Hemodynamics During an Ambulance Flight

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CASE STUDY

Abstract

Transportation of patients may present challenges, especially if they need intensive care, require mechanical ventilation, or are hemodynamically unstable. In the reported case study, Picco-based measurements were used to track hemodynamic changes in a patient throughout the duration of a transfer, which included an air ambulance transport. If air medical transport is indicated, several additional physical and chemical considerations require awareness during the trip, planning, and pretransport patient preparation: first, that decreasing atmospheric pressure leads to reduced blood oxygenation, and second, that intracorporeal volume shifts may occur during takeoff and landing. To our knowledge, our findings represent the first measurements with a Picco system during interhospital patient transport that included an air medical flight.

Introduction

The need for interhospital transfer of intensive care patients has steadily increased in recent years. One reason is the increasing use of central clinics and facilities offering specialty services, such as intensive care units and coronary angiography.

When local therapeutic resources for complex treatments are limited, or when specialized patient care is indicated, an interhospital transfer is recommended to facilitate the most appropriate treatment for the patient. For optimum outcomes, transports should be conducted as early as possible in the illness/injury process, with adherence to a high level of care standards.1

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Compared with shorter-distance surface-bound transports, air transports have the advantage of being much faster. For longer distances, few, if any, other viable alternatives may exist.

As noted previously, 2 special considerations during air medical transport include the change in physical conditions at higher altitudes and the unique conditions incurred as a result of the transfers into and out of the plane, as well as during takeoff and landing.

As one ascends to increasing altitudes, the air pressure decreases. To compensate for this, modern airplanes have systems that artificially increase the cabin pressure in passenger compartments. In most planes, the cabin pressure at cruising altitude (10-12 km; 32,000-39,000 ft) corresponds to a pressure at 2,000 to 2,500 m (6,500–8,200 ft) in height. This is according to the law of Boyle–Mariotte:

\[ p_1 \frac{V_1}{V_2} = \text{const} \]

The pressure of ideal gases is inversely proportional to the volume. This results in a decreasing pressure and an increasing gas volume during ascent. On descent from altitude, the opposite occurs. From a medical perspective, this may exert a significant potential impact on every closed and air-filled compartment inside the human body (eg, pneumothorax, pneumocephalus, middle ear, and intestines).

In addition, the partial pressure of oxygen decreases in proportion to total air pressure at increasing altitudes. Increased altitude will result in an increased oxygen demand in attempts to maintain normal blood oxygen levels (Henry’s law).

To provide enough oxygen for all organs, the heart rate has to increase in conditions of developing hypoxia. Up to 2,250 m (7,300 ft), the volume ejected by the heart per minute usually remains constant. This means that with the increase in heart rate, stroke volume decreases. Above 2,250 m (7,300 ft), the lower partial pressure of oxygen (pO2) leads to vasoconstriction of the lung vessels. According to the Euler–Liljestrand mechanism, this increases the resistance of the lung vessels.3

When air medical helicopters fly at an altitude of approximately 1,500 m (5,000 ft), air-filled compartments in the body expand by a factor of 1.2. Here, height-related changes in pO2 are small and in most cases, negligible. Changes in pO2 become more relevant when critically ill patients are transported at higher cruising altitudes. At sea level, patients with a pO2 of 60 mmHg, for example, will have an oxygen saturation of approximately 90%. A cruising height of 1,500 m (5,000 ft), however, may cause a decrease in oxygen saturation to approximately 70%.
These considerations are also relevant for airline-based transport. In most commercial airplanes, cabin pressure will not drop below 565 mmHg (2,400 m; 8,000 ft), but in some conditions, cabin pressure may reach altitude values of 542 mmHg (2,700 m; 8,915 ft). From 2,100 to 2,400 m (7,000–8,000 ft), oxygen saturation falls by 4%, presenting an even greater risk of hypoxia.

Typically, Rega ambulance jets have a cruising altitude of approximately 12,000 m, with a corresponding cabin pressure of 565 mmHg (2,400 m; 8,000 ft). At this altitude, the pulmonary-arterial pressure of a healthy person will not change as long as the alveolar oxygen partial pressure does not drop below 65 mmHg. For persons with preexisting pulmonary-vascular conditions, a small reduction in the oxygen supply can result in an increase in the intrathoracic vascular resistance and induce negative cardiopulmonary responses, which may in turn lead to decompensation.

In addition to the changing physical conditions involving the cardiovascular system during flight, potential challenges also lie in the situation of jet-based interfacility transport. The supine patient position during takeoff may lead to pathophysiologic intracorporeal volume shifts, such as venous blood pooling, with most of the blood volume shifting toward the lower extremities.

The resultant reduction in thoracic blood volume leads to a lower cardiac output, which may cause additional severe problems for patients—especially those with preexisting heart conditions.

To evaluate hemodynamic changes during patient repatriation, a decision was made to use a Picco device. The Picco system was developed by Pulsion in Germany, and it is indicated for patients when cardiovascular and volumetric monitoring is required. It measures the cardiac output (CO) discontinuously via transpulmonary thermodilution technology and also determines CO via continuous arterial pulse contour analysis (PCCO). Additionally, heart rate (HR) and the systolic and diastolic blood pressure are measured to calculate the mean arterial blood pressure (MAP). Advanced analysis of the thermodilution curve, including the mean transit time and exponential downslope time, determine intravascular and extravascular fluid volumes.

When the corresponding patient data (body weight and height) are used, the Picco system indexes all parameters in relation to the patient body surface area. For the thermodilution measurements, 15 to 20 mL (0.5–0.7 fl oz; weight dependent) of cold NaCl 0.9% solution is rapidly injected through a central venous line past a temperature sensor. The decrease in temperature caused by the cold bolus injection is then detected downstream by a special catheter placed in the arterial system (Fig. 1).

