The air medical transport of cardiac patients is a rapidly expanding practice. For various medical, social, and economic indications, patients are being flown longer distances at commercial altitudes, including international and intercontinental flights. There are data supporting the use of short-distance helicopter flights early in the course of a cardiac event for patients needing emergent transfer for percutaneous coronary intervention or aortocoronary bypass. When considering elective long-distance air medical transport of cardiac patients for social or economic reasons, it is necessary to weigh the benefits against the potential risks of flight. A few recent studies suggest that long-distance air medical transport is safe under certain circumstances. Current guidelines for air travel after myocardial infarction do not address the use of medical escorts or air ambulances equipped with intensive care facilities. Further research using larger prospective studies is needed to better define criteria for safe long-distance air medical transport of cardiac patients.

Key words: aeromedical transport; air ambulance; air medical transport; cardiac transport; myocardial infarction; patient transport

Abbreviations: ACC = American College of Cardiology; AHA = American Heart Association; AMA = American Medical Association; AsMA = Aerospace Medical Association; MI = myocardial infarction; $P_{O_2}$ = partial pressure of inspired oxygen

The use of air medical transport services provided by private and insurance company-affiliated air ambulance companies has risen significantly over the past 15 years. In 1992 alone, the 250 US-based and 12 internationally based air medical transport operators belonging to the Association of Air Medical Services performed $>160,000$ transfers over a wide range of distances. For a combination of medical, social, and economic reasons, cardiac patients with increasing acuity of illness are being transported distances spanning the globe.

Air medical transport is performed using rotary wing aircraft (ie, helicopter) or fixed-wing aircraft (eg, engine propeller or jet air ambulance, or medical escort on a commercial airline). Rotary-wing aircraft are used for emergency transport over short distances, whereas fixed-wing aircraft are used for transport over longer distances (eg, $>150$ miles). For long-distance transport that is elective (ie, for economic and/or social reasons), patients in relatively stable condition may be medically escorted aboard a commercial aircraft. Elective long-distance transport of patients in less stable condition (eg, early post-myocardial infarction [MI], receiving mechanical ventilation, or receiving IV vasopressors or antiarrhythmic agents) and emergency long-distance transport is performed using fixed-wing air ambulances. The type of fixed-wing aircraft used for air ambulance transport generally depends on the distance to be traveled, with single- or twin-engine propeller aircraft reserved for shorter flights, whereas jets may even be used to transport across continents. The quality of air ambulance services may vary across companies. Generally, air ambulances should be configured to function as flying ICUs with a full range of pharmaceuticals, and compact portable
medical equipment including IV pumps, cardiac and hemodynamic monitor, defibrillator, ventilator, pulse oximetry, and blood gas analyzer. The medical crew should include an intensive care trained physician, nurse, and/or medic.

When air medical transport is considered elective (e.g., repatriation of patients from foreign countries where quality medical care is available), the risks and benefits should be considered. The social benefit of returning patients to their country is treatment in their language near their family and support system. For patients with travel insurance, if the anticipated cost of hospitalization exceeds the cost of air medical transport, insurance companies may prefer to repatriate patients to local health-care systems as soon as possible. Although the apparent benefits often justify the cost of air medical transport (whether paid for by the patient or an insurance company), the potential risks are less clearly defined. The transport of a patient with a recently stabilized coronary syndrome, in a hypoxic environment without possibility of surgical backup, is a potentially hazardous situation that demands rigorous patient selection.

This article aims to review the subject of air medical transport of patients with cardiac disease. The issues to be discussed include the history of air medical transport, the physiology and potential risks of flight, the data available regarding air transport of cardiac patients, the present state of technology available in an air ambulance, and the current guidelines regarding air travel for cardiac patients.

