Successful Trans-Atlantic Air Ambulance Transfer of a Patient Supported by a Bi-Ventricular Assist Device

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The ventricular assist device (VAD) is a hemodynamic support device that augments cardiac output for patients with severe ventricular dysfunction. With improved reliability and technological advances, the use of VADs to support patients is increasing. Many VAD-dependent patients ultimately require heart transplants that are only available in specialized centers, necessitating an interhospital transfer. To date there are few reports of long-distance fixed wing aeromedical transport of patients dependent on a VAD. Here we describe the successful transfer of a patient supported by a biventricular assist device (BiVAD) from Cambridge, UK, to Durham, NC, via fixed-wing jet aircraft. During this transfer, we observed hemodynamic alterations secondary to gravitational forces, which should be anticipated and may be mitigated with simple maneuvers. With high-level logistical planning and appropriate medical oversight, patients dependant on BiVADs can be safely transported by fixed wing aircraft over long distances.

Keywords: ventricular assist device, air ambulance, acceleration forces, hemodynamics.

THE VENTRICULAR assist device (VAD) provides hemodynamic support in patients with severe ventricular dysfunction. Although it is frequently used as a "bridge" to cardiac transplantation, more and more commonly the VAD is a form of destination therapy or even a bridge to recovery. The VAD can augment either the left or right ventricular output (LVAD, RVAD) or can be used in combination (BiVAD). Conventionally the RVAD consists of an outflow cannula in the right atrium and an inflow cannula in the pulmonary artery while the LVAD consists of an outflow cannula in the left atrium and an inflow cannula in the aorta. The diverted blood is oxygenated through an intra- or extra- (as was the case here) corporeal pump/oxygenator.

Although there are published reports outlining the logistical challenges of transporting patients supported by mechanical assist devices such as an intra-aortic balloon pump (IABP) (4,10) there are few published reports detailing an air ambulance (rotary or fixed wing) long-distance transportation of a patient supported by a VAD (5–7). Here we present a case of a successful trans-Atlantic fixed-wing transfer of a patient on a BiVAD as a bridge to cardiac transplantation.

CASE REPORT

In October 2010, a 47-yr-old man presented to a local hospital in Norfolk, UK, with signs and symptoms of an acute coronary syndrome. He was initially treated with thrombolysis (streptokinase), then underwent coronary angiography, which demonstrated 98% stenosis of the left main coronary artery. Immediate rescue percutaneous coronary intervention was unsuccessful as he developed cardiogenic shock, requiring intubation and placement of an IABP. He was transferred emergently, via ground ambulance, to Papworth Hospital, the regional cardiac center in Cambridge, UK, where he underwent implantation of a Levitronix Centrimag (Zurich, Switzerland) BiVAD (9). This life-saving device was indicated due to the grave prognosis of a patient with left main stenosis and cardiogenic shock (8).

In the intensive care unit the patient stabilized on the BiVAD. His postoperative course was complicated by an upper GI bleed, pneumonia, and a sternal wound infection, all of which were aggressively treated in the usual fashion. The patient underwent a right and left pump change of the BiVAD on November 2, 2010, at which point there was insignificant recovery of ventricular function. He subsequently received a tracheostomy and was weaned from mechanical ventilation. The patient experienced a cerebrovascular accident over the distribution of his left middle cerebral artery on November 4, 2010, which was manifested initially as right-sided hemiplegia. As an American citizen he was accepted for cardiac transplantation at Duke University Medical Center in Durham, NC. An incident management team was assembled and included: International SOS coordinating doctors (based in London and Philadelphia), a representative of the BiVAD manufacturer (Levitronix), treating medical officers, the escort team (cardiac surgeon, perfusionist, respiratory therapist), and an operations manager with the AA provider. The transfer was executed following multiple conference calls between the incident management team

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to lay out the safest plan of action. As a result of these communications we were able to determine the need to:

1. Acquire and test the Levitronix Centrimag transport pumps prior to the transfer.
2. Acquire back-up battery sources for the Levitronix pumps with a total battery life of 4 h.
3. Confirm VAD driver consoles were for 110 to 220 V supply to accommodate the UK to aircraft to U.S. power supplies.
4. Acquire back-up driver consoles, drivers, flight power surge suppressors, Universal Power Supply units, and UK and U.S. power cables.
5. Rehearse step by step the plan of action of the transfer.

