

# Actionable Patient Safety Solutions™ (APSS™): Air Embolism

## How to use this guide

This APSS provides evidence-based resources and recommendations for air embolism for executives, leaders, clinicians, and performance improvement specialists. This document is intended to be used as a guide for healthcare organizations to examine their own workflows, identify practice gaps, and implement improvements. In it, you will find:

**Best Practice Summary:** A high level summary of evidence-based, clinical best practices. (page 2)

**Executive Summary:** Executives should understand the breadth of the problem and its clinical and financial implications. (page 2)

**Leadership Checklist:** This section is for senior leaders to understand common patient safety problems and their implications related to air embolism. Most preventable medical harm occurs due to system defects rather than individual mistakes. Leaders can use this checklist to assess whether best practices are being followed and whether action is needed in their organization around air embolism. (page 3)

**Clinical Workflow:** This section includes more specific information around air embolism across the continuum of care. Leaders should include the people doing the work in improving the work. This section outlines what should be happening on the frontline. Clinicians can use this section to inform leaders whether there are gaps and variations in current processes. This is presented as an infographic that can be used for display in a clinical area. (page 4)

**Education for Patients and Family Members:** This section outlines what frontline healthcare professionals should be teaching patients and family members about air embolism. Clinicians can inform leaders whether there are gaps and variations in current educational processes. (page 5)

**Performance Improvement Plan:** If it has been determined that there are gaps in current processes, this section can be used by organizational teams to guide them through an improvement project. (page 6)

**What We Know about Air Embolism:** This section provides additional detailed information about air embolism. (page 8)

**Resources:** This section includes helpful links to free resources from other groups working to improve patient outcomes and safety. (page 11)

**Endnotes:** This section includes the conflict of interest statement, workgroup member list, and references. (page 12)

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# Best Practice Summary

## Admission:

- Assess patient risk factors for an air embolism.
- Focus prevention efforts on reducing the risks of developing air embolism among high-risk patient populations such as patients undergoing neurosurgical procedures, intubated patients on a ventilator, and patients with central intravascular catheters.

## Routine Care:

- Ensure the patient is optimally-positioned to reduce risk of air embolism.
- Ask the patient to perform the Valsalva maneuver as appropriate.
- Use [methods and technologies to detect an air embolism](#).
- Avoid injecting the complete volume of syringe contents.
- Educate patients and family members about air embolism prevention.

## Management:

- Recognize signs and symptoms of an air embolism, intervene immediately, and consider activating the rapid response system.
- Once the patient is stabilized, examine the patient's physical and neurological state and minimize the size of the air embolism by administering 100% oxygen via non-rebreather
- In life threatening cases of air embolism aspiration may be necessary to resolve an air lock of the right ventricular outflow tract.
- Consider the use advanced management care such as the initiation of pressors and mechanical ventilation in serious cases

# Executive Summary

## The Problem

Because 15% of air embolism cases are asymptomatic and nearly all are sudden, standardized, universal prevention procedures are essential to reduce the occurrence ([McCarthy et al., 2017](#)). The prevention techniques are already available in most hospitals, therefore require little additional investment, but require prioritization and bundling to ensure consistency in delivery of air embolism prophylaxis.

## The Cost

Costly clinical implications among air embolism cases, such as neurological damage and death are associated with a 3.3% mortality rate ([Aujesky et al., 2008](#)). The cost of treatment is estimated to be approximately \$8,000-\$12,000 per patient. Treatment costs strongly outnumber the prevention costs and are more burdensome to the organization and all individuals involved even in cases where the patient survives significant damage.

## The Solution

This document provides a blueprint that outlines the actionable steps organizations should take to successfully reduce air embolism cases and summarizes the available evidence-based

practice protocols. This document is revised annually and is always available free of charge on our website.