**History of Air Medical Transport**

The origins of rotary-wing air medical transportation date back to 1944 when the US military first used helicopters for air medical evacuation of the injured in Burma. US military helicopter evacuation dramatically expanded during the Vietnam War in the 1960s. The success of US military helicopter evacuation in Vietnam established the foundation for, and acceptance of, helicopter transport in hospital systems. Civilian helicopter emergency medical services have their roots in military air medical evacuation programs. In 1966, the US Highway Safety Act allowed for the transfer of military helicopter technology for civilian use. US civilian air emergency medical services began in Denver in 1972. With the increasing availability of cardiac catheterization laboratories in tertiary care hospitals in the 1980s, the demand for emergency air medical transport of cardiac patients increased rapidly. Emergency helicopter transport was a faster and more efficient way to transport patients from rural settings for reperfusion techniques such as thrombolysis or angioplasty following acute MI. The number of civilian air medical transport programs rapidly grew to a total of 280 by 1995.

The first fixed-wing air ambulance transport of patients occurred on the French Dorand AR II in 1917. The use of air ambulance transport expanded mainly in the military and increased significantly during World War II. The first operational units dedicated to air medical evacuation on fixed-wing aircraft were organized by the US military in 1943. These flights were headed by a physician (the flight surgeon) and generally consisted of six flight nurses as well as six medical technicians. The use of air medical evacuation continued to expand during the Vietnam War, but remained limited to patients in relatively stable condition. Due to the dramatic evolution in medical care, more patients in unstable condition (including cardiac patients after MI) are being transferred by air ambulance for more advanced diagnosis and therapy in recent years. Though initially developed by the military, the air ambulance industry and the number of private air ambulance companies in the United States and worldwide has increased significantly in the last 30 years.

**Physiology and Potential Risks of Flight**

Areas of concern regarding air medical transport of cardiac patients include the effects of hypoxia at altitude, the effects of gas expansion at altitude, the effects of anxiety about flying, and the potential for complications related to movement of patients. Concerns regarding the effects of altitude are generally limited to fixed-wing aircraft as opposed to rotary-wing aircraft that fly at altitudes (eg, < 1,000 feet) where barometric pressure changes are minimal.

**Effects of Hypoxia at Altitude**

In contrast with rotary-wing aircraft, fixed-wing engine propeller aircraft fly at altitudes of > 15,000 feet and jets fly at altitudes of 28,000 to 43,000 feet. Barometric pressure progressively decreases with altitude from 760 mm Hg at sea level to 140 mm Hg at 40,000 feet. The partial pressure of inspired oxygen (P<sub>O</sub><sub>2</sub>) decreases proportionally to the decrease in barometric pressure at increasing altitude (P<sub>O</sub><sub>2</sub> = 0.21 × [barometric pressure – water vapor pressure]). The water vapor pressure at a normal body temperature is 47 mm Hg regardless of altitude. The P<sub>O</sub><sub>2</sub> at 40,000 feet (approximately 20 mm Hg) is incompatible with human life. In order to make it possible for humans to fly at such altitudes, aircraft are pressurized to achieve cabin pressures at cruising altitudes equivalent to barometric pressures at 5,000 to 8,000 feet of altitude.
At a cabin pressure of 8,000 feet, \( P_{O_2} \) decreases from 150 mm Hg at sea level to 107 mm Hg. In normal patients, this has been shown to decrease \( P_{O_2} \) from 98 to 55 mm Hg.\(^7\) In healthy individuals, this results in only a small decrease in blood oxygen saturation to approximately 90%; however, if a patient already has a reduced \( P_{O_2} \) on the ground, the decrease in oxygen saturation at altitude will be more significant.

Bendrick et al\(^{10}\) studied in-flight oxygen saturation decrements during the air medical evacuation of 24 patients with ischemic heart disease whose resting ground saturation ranged from 92 to 100%. They found a mean saturation decrease of 5.5% at a mean cabin altitude of 6,900 feet. Three patients were administered supplemental oxygen for desaturation below 90%. Vohra and Klocke\(^{11}\) studied a group of patients with chronic obstructive lung disease whose baseline oxygen saturations averaged 93.2%. At a simulated altitude of 10,000 feet, their saturations dropped to 87.5%. Hypoxia was easily corrected with the administration of low-flow oxygen.