The plan was then instituted:

1. The transport team at the Papworth bedside converted the hospital support pumps and consoles to the transport pumps/consoles (20-s procedure).
2. The patient was loaded in a ground ambulance with the backup batteries, where the pumps/consoles were switched to AC power via a converter (110-220 V) in the vehicle for the 20-min transfer.
3. Upon arrival on the tarmac, the patient, again on battery power, was lifted with all the equipment into the cabin of the Gulf Stream III (GIII) with the assistance of a forklift.
4. The equipment and patient were secured and connected to the aircraft's 110-V AC power units.

Vital signs were evaluated once the patient was secured in the aircraft. The support on the LVAD was 4.5l achieved with an rpm of 3300 and the flow on the RVAD was 4.35l achieved with an rpm of 3100 rpm. The RVAD consisted of an outflow cannula in the right atrium and an inflow cannula in the pulmonary artery while the LVAD consisted of an outflow cannula in the left atrium and an inflow cannula in the aorta. All cannulae exited the patient subcostally. His oxygen saturation was 96% on room air. His heart rate was 109 bpm with a mean arterial pressure of 77 mmHg.

Positioning the patient, equipment, and medical team in the aircraft was very deliberate:

1. The patient's stretcher was positioned with his head toward the cockpit.
2. The Levitronix drivers were secured to the bed just next to the patient's knees. Both driver consoles and display screen were secured at the foot of the bed facing the perfusionist.
3. The patient infusions and monitor (ECG and radial arterial line) were placed at the head of the patient facing the transport RN (to the left of the patient). Note that both pulse oximeter and inflatable cuff blood pressure monitor were not used due to the small/intermittent systemic arterial pressure waveform and blood color differential of the VAD lines.
4. The 9-h flight time was uneventful over the 3869 statute miles. The cruising altitude was 40,000–43,000 ft above sea level and the cabin altitude pressure was kept at 6000 ft above sea level.

Upon takeoff from Cambridge and Gander, Newfoundland (fuel stop), for 30 s of climb the RVAD and LVAD flow decreased to 2.8 $L \cdot min^{-1}$ (33% reduction in flow). The rapid return of output to baseline was coincident with the auto flexing of the patient's calf muscles. The event had no clinical significance, nor was it associated with any compensatory tachycardia.

Conversely during landing, the abrupt deceleration resulted in a transient increase in both VADs' outputs. The RVAD increased from 4.3 $L \cdot min^{-1}$ to 5.2 $L \cdot min^{-1}$ and the LVAD increased from 4.5 $L \cdot min^{-1}$ to 5.1 $L \cdot min^{-1}$. Both of these increases were transient and resolved within 30 s after the aircraft completed its braking procedure. As above the patient was clinically unaffected by these transient changes in flow.

The BiVAD did experience two noncritical instances of reductions in pump flow midway through the flight, responding immediately to intravenous fluid boluses of 50 ml and 100 ml of Gelofusine, respectively. The patient was kept NPO and was maintained with an IV fluid isotonic drip of 70 $ml \cdot h^{-1}$. His urine output remained constant at 35 $ml \cdot h^{-1}$. His fluid balance for the whole transport was marginally positive, not taking into account insensible losses.

The precautions taken preflight were repeated postflight:

1. Upon arrival in Raleigh/Durham the patient was unloaded with the assistance of a cargo ramp after conversion to battery pack operation.
2. The patient was transferred to Duke in an ALS ambulance with all equipment powered by 110 V AC power units and arrived in the cardiac transplant unit.
3. At destination the transport power units were replaced by those in the ICU without incident.

Vital signs (including VAD flow rates) did not significantly change from preflight. There was a formal debrief (inclusive of exchange of medical reports) between the escort team and the receiving team. The bed-bed transfer was 12 h in duration.

DISCUSSION

A thorough literature review did not reveal any previous reports of a long-distance fixed-wing transfer of a patient with a BiVAD. We will discuss the BiVAD, the aircraft, and the hemodynamic changes observed in flight. The Levitronix Centrimag is a centrifugal pump designed for short-term extracorporeal support for management of cardiogenic shock. It was used in this case as a bridge to decision (transplantation vs. intracorporeal VAD) in this patient with refractory acute cardiogenic shock.

This BiVAD (Levitronix Centrimag) is distinguished from other FDA-approved devices (i.e., AbioMed or Thoratec) in that it does not contain seals or bearings. Furthermore, the pumps do not contain flexing sacs, diaphragms, or valves which may degrade and fail, limiting the potential duration of use. In addition, this device is compact, facilitating transport in confined spaces, and its configuration is thought to minimize blood trauma (9). The cardiac unit at Papworth uses this device extensively and chose it in anticipation of a limited pretransplant course. We have no evidence to suggest that any of the aforementioned other devices would have fared any better or worse during transfer.