## Leadership Checklist

On a monthly basis, or more frequently if a problem exists, the executive team should review the outcomes of patients at risk for air embolism. Use this checklist as a guide to determine whether current evidence-based guidelines are being followed in your organization:

- Measure and report the incidence of air embolism.
- If air embolism incident rates indicate room for improvement, initiate a PI (performance improvement) project. If a problem is not indicated, routinely reassess to identify gaps, and ensure integrity of the data collected.
- Ensure frontline involvement in air embolism prevention improvement activities. Maintain their engagement and remove barriers to progress.
- If a PI plan is put in place, measure the associated process outcomes.
- Ensure that air embolism prevention protocols are embedded into clinical workflows, whether electronic or paper.
- Ensure there are enough staff to effectively manage necessary preventive care.
- Ensure adequate training and documentation of air embolism prevention competencies and skills.
- Eliminate barriers to making rapid changes to documentation templates and order sets.
- Debrief on a regular basis to solicit team feedback about barriers to sustained compliance. Adjust the plan quickly and nimbly as needed.
- Hold staff accountable for providing the standard of care and reward success.
- Ensure that leaders have a simple process to oversee air embolism prevention improvement work while also considering how it aligns with other initiatives across the organization.
- Implement an electronic health records (EHR) system with decision-making support to ensure that every patient has an air embolism prevention and detection plan in place at all times during hospitalization.
- Educate clinicians on technologies that reduce the number of air embolism by preventing, detecting, and actively removing air in intravenous access lines.
- Establish a protocol to test physician competencies of placement of central venous catheters to prevent air embolism.
- For each potential air embolism cause, develop a checklist protocol for all caregivers to follow to avoid air embolism events.
  - Example: Pressurized intravenous infusion systems.
    - Eliminate all air from IV infusion bags before connecting to a patient.
    - Use an air detection technology to detect and eliminate air from infusion tubing.

# Clinical Workflow

## 1. ADMISSION

- Conduct a risk assessment and consider patient risk factors, especially those associated with planned hospital procedures.



## 2. PREVENTION

- Follow procedural precautions to reduce likelihood of air embolism in high-risk patient populations groups such as patients undergoing neurosurgical procedures, on a ventilator, and with central intravascular catheters.



## 3. ROUTINE CARE

- When placing and removing central venous catheters ensure the patient is well positioned (Trendelenburg position) and hydrated in order to have optimal placement. Have the patient perform a Valsalva maneuver upon removal or remove the catheter upon exhalation.
- During an angiogram, identify high-risk patients in advance. Hold syringes upright to ensure that any air travels away from the catheter and use air-in-line detection devices. Do not inject complete volume of syringe.
- Be aware of how to use common monitors to detect air embolism in patients
- Be aware of how air embolism signs present in conscious patients and clinical signs to watch out for
- Signs and symptoms are dependent on the volume of air. See the signs and symptoms by volume table in the [What We Know](#) section.



## 4. MANAGEMENT

As soon as an air embolism is suspected, steps should be taken immediately to prevent further air embolism.

- Prevent further air entrainment by removing the underlying cause.
- If an intra-arterial cannula is present, stop the flush immediately and fully open the rotating hemostatic valve. Allow the arterial pressure to slowly push the air back out or enhance the process by turning the system vertically.
  - If the patient is unresponsive, address airway, breathing, and circulation and initiate CPR as needed.
- Activate rapid response team or call additional staff for help.
  - Use pharmacological hemodynamic support as needed to maintain blood pressure and organ perfusion, including inotropes (dobutamine) and vasoconstrictors (phenylephrine, norepinephrine) to support systemic blood pressure
- Once stabilized, examine the patient, physically and neurologically, and administer 100% oxygen via a non-rebreather to minimize the size of the air embolus.
- In the case of a venous air embolism, perform Durant's maneuver (45-degree left-side down position) and keep the patient in the flat supine position (head down position has been suggested to worsen the cerebral edema).
- Activate cardiopulmonary resuscitation as indicated.
- Advanced management may include the initiation of pressors and mechanical ventilation.
- Use Positive End-Expiratory Pressure (PEEP) on ventilator during high-risk procedures on mechanically-ventilated patients
- Aspiration may be necessary in the event of an air lock of the right ventricular outflow tract. See [Garg et al.](#) for the intracardiac aspiration for a life-threatening air embolism.