The physiologic response to a lowered \( P_{O_2} \) is chemoreceptor-induced hyperventilation, mediated primarily by an increase in tidal volume. Any residual systemic hypoxia is compensated for with increased cardiac output, mediated primarily through tachycardia.\(^9\) The increase in cardiac output in patients during international air ambulance missions was found to be proportional to the drop in oxygen saturation.\(^{12}\) Altitude-related decreases in \( P_{O_2} \) have been demonstrated to decrease ischemic threshold in men with exercise-induced angina, with cardiac ischemia occurring at the same internal workload (heart rate-BP product) but lower external workload (treadmill speed and incline) at higher altitude (10,000 feet vs 5,000 feet).\(^{13}\) Hypoxia is also a stimulus for atrial arrhythmias and is associated with premature ventricular contractions.\(^8\) The potential for increased sympathetic nervous system activity in-flight is an additional factor predisposing to arrhythmia.\(^{14}\)

Effects of Expansion of Gases at Altitude

In accordance with Boyle’s law \((V_2 = V_1 P_1 / P_2)\), the volume to which a given quantity of gas is compressed is inversely proportional to the surrounding pressure.\(^2\) Consequently, any gas trapped in a closed space will expand by approximately 35% when going from sea level to 8,000 feet of altitude. This is of particular concern in a patient with a pneumothorax that will expand and cause desaturation or even hemodynamic compromise if it becomes a tension pneumothorax. A patient with a pneumothorax should have a chest tube placed and left unclamped. Similarly, chest tubes or drains placed for other reasons (eg, after coronary artery bypass surgery) should also be unclamped and monitored. Gas trapped in an obstructed hollow viscus may expand and cause the viscus to rupture. Air can also be enclosed in medical equipment. Air in endotracheal tube cuffs will expand, and the cuff pressure should be adjusted to avoid trauma to the trachea. IV bags rather than bottles should be used because air in a bottle will expand and increase flow rate. All IV lines are best placed on pumps.\(^{15}\)

Effects of Anxiety About Flight

Patient anxiety can have an impact on cardiovascular status during transport. Cardiac ischemia may be provoked by the elevated catecholamine levels and tachycardia that result from extreme nervousness. Deimmons and Cook\(^{16}\) monitored anxiety levels of patients during air medical transport and noted that anxiety was greatest in anticipation of the flight. Patients with little or no experience flying were more nervous. Their level of anxiety decreased steadily during their flights. Most patients were more anxious about their medical condition than the flight itself.

Complications Related to Movement of Patients

The transfer of hospitalized patients is associated with complications related to physical movement from a bed to a stretcher or examination table. Complications range in severity from minor (ie, pulling out an IV line) to potentially life threatening (ie, pulling out an endotracheal tube). The risk of a complication relates to the amount of instrumentation of the patient, and to the complexity of the machinery. Critical care patients are therefore at greatest risk of a complication during transfer. The frequency of complications during intrahospital transport has been observed to be 5 to 6%.\(^{17}\) Meticulous packaging of a patient prior to any transfer is essential to minimize the risk of transport-related complications.

Safety of Air Medical Transport

The safety of air medical transport depends on both aviation and medical aspects. Aviation aspects have been a particular concern with air medical rotary-wing aircraft that have shown a tendency to crash and result in fatal and nonfatal injuries.\(^3\) Poor weather was identified as the greatest hazard to emergency medical service helicopter operations in a study by the National Transportation Safety Board published in 1988. Helicopter air ambulance acci-
dent rates have since declined considerably. The Association of Air Medical Services, an international organization established in 1980, also encourages safety, quality assurance, and quality improvement.

The medical safety aspects of air transport relate to the stability of a patient’s condition, the potential for exacerbation of that condition by physiologic or physical factors related to air transport, and the quality of technology and medical personnel available. It must also be considered that depending on the type, location, and duration of transport, the delay in making an emergency landing for definitive treatment in a hospital may be substantial. The following review of the literature summarizes the data on the safety of air medical transport of cardiac patients. Data regarding short-distance emergency helicopter transport, long-distance emergency air ambulance transport, long-distance elective commercial transport, and long-distance elective air ambulance transport are discussed separately.

