Actionable Patient Safety Solution (APSS) #12B: AIR EMBOLISM

Executive Summary Checklist

Inadvertent air embolism causes serious mortality and morbidity in hospitalized patients.

☐ Healthcare leadership should support the design and implementation of standards and provider training programs for AE risk reduction by:
  ● Accurately stratifying risk by ensuring that providers perform an AE Risk Assessment.
  ● Measure appropriate quality indicators related to AE, to close performance gap.
  ● Complete an in-depth chart review for in-hospital air embolism events to identify opportunities for improvement, and act on the lessons learned from that review.
  ● Adhere to AE best practices from national organizations.
  ● Ensure that healthcare professionals receive annual training on AE policies and processes.

☐ Assess patient-specific increased risk for AE among patients with the following:
  ● Known presence of right-to-left shunt anatomy, including patent foramen ovale (PFO), patent ductus arteriosus (PDA), atrial septal defect (ASD), etc.
  ● Requirements for large volumes of intravenous fluids, or rapid infusions using pressurized systems (e.g., major trauma surgery).
  ● Presence of or need for central venous access of any type.
  ● High-Risk surgical procedure or surgery in a high-risk position (surgery site above heart).

☐ Educate patients and families on AE risks, complications, signs and symptoms.

☐ Select technologies that reduce incidence of AE by preventing and detecting air in intravenous access lines (e.g., Clearline®).

☐ Implement an EHR with decision making support to ensure that every patient has an AE prevention and detection plan in place at all times during hospitalization.
The Performance Gap

Air embolism (AE) is defined as the presence of air (or other gas) in either the arterial or venous circulation. In the hospital setting, this is usually the result of inadvertent injection of air into the venous system. However, it can also result from traumatic injuries, surgical procedures, or exposure of venous access systems (e.g., central venous lines) to the open air. Inadvertent air injections can be sudden, as from an air-filled syringe or pumping system, or gradual, as through a continuous IV infusion. Outside of the hospital, air embolism can occur during SCUBA diving or with blast injuries.

In adults with normal anatomy (no right-left shunts), venous air embolism will enter the pulmonary circulation and become trapped in the lungs. Small amounts of pulmonary air embolism may be well tolerated – even up to 50 ml or more in a healthy adult. However, at some point the air load in the lung capillaries will impede the pulmonary circulation, resulting in pulmonary hypertension and eventually right-heart failure (cor pulmonale). This can lead to circulatory collapse and death.

The problem of venous AE becomes more immediately serious in the presence of any form of right-to-left (or transpulmonary) shunt, such as patent foramen ovale (PFO), atrial septal defect (ASD) or patent ductus arteriosus (PDA). PFO has an incidence of 25-30% in otherwise healthy adults, and most of these are asymptomatic and undiagnosed (HAGEN, SCHOLZ and EDWARDS, 1984). The presence of one of these forms of R-L shunt allows venous AE to bypass the lungs and enter the arterial circulation as a “paradoxical embolism,” where even small amounts of air can block circulation to vital organs. The brain is particularly vulnerable to arterial air embolism, where even a few milliliters of air can cause a major stroke. Because of the high incidence of undiagnosed PFO in adults, we usually do not know which patients are at risk. For any patient with a known diagnosis of potential right-left shunt, the increased risk of AE must be documented in the EMR, and clearly explained to all care-team members. The incidence of right-left shunts is much greater in newborns than adults; hence all infants should be treated as high risk for venous AE entering the arterial circulation.

Signs and symptoms of air embolism in conscious patients can include chest pain, dyspnea, shortness of breath, decreased level of consciousness, unconsciousness, sudden cardiac arrest, or neurological deficit from transient ischemic attack (TIA) or stroke. (See also signs and symptoms of VTE, in APSS #12A above.) Slower infusions of venous air may be asymptomatic until serious damage to the pulmonary circulation has occurred. The 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).

The literature on the various types of venous or arterial air emboli seems to agree on one important point: most of these should be considered “never events” – potential disasters that should never occur if proper safeguards, precautions, and procedures are followed. A retrospective case study by Albin showed that air embolism occurred in 100 of 400 patients who underwent craniotomy in the sitting 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. An excellent review of venous air embolism during surgery is found in (Palmon, Moore, Lundberg and Toung, 1997).