## Education for Patients and Family Members

The outline below illustrates all of the information that should be conveyed to the patient and family members by someone on the care team in a consistent and understandable manner.

- Explain what an air embolism is, how it occurs, and the clinical significance if detected.
- Identify the patient's risk factors for an air embolism.
- Discuss the air embolism preventive measures in place.
- Describe what they should watch out for that may be a risk factor for an air embolism (e.g., patient positioning).
- Discuss [home infusion therapy](#) with the patient and family members. If the patient will be undergoing home infusion therapy, advanced education on air embolism prevention is necessary to prevent introduction of air into the patient's line access. Help the patient understand the alarms on the pumps and the proper patient positioning.

# Performance Improvement Plan

Follow this checklist if the leadership team has determined that a performance improvement project is necessary:

- **Gather the right project team.** Be sure to involve the right people on the team. If possible, you'll want two teams: an oversight team that is broad in scope, has 10-15 members, and includes the executive sponsor to validate outcomes, remove barriers, and facilitate spread. The actual project team consists of 5-7 representatives who are most impacted by the process. In general, the key is having the right people on the team (people impacted by the process, executive sponsors, and subject matter experts), no matter the size of the organization. Whether a discipline should be on the advisory team or the project team depends upon the needs of the organization. Patients and family members need to be involved in all improvement projects, as there are many ways they can contribute to safer care. Define what constitutes a quorum, which team members are needed to make the quorum, and who can serve as alternatives.

### Complete this Lean Improvement Activity:



Conduct a [SIPOC](#) analysis to understand the current state and scope of the problem. A SIPOC is a lean improvement tool that helps leaders to carefully consider everyone who may be touched by a process, and therefore, should have input on future process design.

## RECOMMENDED AIR EMBOLISM PREVENTION AND IMPROVEMENT TEAM

- Physicians
- Nurses
- Physical therapists
- Occupational therapists
- Residents
- Quality and safety specialists
- Risk management specialists
- Pharmacists
- Information technologists
- Rapid Response Team members
- Admitting and registration staff

Table 1: Understanding the necessary disciplines for an air embolism prevention improvement team

- **Understand what is currently happening and why.** Reviewing objective data and trends is a good place to start to understand the current state, and teams should spend a good amount of time analyzing data (and validating the sources), but the most important action here is to go to the point of care and observe. Even if team members work in the area daily, examining existing processes from every angle is generally an eye-opening experience. The team should ask questions of the frontline during the observations that allow them to understand each step in the process and identify the people, supplies, or other resources needed to improve patient outcomes.

Create a [process map](#) once the workflows are well understood that illustrates each step and the best practice gaps the team has identified ([IHI, 2015](#)). Brainstorm with the advisory team to understand why the gaps exist, using whichever [root cause analysis tool](#) your organization is accustomed to ([IHI, 2019](#)). Review the map with the advisory team and invite the frontline to validate accuracy.



#### AIR EMBOLISM PREVENTION PROCESSES TO CONSIDER ASSESSING

- Central line placement procedures
- Process of diagnosis
- Indications used for detection
- Activation of rapid response
- Patient positioning

Table 2: Consider assessing these processes to understand where the barriers contributing to air embolism rates may be in your organization

- **Prioritize the gaps to be addressed and develop an action plan.** Consider the cost effectiveness, time, potential outcomes, and realistic possibilities of each gap identified. Determine which are priorities of focus for the organization. Be sure that the advisory team supports moving forward with the project plan so they can continue to remove barriers. Design an experiment to be trialed in one small area for a short period of time and create an action plan for implementation.

#### The action plan should include the following:

- Assess the ability of the culture to change and adopt appropriate strategies
- Revise policies and procedures
- Redesign forms and electronic record pages
- Clarify patient and family education sources and content
- Create a plan for changing documentation forms and systems
- Develop the communication plan
- Design the education plan
- Clarify how and when people will be held accountable



#### TYPICAL GAPS IDENTIFIED IN AIR EMBOLISM PREVENTION

- Little prioritization around air embolism precautions
- Staff members do not know the clinical indicators of an air embolism
- Lack of understanding of personalized roles in air embolism prevention
- An air embolism is difficult to detect with current techniques.
- The length of time between suspicion and rapid response team activation is significant.