**Short-Distance Emergency Helicopter Transport**

The majority of data on air medical transportation of cardiac patients come from short-distance emergency helicopter flights. Five major reports describing the air medical transfer of patients early in the course of acute MI are summarized in Table 1. Kaplan et al. report on 104 patients with suspected acute MI transferred by helicopter for emergency reperfusion within 36 h of symptom onset. While there were no in-flight deaths, in-flight complications (serious hypotension or new arrhythmias requiring treatment) occurred in 13 patients (12%). Physicians were required to exercise medical skill or judgement during 26% of the transports. Similarly, Bellinger et al. describe 250 patients transported by helicopter within 12 h of onset of symptoms of acute MI for emergent cardiac catheterization. Of the 240 patients who received thrombolytics, 72% had therapy instituted before or in-flight. Complications included hypotension in 25 patients (10%) and arrhythmias in 25 patients (10%). The in-flight arrhythmias consisted of third-degree AV block (eight patients) and nonsustained ventricular tachycardia (seven patients), and did not result in any significant morbidity.

Topol et al. reported on 150 patients with evolving MI transported by helicopter to a tertiary care institution for acute intervention. No patients died or experienced hemodynamic instability or bleeding complications during transfer. Fifty-five patients received thrombolytic therapy initiated prior to transfer. Arrhythmic complications (ventricular tachycardia and third-degree AV block), although increased in the population receiving thrombolytics, were infrequent (8 of 150 patients) and transient.

Fromm et al. compared 95 acute MI patients transported by helicopter within 12 h of initiation of thrombolytic therapy to 119 nontransported acute MI patients similarly treated. In-flight complications included medically managed hypotension in 18 patients, but no episodes of cardiac arrest or cardioversion. There was no increase in bleeding complications compared to the nontransported control population. In a study by Spangler et al. of 192 acute MI patients transferred by helicopter, 110 patients received thrombolytic therapy prior to transfer and the remainder received thrombolytic therapy after transfer. Patients with inferior MI treated with thrombolytics prior to flight were more likely to experience symptomatic bradycardia and hypoten-

<table>
<thead>
<tr>
<th>Source</th>
<th>Year</th>
<th>Diagnosis</th>
<th>Patients, No.</th>
<th>In-flight Cardiac Adverse Events*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaplan et al.</td>
<td>1987</td>
<td>MI</td>
<td>104</td>
<td>Hypotension (n = 9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Arrhythmia (n = 4)</td>
</tr>
<tr>
<td>Bellinger et al.</td>
<td>1988</td>
<td>MI</td>
<td>250</td>
<td>Transient hypotension (n = 21)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sustained hypotension (n = 4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Third-degree AV block (n = 8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nonsustained ventricular tachycardia (n = 7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ventricular tachycardia (n = 3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sinus bradycardia (n = 4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Atrial fibrillation or flutter (n = 3)</td>
</tr>
<tr>
<td>Topol et al.</td>
<td>1986</td>
<td>MI</td>
<td>150</td>
<td>Ventricular tachycardia (n = 7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Third-degree AV block (n = 1)</td>
</tr>
<tr>
<td>Fromm et al.</td>
<td>1991</td>
<td>MI</td>
<td>95</td>
<td>Hypotension (n = 18)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bleeding (n = 41)</td>
</tr>
<tr>
<td>Spangler et al.</td>
<td>1991</td>
<td>MI</td>
<td>192</td>
<td>Bradycardia (n = 24)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hypotension (n = 21)</td>
</tr>
</tbody>
</table>

*In-flight cardiac adverse events were managed with onboard medications and did not result in any significant morbidity or mortality.
sion requiring atropine compared to patients treated after the flight, but there was no in-flight mortality in either group.

The first randomized study to suggest outcome benefit from helicopter transport is the recently published Air Primary Angioplasty in Myocardial Infarction Study. The study randomized 138 patients with high-risk, acute MI at centers without coronary angioplasty capabilities to either on-site thrombolysis or transfer for primary angioplasty by the most expedient means (air or ground transport). Of the 71 patients transferred, 21% were by helicopter (mean distance, 57 miles) and 79% were by ground ambulance (mean distance, 26 miles). Despite a delay in time from arrival to treatment (155 min vs 51 min), patients randomized to transfer had decreased hospital stay (6.1 days vs 7.5 days, \( p = 0.015 \)) and 38% reduction (8.4% vs 13.6%, \( p = 0.331 \)) in major cardiac adverse events (death, reinfarction, or stroke) at 30 days.

