combination of modules specifically designed to be changeable. The organization had to be modular, to be installed or uninstalled quickly and easily on the plane, and also adapt to a specific mission. The technical platform includes patient care modules and logistical modules. The ICM allows the management of a patient on a respirator. The LCM allows the support of two lightly wounded. The medical team includes two intensivists, two air forces physicians, three anesthetist nurses, two air conveyors, and two nurses. A 12th place is reserved for a specialist (neurosurgeon, psychiatrist, cardiologist) or a liaison officer as part of a mission for the benefit of another nation. The team is sized to ensure its ability in taking charge of about 6 to 12 injured people during about 10 hours for a mission lasting a total of 30 to 50 hours. The MEDEVAC system emphasizes the versatility and efficiency of a solution based on mission-tailored "plug and play" modules, easily and quickly installable aboard a nondedicated aircraft.

References

1. Venticinque SG, Grathwohl KW. Critical care in austere environment: providing exceptional care in unusual places. Crit Care Med 2008;36:S284-92.
2. Beninati W, Meyer MT, Carter TE. The critical care air transport program. Crit Care Med 2008;36:S370-6.
3. Carlton PK, Jenkins DH. The mobile patient. Crit Care Med 2008;36:S255-7.
4. Holcomb JB, Stansbury LG, Champion HR, et al. Understanding combat casualty care statistics. J Trauma 2006;60:397- 401.
5. Johannigman JA. Maintaining the continuum of en route care. Crit Care Med 2008;36:S377-82.
6. Trunkey D. Lessons Learned. Arch Surg 1993;128:261-4.
7. Mabry EW, Munson RA, Richardson LA. The wartime need for aeromedical evacuation physicians: the U.S. Air Force experience during Operation Desert Storm. Aviat Space Environ Med 1993;64:941-6.
8. Coste S, Tourtier JP, Daudé C, Viaggi M, Morgand E, Borne M. Strategic aeromedical evacuation of the French Army: epidemiology of the last ten years. Crit Care 2010;14:P274.
9. Mason PE, Eadie JS, Holder AD. Prospective observational study of U.S. Air Force Critical Care Transport Team operations in Iraq. Ann Emerg Med 2006;48:S104.
10. Gawadne A. Casualties of war: military care for the wounded from Iraq and Afghanistan. N Engl J Med 2004;351:2471-5.
11. Johannigman JA. Critical care aeromedical teams (CCATT): then, now and what's next. J Trauma 2007;62:S35.
12. Patel SB, Callahan TF, Callahan MG, Jones JT, Graber GT, Foster KS, et al. Anadaptive noise reduction stethoscope for auscultation in high noise environments. J Acoust Soc Am 1998;103:2483-91.
13. Hunt RC, Bryan DM, Brinkley VS, Whitley TW, Benson NH. Inability to assess breath sounds during air medical transport by helicopter. JAMA 1991;265:1982-4.
14. Bishop LC. Aviation Auscultation. JAMA 1990;263:233.
15. Cottrell JJ, Kohn GM. Aviation ausculation. JAMA 1990;263:233.
16. Poulton TJ, Worthington DW, Pasic TR. Physiologic chest sounds and helicopter engine noise. Aviat Space Environ Med 1994;338-40.
17. Tourtier JP, Libert N, Clapson P, Tazarourte K, Borne M, Grasser L, et al. Auscultation in flight: comparison of conventional and electronic stethoscopes. Air Med J 2011;30:158-60.
18. Young SHH. Gallery of USAF weapons. Air Force Magazine 2007;90:146.
19. Topley D. Haiti critical care air transport team mission. Aviat Space Environ Med 1998;69:705-6.
20. Sariego J. CCATT: a military model for civilian disaster management. Disaster Manag Response 2006;4:114-7.
21. Kirby RR, Dgiovanni AJ, Bancroft RW, McIver RG. Function of the Bird respirator at high altitude. Aerospace Med 1969;40:463-9.
22. Thomas G, Brimacombe J. Function of the Dräger Oxylog ventilator at high altitude. Anaesth Intensive Care 1994;22:276-80.
23. Roeggla M, Roeggla G, Wagner A, Eder B, Laggner AN. Emergency mechanical ventilation at moderate altitude. Wilderness Environ Med 1995;6:283-7.
24. Roeggla M. Mechanical ventilation at moderate altitude. Anaesth Intensive Care 1995;23:515-6.
25. Flynn JG, Singh B. The performance of Dräger Oxylog ventilators at simulated altitude. Anaesth Intensive Care 2008;36:549-52.
26. Tourtier JP, Leclerc T, Cirodde A, Libert N, Man M, Borne M. Acute respiratory distress syndrome: performance of ventilator at simulated altitude. J Trauma 2010;69:1574-7.
27. Barnes SL, Branson R, Gallo LA, Beck G, Johannigman JA. En-route care in the air: snapshot of mechanical ventilation at 37,000 feet. J Trauma 2008;64:S129-34.
28. Rodriquez D Jr, Branson RD, Dorlac W, Dorlac G, Barnes SA, Johannigman JA. Effects of simulated altitude on ventilator performance. J Trauma 2009;66:S172-7.
29. Dorlac GR, Fang R, Pruitt VM, Marco PA, Stewart HM, Barnes SL. Air transport of patients with severe lung injury: development and utilization of the acute lung rescue team. J Trauma 2009;66:S164-71.
30. Renz EM, Cancio LC, Barillo DJ, White CE, Albrecht MC, Thompson CK, et al. Long range transport of war-related burn casualties. J Trauma 2008;64:S136-44.