Table 3: By identifying the gaps in air embolism prevention compliance, organizations can tailor their project improvement efforts more effectively

- **Evaluate outcomes, celebrate wins, and adjust the plan when necessary.** Measure both process and outcome metrics. Outcome metrics include the rates outlined in the leadership checklist. Process metrics will depend upon the workflow you are trying to improve and are generally expressed in terms of compliance with workflow changes. Compare your outcomes against other related metrics your organization is tracking.

Routinely review all metrics and trends with both the advisory and project teams and discuss what is going well and what is not. Identify barriers to completion of action plans, and adjust the plan if necessary. Once you have the desired outcomes in the trial area, consider spreading to other areas ([IHI, 2006](#)).

It is important to be nimble and move quickly to keep team momentum going, and so that people can see the results of their labor. At the same time, don't move so quickly that you don't consider the larger, organizational ramifications of a change in your plan. Be sure to have a good understanding of the other, similar improvement projects that are taking place so that your efforts are not duplicated or inefficient.

[Read this paper](#) from the Institute for Healthcare Improvement to understand how small local steps



#### AIR EMBOLISM METRICS TO CONSIDER ASSESSING

- Length of stay
- Readmission
- Transfer to ICU
- Rapid response team activation
- Use of air embolism precautions and technologies by unit

Table 4: Consider evaluating related metrics to better understand air embolism presence and contributing factors

## What We Know About Air Embolism

Air embolism is the presence of gas (usually air) in the circulatory system. In the hospital setting, air embolism is usually the result of inadvertent injection of air into the venous system. Specifically, when a blood vessel is open to air and there is a pressure gradient favoring the passage of the air into the blood vessel, air can be drawn into the vasculature. Exposure to medical and surgical procedures present a high risk for air embolism, so much so that without these procedures, patients would have little to no risk of air embolism.

Inadvertent air injections can be sudden, as from an air-filled syringe or pumping system, or gradual, as through a continuous IV infusion. If gradual, it may not cause symptoms until serious damage to the pulmonary circulation has occurred. A patient's ability to tolerate and compensate for air embolism is variable, depending on general health status and presence of specific diseases (e.g., cerebrovascular).

Because CMS has categorized air embolism as one of its never events, meaning hospitals will not be reimbursed for the additional costs associated with hospital-acquired air embolisms, healthcare organizations have prioritized their prevention in recent years.

Although air embolisms are preventable, prevention is difficult. For example, patient positioning can be leveraged to prevent air embolisms. However, the optimal positioning to reduce air embolism may put the patient at risk for other complications. It is important to assess the risks and benefits of optimal positioning to prevent air embolism with risks for other complications during surgery.

Clinicians also face the challenge of recognizing and diagnosing air embolisms. There is no hallmark sign or symptom and the air embolism can manifest in various ways. Thus, an understanding of which patients are at an increased risk and when patients may be at a heightened risk can prepare the care team in the case of suspected air embolism, based on information from the patient and monitoring devices.

The vagueness of symptoms and subsequent lack of clinical experience in diagnosis can cause clinicians to think air embolisms are less common than is truly accurate. Consequently, they may not always be vigilant for recognition and prevention when providing care. However, because air embolisms can occur in virtually any setting when even just administering an intravenous medication, healthcare providers across the board should be educated and aware of the importance of air embolism prevention.

### **Right-left shunts, certain surgeries, and cannulation increase the risk of an air embolism.**

**Right-left shunt:** The risk of AE becomes more immediately serious in patients with any form of right-left shunt (an opening that allows blood to flow from the right side of the heart to the left), such as patent foramen ovale (PFO), atrial septal defect (ASD) or patent ductus arteriosus (PDA). 25-30% of healthy adults have PFO, and most of these are asymptomatic and undiagnosed ([Hagen, Scholz and Edwards, 1984](#)). For any patient with a known diagnosis of potential right-left shunt, the increased risk of air embolism must be documented in the EMR and clearly explained to all care-team members.