In summary, the data on emergency helicopter transport of patients with acute MI suggest that such transport is safe, based on the absence of in-flight deaths or significant morbidity. The most frequent in-flight problems were nonfatal hypotension and arrhythmias, managed by onboard medical personnel equipped with IV fluids and medications.

### Long-Distance Emergency Air Ambulance Transport

Data regarding seven published studies of all long-distance air transport of cardiac patients are summarized in Table 2. Three of these studies document long-distance emergent transport of cardiac patients by fixed-wing air ambulance. Incenogle described 11 patients in cardiogenic shock (receiving IV inotropic support, 8 requiring intra-aortic balloon pumps), transported a median of 1,160 miles: 6 patients by air ambulance and 5 patients by ground ambulance. All patients survived the transport without any medical complications of travel.

Connor and Lyons reported on the air medical evacuation of seven patients after acute MI by the US Air Force. All patients were transported from remote areas to larger medical facilities capable of providing adequate medical care. The patients were transported within 7 days of symptom onset, after thrombolysis and at least 24 h of hemodynamic stability. Transportation time ranged from 4.4 to 12.2 h, and there were no in-flight complications.

Castillo and Lyons reported the transoceanic air evacuation of 59 patients with unstable angina requiring care not locally available. In-flight information available for 31 patients revealed only minor in-flight complications (chest pain, desaturation < 90%, elevated BP) in five patients.

### Table 2—Long-Distance Air Medical Transport of Cardiac Patients

<table>
<thead>
<tr>
<th>Source</th>
<th>Year</th>
<th>Type of Transport</th>
<th>Diagnosis</th>
<th>Patients, No.</th>
<th>Days After Presentation, No.</th>
<th>In-flight Cardiac Adverse Events*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incenogle</td>
<td>1988</td>
<td>Emergency air ambulance</td>
<td>Cardiogenic shock</td>
<td>6</td>
<td>Not available</td>
<td>None</td>
</tr>
<tr>
<td>Connor and Lyons</td>
<td>1995</td>
<td>Emergency air ambulance</td>
<td>MI</td>
<td>7</td>
<td>2–7</td>
<td>None</td>
</tr>
<tr>
<td>Castillo and Lyons</td>
<td>1999</td>
<td>Emergency air ambulance</td>
<td>Unstable angina</td>
<td>59</td>
<td>&lt; 1</td>
<td>Chest pain (n = 3) Desaturation &lt; 90% (n = 1) Hypertension (n = 1) Chest pain (n = 3) Dyspnea (n = 1) Hypotension (n = 1) Bradycardia (n = 1) None</td>
</tr>
<tr>
<td>Cox et al</td>
<td>1996</td>
<td>Elective commercial</td>
<td>MI</td>
<td>196</td>
<td>3–53</td>
<td>None</td>
</tr>
<tr>
<td>Zahger et al</td>
<td>2000</td>
<td>Elective commercial</td>
<td>Acute coronary syndrome</td>
<td>21</td>
<td>18.2 ± 11 (mean ± SD)</td>
<td>None</td>
</tr>
<tr>
<td>Roby et al</td>
<td>2002</td>
<td>Elective commercial</td>
<td>MI</td>
<td>38</td>
<td>10–27</td>
<td>Chest pain (n = 2) Desaturation &lt; 90% (n = 5) ST-segment depression (n = 2) Ventricular ectopy (n = 3) Nonsustained ventricular tachycardia (n = 2) Chest pain (n = 4) Desaturation &lt; 91% (n = 1)</td>
</tr>
<tr>
<td>Esselberg</td>
<td>2001</td>
<td>Elective air ambulance</td>
<td>MI</td>
<td>51</td>
<td>2–31 (mean 8)</td>
<td>None</td>
</tr>
</tbody>
</table>

*All in-flight cardiac adverse events were transient or easily reversible by treatment with onboard medications.
inpatient records at receiving hospitals confirmed significant coronary artery disease in the majority of patients, and the absence during admission of complications attributable to air medical transport.