The GIII was selected as the aircraft of choice for multiple reasons, including, but not limited to, the egress capability of the wider cargo door, cabin size, and configuration. It would have been technically difficult to transport such a patient with this equipment and the accompanying medical team in our standard AA: Learjet 35. Furthermore, the GIII is able to complete such a long mission with limited fuel stops and, therefore, a shorter out-of-hospital time.

No doubt the hemodynamic changes noted on takeoff and landing (↓ and ↑ in preload, respectively) reflect to a large extent the G forces experienced in the GIII cabin. Experimentally it has been previously demonstrated that exposure to acceleration forces ($+G_z$) causes changes in cardiac preload and afterload and can even induce dysrhythmias (11). However, the decrease in flow to 2.8 $L \cdot min^{-1}$ (33%) on takeoff reflected more than just G forces and may very well have been compounded by intravascular volume depletion and/or some relative vasodilatation.

During the takeoff phase of flight in a GIII the takeoff speed in normal conditions (no wind or excessive temperatures) is 145 kn with a rate of climb of 3000 $ft \cdot min^{-1}$ (914 $m \cdot min^{-1}$), with a deck angel of no more than 7°. Slow release of the brakes when engines reach the correct engine power ratio is essential to a slow and seamless rate of acceleration. Initial climbing speed increases to 250 kn; however, the gradual increase to the rate of climb and speed will minimize any G force. The GIII does not exceed 1.2 G as measured by the G meter.

Approach and landing phase of flight is again affected by the airport environment, including air traffic, weather, visibility, surrounding terrain, and approaches. Typically the rate of decent is determined by Air Traffic Control and published navigational charts map the various angles and speeds. A seasoned pilot will study the navigational aids to prepare and anticipate the approach in order to lessen the effects of changes in speed, angle, and altitude. Once the pilot has locked on the glide slope locator, the approach speeds slow to 140–135 kn and the angle of decent should be no more than 3.5°. However, with proper use of the flaps, slats, and trim, the deck angle in the cabin will be nose up throughout the entire decent.

As described above, the influence of acceleration and deceleration forces during takeoff and landing resulted in a significant hemodynamic impact on the BiVAD system. On takeoff, with the patient positioned with his head toward the nose of the aircraft, the acceleration forces resulted in temporary pooling of blood in his legs. This loss in venous return was significant enough to decrease the RVAD flow by 33% and subsequently decreased the LVAD flow. In a normally functioning heart, this would have resulted in a compensatory tachycardia. This hemodynamic alteration demonstrated the sensitivity of the BiVAD system to relative hypovolemia, even temporarily. It was also interesting to demonstrate that a simple maneuver such as contraction of the gastrocnemius could just as rapidly produce an increase in venous return and restore the BiVAD blood flows to baseline. As expected, based on the discussion above, during the deceleration phase of landing, we documented a transient increase in the BiVAD flows produced by the shifting of blood from the lower extremities to the core produced by the gravitational forces. Similar hemodynamic changes have been demonstrated in hypovolemic patients by raising their lower extremities above the level of the heart.

From the point of view of future fixed-wing transports of patients dependent on VADs, where their feet are facing aft it would be advisable to consider at least, in awake patients, contraction of their gastrocnemius on takeoff, or in sedated patients, the use of sequential pneumatic compression stockings or even a leg raise during this period of the transport. It is also advisable to ensure these patients are not hypovolemic prior to transport and to monitor them carefully in flight for signs of hypovolemia created by the low-humidity environment in a pressurized aircraft. The increase of venous return noted on landing was easily accommodated by the hardware. Patient heat loss from the extracorporeal VAD circuits was not an issue due to simply covering the patient with blankets. Care was taken, however, to avoid covering the pump motor units, which can overheat and even fail in extreme environments.

Until recently, the practice of transporting patients on any sort of mechanical cardiovascular support was uncommon. With technological advances in equipment and improved training and experience among medical crews, it has become much more commonplace. This is demonstrated by a description of 173 transfers of patients dependent on IABP via helicopter over the course of 2 yr by one group alone (10). In cases of severe heart failure, however, use of VADs may be the only therapeutic option. Evidence supports VAD use as a bridge to transplant by improving mortality and success of transplants (1–3). As more centers begin to use VADs, the necessity to transfer patients on a VAD to a heart transplant center is also expected to increase. Based on our experience outlined above, a focus on careful medical crew and aircraft selection, as well as detail oriented logistical planning and supervision, are essential to ensure safe and successful transfers of VAD-dependent patients via fixed-wing aircraft. Finally, we advise the flight surgeon transporting a VAD-dependent patient to travel with a checklist to avoid omission of any one detail which could have a negative impact on the outcome of the case.

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