**Certain surgeries:** The brain is particularly vulnerable to air embolism, where even a few milliliters of air can cause a major stroke. A retrospective case study showed that AE occurred in 100 of 400 patients who underwent craniotomy in the seated position – an incidence of 25% ([Albin, 2011](#)). Other surgical procedures that create high risk for air embolism include cardiopulmonary bypass, in which there are many reports of fatal cases ([van, Koene and Mariani, 2014](#); [Robich et al., 2017](#)), as well as intrathoracic surgery, major joint surgery, Cesarean section, eye surgery ([Gayer et al., 2016](#)), pacemaker placement ([Xiao et al., 2016](#)), and major trauma. See “Surgical Procedures Associated with Vascular Air Embolism” and “[Examples of Nonoperative Procedures Associated with Vascular Air Embolism](#)” for a more comprehensive list of high-risk events and “[Relative Risk of Air/Gas Embolism](#)” for delineation of procedures by risk.

**Cannulation:** An air embolism can also occur when any type of intravascular cannula is used. This includes standard peripheral intravenous catheters, central venous catheters, pulmonary artery catheters, dialysis catheters, and arterial catheters. Pressurized intravenous infusion systems create a particularly serious risk of massive venous air embolism. One-liter plastic bags of intravenous crystalloid contain up to 150 cc of air. If this air is not carefully removed before the fluid bag is placed in a pressurized device, it can be forcefully pumped into the patient’s vein. There have been a number of published case reports of fatal or near-fatal AE from this mechanism ([Adhikary and Massey, 1998](#); [Aldridge, 2005](#)). Central circulation catheters (CVP, PA, “triple lumen”, etc.) pose an even higher risk. If such a catheter becomes disconnected and exposed in a sitting patient who spontaneously breathes, the pressure from inhaling can rapidly

suck massive amounts of air directly into the heart, with fatal results.

The volume of air and the rate of accumulation directly influence the morbidity and mortality of air embolism ([Mirsky et al., 2007](#)). Although the amount of air necessary to provoke circulatory failure is debated, it has been suggested that the lethal volume is approximately 200-300 mL ([Mirsky et al., 2007](#)), while other studies suggest that less than 50 mL of air is required ([Feil, 2015](#)). Both the volume and rate of the air accumulation are dependent on the size of the opening and the pressure gradient ([Mirsky et al., 2007](#)).

Signs and symptoms are dependent on the volume of air (table adopted from [Mirsky et al., 2007](#)).

| SMALL AMOUNT (<.5 ML/KG)  | MEDIUM AMOUNT (.5-2.0 ML/KG)   | LARGE AMOUNT (>2.0 ML/KG)  |
|---|--|--|
| <ul style="list-style-type: none"> <li>• Decreased EtCO<sub>2</sub></li> <li>• Increased EtN<sub>2</sub></li> <li>• Oxygen desaturation</li> <li>• Altered mental status</li> <li>• Wheezing</li> </ul> | <ul style="list-style-type: none"> <li>• Breathlessness</li> <li>• Wheezing</li> <li>• Hypotension</li> <li>• Pulmonary hypertension</li> <li>• Right heart strain</li> <li>• Peaked P waves</li> <li>• Jugular venous distension</li> <li>• Myocardial ischemia</li> <li>• Altered mental status</li> <li>• Cerebral ischemia</li> <li>• Bronchoconstriction</li> <li>• Pulmonary vasoconstriction</li> </ul> | <ul style="list-style-type: none"> <li>• Chest pain</li> <li>• Right heart failure</li> <li>• Cardiovascular collapse</li> </ul> |

## Clinical Implications

Central lines are the most common source of air embolism in the emergency department, with an incidence in 1 in 40 to 1 in 3000 central line cases ([Feil, 2015](#)).

It has been suggested that the average length of stay for patients with pulmonary air embolism is approximately six days with a post-discharge mortality rate of approximately 3.3% ([Aujesky et al., 2008](#)). It is important to note that in nearly 15% of cases, the patient may be completely asymptomatic ([McCarthy et al., 2017](#)).