**Long-Distance Elective Commercial Transport**

There are three published studies reporting on the safety of commercial air travel after MI. Cox et al 28 described 196 commercially transported patients 3 to 53 days after MI. There were nine incidents requiring physician intervention, six of which can be classified as potentially cardiac (chest pain, dyspnea, transient hypotension, or bradycardia). Four of these six incidents occurred in patients transported < 14 days after MI, and each resolved after physician intervention. The authors conclude that international air medical transport of patients by commercial airline may be safely accomplished 2 to 3 weeks after acute MI when accompanied by a physician.

Zahger et al 29 prospectively followed up 21 tourists with acute coronary syndrome in Jerusalem. Patients considered high risk (on the basis of extensive ECG changes, recurrent angina, heart failure, ventricular dysfunction, or malignant arrhythmia) were offered coronary angiography. Patients who were not high risk underwent exercise testing followed by angiography if indicated. Of the seven patients who underwent angiography, five patients required revascularization. The 21 patients returned home by commercial aircraft (flight duration, 12.5 ± 3 h) 18.2 ± 11 days (mean ± SD) after admission. Telephone follow-up at 21 ± 13 days after their return revealed that no patients had cardiac symptoms en route. It is concluded that a long-distance commercial flight is safe within 2 to 3 weeks after acute coronary syndrome in patients without markers of high risk.

Recently, Roby et al 30 conducted a randomized study on 35 patients medically escorted home on commercial airlines approximately 2 weeks after an uncomplicated MI. All patients had Holter monitors and pulse oximeters. The treatment group consisted of 19 patients randomized to oxygen supplementation at 2 L/min via nasal prongs during flight. The 19 control patients received supplemental oxygen only if they experienced symptoms, desaturation, or ECG changes, as occurred in 5 patients. In-flight adverse events (transient ST depression, arrhythmias, chest pain, and desaturation < 90%) were identified in six treatment and eight control patients, and managed by medical escorts without consequence. The results suggest that medically escorted and monitored commercial air travel 2 weeks after uncomplicated MI is safe. There was no evidence that routine use of oxygen (as opposed to use only for symptoms, desaturation or ECG changes) decreases adverse events.

**Long-Distance Elective Air Ambulance Transport**

There is one published retrospective study 31 on the safety of elective long-distance air medical transportation of cardiac patients by air ambulance. Eighty-three cardiac patients were transported by air ambulance without any major complications. There were 51 patients transported after MI, 26 of whom were classified as complicated (Killip class II-IV). Easily reversible minor complications (chest pain or desaturation < 91%) occurred in five patients, all of whom were transported within 7 days of admission. The incidence of minor complications was greatest in complicated MI patients transported < 72 h, and uncomplicated MI patients transported < 48 h after resolution of chest pain. The study suggests that elective air ambulance transport after MI is safe 3 to 7 days after admission or 48 to 72 h after resolution of chest pain.

**Use of Cardiac Devices During Air Medical Transport**

Technological support on air ambulances has improved tremendously in the past 15 years with advances in computer technology. Most intensive care facilities can now be packaged into the confines of a private aircraft. It should be noted, however, that due to cost issues and user familiarity, not all air ambulance providers possess or utilize equipment of the same sophistication.

Temporary pacemakers can be required in a significant percentage of acute MI situations. The helicopter based study by Vukov and Johnson 32 looked at the utility of external and transvenous pacemakers during the first hours of myocardial infarction. Nineteen percent of patients had an episode of symptomatic bradycardia during air transport from a rural setting to a tertiary care center. Of these patients, 16% required no therapy, and 43% responded to atropine. Half of the patients unresponsive to atropine were transvenously paced, and the remaining patients were successfully externally paced.