From analysis of the thermodilution curve, the CO, cardiac function index, extravascular lung water (EVLW), and global end-diastolic volume are calculated. The parameters of intrathoracic blood volume index and extravascular lung water index (EVLWI) are estimated by the thermodilution method. The CO and global end-diastolic volume are indexed to the patient specific body surface area. EVLW is indexed to the patient-predicted body weight to increase accuracy.

The EVLW is the only easily obtained parameter that allows quantification of the intrathoracic fluid status. This quantification can be particularly important with persistent lung edema where the pulmonary vascular permeability is elevated.

In addition, the thermodilution method in the Picco system automatically calibrates the continuous pulse contour analysis, providing the following parameters: continuous cardiac output, HR, stroke volume (SV), stroke volume variation (SVV), and systemic vascular resistance index (SVRI).

The following case report describes the use of the Picco system during a patient transfer, including pretransport preparation at the departing hospital, transfer to the airport, the entire flight, and ultimately, landing and transfer to the receiving hospital. To our knowledge, the reported data provide the first information compiled regarding the hemodynamic consequences of surface and subsequent air medical transport.

Case Report

July 29, 2010, a 61-year-old patient (female, 170 cm [5 ft], 115 kg [253 lb]) with pneumonia-related acute respiratory distress syndrome was transported via a Rega jet from Lugano (south of the Alps in Switzerland) to Zürich (north of the Alps in Switzerland; approximately 90 nautical miles). The maximum flight altitude was 18,000 ft (5,486 m). The total transport time was 370 minutes, which included 90 minutes for device insertion, patient monitoring, and pretransport preparation at the departing hospital; patient handover at the receiving hospital of 30 minutes; and “in-transport” time of 250 minutes.

Of interest, the patient was fully mechanically ventilated throughout the transport. Blood gas analysis was done before, during, and after the flight. At the departing hospital, the initial measurements were obtained using a mobile device connected to a previously inserted Picco catheter. MAP, HR, and central venous pressure were monitored by...
During transfer to the airport, 2 additional injections of norepinephrine (5 μg and 10 μg) were necessary to keep the MAP above 60 mmHg. During subsequent transport, the pre-existent norepinephrine infusion of 4 μg/min was sufficient.

Over the entire transfer, 1,150 mL (40 fl oz) of volume were given, of which 250 mL (9 fl oz) colloids were required during the ambulance ride to the airport. Total diuresis was 6.4 L/min, with a short decrease during takeoff (5.6 L/min) and in the ambulance to the receiving hospital (5.6 L/min; Fig. 3). Similar findings were recorded for SV (range from 64 to 97 mL). EVLWI varied between 12 and 15 mL/kg. This then increased on arrival at the receiving hospital to 19 mL/kg. Relevant in-flight variations of EVLWI were not observed. SVV varied between 9% and 12% during all phases of transport, except during airport transfer (19%).

### Discussion

To our knowledge, our findings represent the first measurements with a Picco system during interhospital patient transport that included an air medical flight. An Internet literature search in online Pubmed was unable to identify any preexisting data on the hemodynamic changes of intensive care patients during airborne transportation.

Our data showed that, contrary to our expectations, CO and vascular resistance increased during the flight. With the exception of 2 boluses of norepinephrine, the MAP remained stable at approximately 80 mmHg on a continuous norepinephrine infusion of 4 μg/min. The heart rate decreased during the flight, and EVLWI did not change significantly.

Unfortunately, it is not possible to draw any general conclusions from the data collected, because this is a single case report without statistical significance attributable to lack of patient variations. Additionally, the bolus injection of norepinephrine at the beginning of transport could have influenced the Picco measurements. The same could have been the case with the volume administration; however, the reduced volume demand during transport could be interpreted as a strong indication of the increased in-flight PCCO. The fact that the SVRI increased, although PCCO also increased during the flight, is not yet explainable.
The marked increase of the PCCO at the receiving hospital may be attributable to an error in the measurement of SV, but this was not the case for the rest of the entire transport. The presented case shows data from a patient with severe acute respiratory distress syndrome. These data could vary significantly in patients with coronary heart disease, arterial hypertension, left and right congestive heart failure, or severe trauma. Age-related differences could also have an impact on Picco measurements, but this is not yet clarified.

In addition, it is also possible that movement artifact can lead to an impairment of Picco measurements. Therefore, the data evaluated during ambulance transfer require careful interpretation. More investigations are ongoing, which should further complement the results presented here. In particular, it would be very interesting to verify whether the CO and vessel resistance are also found to be elevated in other patients.

Although no definite conclusions can be drawn from the data presented here, the following recommendations may be derived from existing publications:

- Intra- and interhospital transports of patients with multi-organ failure need highly experienced personnel.\(^8,9\)
- Out-of-hospital standards of monitoring and therapy should be the same as in hospitals,\(^10\) and they should not be interrupted at any time.\(^8,9,11\)

- With appropriate hemodynamic stabilization, adequate ventilation, and continuous monitoring, critically ill patients can be safely transported.\(^12,13\)

The basics for safe transportation of intensive care patients include the following factors:

- Optimum pretransport preparation
- Consistent continuous therapy
- Continuous monitoring
- Highly qualified personnel
- Predefined algorithms and concepts

A primary goal of interhospital transfer of patients requiring critical care must be uncompromised maintenance of this advanced level of care between the referring and receiving hospitals. In addition to the purely logistical factors, the qualifications of transport staff, timing of transfer, and mode of transport play essential roles in obtaining optimal outcomes.\(^5\)

References