Although air embolism occurrence is rare based on reporting, it is suggested that many instances may go unreported. One study found that, upon analysis of 11,000 central venous catheter placements, there was an air embolism incidence of 1 in 772 ([Vesely, 2001](#)). Arterial air embolism has the potential to cause ischemia or infarction in any organ, even when the volume of air is small.

Air embolism can often be immediately lethal and due to the difficulty in diagnosis, prevention is key.

## Financial Implications

Clinically, air embolism treatment can cost between \$8,000 and \$12,000 dollars per patient ([Clearline, 2016](#)). The damage from air embolism can range from brain damage, cerebral palsy, quadriplegia, and death and the legal settlement is typically in the millions.

## Detection

Presentation is variable, nonspecific, and often sudden ([Campbell, 2014](#)). Air embolism should

be considered as a possible diagnosis in these circumstances ([Mirsky et al., 2007](#)):

- Unexplained hypotension or decrease in EtCO<sub>2</sub> in surgeries performed where the patient is in reverse Trendelenburg position
- Shortness of breath after insertion or removal of a central venous catheter
- Sustained hypotension or hypoxia post-cesarean delivery
- Neurological symptoms, including altered mental status and seizures

In patients under anesthesia, reduced end-tidal CO<sub>2</sub> may be detected as the earliest indicator ([McCarthy et al., 2016](#)). Air-in-line devices in modern infusion pumps are helpful in the detection of bubbles within tubing. Precordial Doppler can also be employed during anesthesia where there is a high-risk for air embolism ([McCarthy et al., 2016](#)).

Methods of Detection of Air Embolism (adapted from [Mirsky et al., 2007](#))

| METHOD  | SENSITIVITY | LIMITATIONS   |
|---|-------------|---|
| Transesophageal Echocardiography  | High        | Expertise required, expensive, invasive, rarely available |
| Precordial Doppler Ultrasound   | High        | Obese patients  |
| Pulmonary Artery Catheter   | High        | Fixed distance, small orifice                             |
| Transcranial Doppler Ultrasound   | High        | Expertise required  |
| End-tidal Nitrogen  | Moderate    | N <sub>2</sub> O, hypotension                             |
| End-tidal Carbon Dioxide (unexplained decrease of 2mmHg)                  | Moderate    | Pulmonary disease   |
| Pulse Oximetry  | Low         | Late changes  |
| Direct Observation  | Low         | No physiologic data                                       |
| Esophageal Stethoscope  | Low         | Late changes  |
| Electrocardiogram (sinus tachycardia, right heart strain, T-wave changes) | Low         | Late changes  |

## Resources



### For Air Embolism Improvement:

- [NCBI: Air Embolism: Practical Tips for Preventions and Treatment](#)
- [NCBI: Acute Management of Vascular Air Embolism](#)
- [MDPI: Air Embolism: Practical Tips for Prevention and Treatment](#)
- [PSA: Reducing Risk of Air Embolism Associated with Central Venous Access Devices](#)
- [NIH: Venous Air Embolism During HOme Infusion Therapy](#)
- [Air Embolism Risk Factors, Detection, and Intervention Presentation](#)
- [Air Embolism Risk Factors, Detection, and Intervention Presentation in Spanish](#)

### For General Improvement:

- [CMS: Hospital Improvement Innovation Networks](#)
- [IHI: A Framework for the Spread of Innovation](#)

- [The Joint Commission: Leaders Facilitating Change Workshop](#)
- [IHI: Quality Improvement Essentials Toolkit](#)
- [SIPOC Example and Template for Download](#)
- [SIPOC Description and Example](#)

## Endnotes

### Conflicts of Interest Disclosure

The Patient Safety Movement Foundation partners with as many stakeholders as possible to focus on how to address patient safety challenges. The recommendations in the APSS are developed by workgroups that may include patient safety experts, healthcare technology professionals, hospital leaders, patient advocates, and medical technology industry volunteers. Workgroup members are required to disclose any potential conflicts of interest.

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