Implantable automatic defibrillators are a recent advancement in the therapy of recurrent ventricular arrhythmias, and consequently there is little information regarding their function during air travel. There have been no reports to date of defibrillator malfunction or inappropriate shocks occurring during air medical transport; however, there has been a case report of increased pacemaker firing rate occur-
ring with a rate responsive pacemaker during helicopter transport, as a result of vibration simulating patient physical activity.\textsuperscript{33} Vibration deriving from both the aircraft engine and air turbulence may also be a source of malfunction of monitors or other medical equipment to which it is transmitted during air medical transport.\textsuperscript{5}

Intra-aortic balloon pumps have greatly aided the treatment of patients in cardiogenic shock awaiting definitive therapy. Safe air transport of these devices has been validated mostly in the transfer of patients from rural centers to tertiary care centers. Studies report that the most frequent problems during the transport of patients with intra-aortic balloon pumps were uncoupling of tubing or electronic connections,\textsuperscript{17} or difficulties with carbon dioxide canisters.\textsuperscript{34} Fortunately, none of the malfunctions caused any serious clinical complications. Flight physicians entrusted with a patient on a balloon pump should be very comfortable with this technology and how to perform simple repairs. The effects of expansion of gases at higher altitudes on the function and size of the inflated balloon must also be taken into consideration. A laboratory study found that intra-aortic balloons increased in volume by 25 to 62.5\%, depending on the model, over a change in altitude from 0 to 10,500 feet.\textsuperscript{35} The authors of that study recommended that intra-aortic pressure should be equalized at every 1,000 feet of ascent in order to maintain constant volume.

The threshold of cardiopulmonary support available in a mobile setting has been most extensively tested by the military in their experience with cardiac bypass machines with their mobile Surgical Transport Team. During the period from January 1989 to 1994, five patients required the use of extracorporeal cardiopulmonary support during transfer to a level-one trauma center. Using a femoral-femoral bypass circuit, four men and one woman were transported an average of 140 miles via fixed-wing aircraft, helicopter, and ground travel. While only two patients survived hospitalization, there were no significant complications during transport.\textsuperscript{36}

The first reported case of an overseas transport of a patient with an extracorporeal left ventricular assist device occurred in 1992. The 18-year-old man with idiopathic dilated cardiomyopathy was transported from Japan to Texas on a 17-h flight at an average altitude of 9,900 feet with no complications, and eventually obtained a heart transplant.\textsuperscript{37} More recently, Novacor Left Ventricular Assist System (World Health Corporation; Ottawa, ON, Canada) recipients were reported to have undergone > 37 commercial air transports throughout Europe, in both rotary and fixed-wing aircraft, without incident.\textsuperscript{38}

### Current Guidelines Regarding Air Travel

The current guidelines regarding long-distance flight and cardiac patients are limited to unescorted commercial airline travel. The American College of Cardiology (ACC) and American Heart Association (AHA) recommend that following uncomplicated MI, patients in stable condition (without fear of flying) may travel by air within the first 2 weeks, provided they are accompanied by companions, carry sublingual nitroglycerin, and request airport transportation to avoid rushing.\textsuperscript{39} Patients who are in unstable condition, are symptomatic, or who experienced a complicated MI (requiring cardiopulmonary resuscitation, experiencing hypotension, serious arrhythmias, high-degree block, or congestive heart failure), are recommended to wait a period of at least 2 weeks following stabilization before commercial air travel. The guidelines of the Aerospace Medical Association (AsMA) state that unescorted commercial airline flight is contraindicated within 3 weeks of uncomplicated MI, within 6 weeks of complicated MI, within 2 weeks of coronary artery bypass surgery, or within 2 weeks of cerebrovascular accident.\textsuperscript{40} Other cardiovascular contraindications to commercial airline flight include unstable angina, severe decompensated congestive heart failure, uncontrolled hypertension, uncontrolled ventricular or supraventricular tachycardia, Eisenmenger syndrome, and severe symptomatic valvular heart disease. The American Medical Association (AMA) guidelines indicate that travel by commercial aircraft is contraindicated within 4 weeks after MI, within 2 weeks after cerebrovascular accident, and for anyone with severe hypertension or decompensated cardiovascular disease.\textsuperscript{7} Table 3 summarizes the current guidelines regarding airline travel for patients with cardiac conditions.

With the advent of fixed-wing air ambulances equipped with intensive care facilities, cardiac patients are being transported earlier than these recommendations for unescorted commercial air travel. Although it seems reasonable that patients could be safely transported sooner under these circumstances, there are no established peer reviewed guidelines at present regarding the early transport of hospitalized cardiac patients by fixed-wing air ambulance.

### Conclusions

Elective long-distance air medical transport of cardiac patients occurs with increasing frequency, as a result of medical, economic, and social pressures to return a patient to their country or medical system. Despite the benefits of early air medical repatriation, there are potential risks involved in transporting
cardiac patients. These risks are related to the adverse effects of hypoxia and gas expansion at altitude, the effects of anxiety about flying, and the potential for complications related to movement of the patient.

There are data supporting the use of short-distance helicopter flights early in the course of a cardiac event for patients needing emergent transfer for percutaneous coronary intervention or aortocoronary bypass. When considering elective long-distance air medical transport of cardiac patients for social or economic reasons, it is necessary to weigh the benefits against the potential risks of flight. A few studies suggest that elective long-distance air medical transport by commercial airline is safe for patients in stable condition 2 to 3 weeks after MI, particularly when patients are accompanied by a medical escort. Another study suggests that, once patients are chest pain free for 48 to 72 h after MI, they may safely undergo elective long-distance air medical transport with the use of fixed-wing air ambulances.

Modern-day air ambulances have true intensive care capabilities, allowing transport of critically ill patients receiving mechanical ventilation, inotropes, and even intra-aortic balloon pumps. There exists compact technology to analyze blood gases and electrolytes during flight, and all forms of IV medications are at the disposal of the flight physician, allowing for a great deal of flexibility. Thrombolytic therapy, pacing, and defibrillation have been shown to be both effective and safe during flight, and may be used in event that an acute myocardial infarction occurs during transport. Bypass circuits and left ventricular assist devices represent the current extremes of cardiac support during flight, used only by devoted centers with fully trained flight crews. More common usage of such devices during long-distance voyages in the future will certainly depend on rigorous training of flight physicians and support staff.

The current guidelines of the ACC/AHA, AsMA, and AMA concerning air travel after acute MI address unescorted travel by commercial airline only. Although it appears reasonable that patients can be transported earlier with the use of air ambulances, there are no established peer-reviewed guidelines at present regarding the early transport of hospitalized cardiac patients by fixed-wing air ambulance.

The future of elective air medical transport will depend on the continued safety of the transport process. Further research using larger prospective studies is needed to properly examine the relevant risk factors involved in long-distance repatriation, and to better define criteria for patient selection and optimal timing of air medical transport of cardiac patients.

### Table 3—Airline Travel Guidelines for Patients With Cardiac Conditions*

<table>
<thead>
<tr>
<th>Variables</th>
<th>ACC/AHA</th>
<th>AsMA</th>
<th>AMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>After uncomplicated MI</td>
<td>2 wk</td>
<td>3 wk</td>
<td>4 wk</td>
</tr>
<tr>
<td>After complicated MI</td>
<td>2 wk after stable</td>
<td>6 wk</td>
<td>4 wk</td>
</tr>
<tr>
<td>After CABG</td>
<td>N/A</td>
<td>2 wk</td>
<td>N/A</td>
</tr>
<tr>
<td>Other contraindications</td>
<td>N/A</td>
<td>Unstable angina, severe heart failure, uncontrolled hypertension, uncontrolled arrhythmia, Eisenmenger</td>
<td>Severe hypertension, decompensated cardiovascular disease</td>
</tr>
</tbody>
</table>

*CABG = coronary artery bypass graft surgery; N/A = not applicable.

### References

2. Frechette P. Hélicoptère: oui ou non? L’Actualité médicale 2001; (January 10 supplement):6–7
4. De Lorenzo RA. Military and civilian aeromedical services: common goals and different approaches. Aviat Space Environ Med 1997; 68:56–60