AE 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 – in other words, with any external cannulation of the circulation for any reason. Pressurized intravenous infusion systems create a particularly serious risk of massive venous air embolism. One-liter plastic bags of intravenous crystalloid, such as Lactated Ringer’s Solution, 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 to atmosphere in a sitting, spontaneously breathing patient, the negative intrathoracic pressure during inspiration can rapidly suck massive amounts of air directly into the heart, with fatal results (Ploner, Saltuari, Marosi, Dolif and Salsa, 1991).
An excellent review and bibliography of the diagnosis and treatment of all of these types of air embolism can be found in (Mirski, Lele, Fitzsimmons and Toung, 2007). Annual death rates from AE are difficult to document, because of the wide variety of causes and clinical settings of these cases. The serious nature of this problem is evidenced by the fact that there have been over 4,000 publications on the topic in the past 30 years (Mirski 2007).

**Leadership Plan**

**Identify**: Senior executive leadership that is committed to a reduction in AE

- Team ideally is led by a physician and administrative champions, ideally the Chief Medical Officer or Chief Nursing Officer
- Gather staff that have an in-depth knowledge base of disease process and prevention of VTE such as:
  - Physicians
  - Nursing Leaders
  - Advance Practice Providers such as Physical and Occupational Therapists
  - Physicians in training
  - Residents
  - Bedside Nurses
  - Quality Improvement staff
  - Safety/Risk
  - Pharmacy
  - Information Technology team with Electronic Medical Record

**Plan**: Senior executive leadership and clinical/safety leaders should agree on the best implementations in order to close their performance gap.

- Plan should include measurable appropriate quality metrics

**Timeline**: Senior executive leadership should select a goal and set a timeline to achieve said goal

**Resources allocated**: Senior executive leaders should set specific budget for said goal and plan

**System leadership and engagement**: Clinical and safety leaders should act as change agents and drive implementation

**Practice Plan**

- **Prevention**
  - Almost all in-hospital AE events are preventable and should never occur. This is the goal of this APSS: to make AE a “never event.”
  - Care providers must be educated in all of the possible causes of AE (see: Performance Gap).
  - For each potential AE cause, develop a check-list protocol to be followed for avoidance of the event.
    - Example: Pressurized intravenous infusion systems.
      - Eliminate all air from IV infusion bags before connecting to patient.
      - Use an air detection technology, such as ClearLine®, to detect and eliminate air from infusion tubing.
  - During surgery: When possible, avoid having surgical site well above level of the heart (e.g., “sitting craniotomy”).
○ Use Positive End-Expiratory Pressure (PEEP) on ventilator during high-risk procedures on mechanically ventilated patients.

● Diagnosis/Detection
  ○ Symptoms in conscious patient: chest pain, dyspnea, shortness of breath, decreased level of consciousness, unconsciousness.
  ○ Clinical signs: hypotension, decreased end-tidal CO2, rapid or irregular heartbeat, “mill-wheel” murmur, decreased SpO2 (late sign), peaked P-waves on ECG.
  ○ Special monitors: trans-esophageal echo (TEE), precordial Doppler, transcranial Doppler, pulmonary artery catheter, end-tidal nitrogen.

● Treatment
  ○ First, prevent further air entrainment by removing the underlying cause: reposition patient, stop intravenous air infusion, flood surgical field, etc.
  ○ Increase inspired oxygen fraction FiO2 to 100%.
  ○ Turn supine patient to 45-degree left-side down position – “Durant Maneuver.”
  ○ Promptly start CPR with chest-compression if no palpable pulse. Compressions may help purge air from heart.
  ○ If a central venous (CVP) or pulmonary artery (PA) catheter is present, attempt to aspirate air from the right atrium.
  ○ Use pharmacological hemodynamic support as needed, including inotropes (dobutamine) and vasoconstrictors (phenylephrine, norepinephrine) to support systemic blood pressure.
  ○ Hyperbaric oxygen therapy: unproven but supported by some clinical evidence.
  ○ Intravenous fluorocarbons: unproven in humans, supported by animal studies.

● Complete an in-depth chart review of hospital-associated AE events. Identify trends such as:
  ○ Service line.
  ○ Physician.
  ○ Diagnosis.
  ○ Risk factors.
  ○ Hospital units.
  ○ Patient mobility.

● Identify gaps in care that increase risk for AE development.

● Implement
  ○ Ensure interventions are patient-centered
  ○ Incorporate AE Risk Assessment into EHR for all new admissions.
  ○ Reassess risk periodically upon change in level of care, clinicians, and prior to discharge.
  ○ Understand your staff’s perception of the importance of AE precautions.
  ○ Consider yearly competence in AE prevention, detection, treatment.
  ○ Ensure that all team members - physicians, nurses, patient care assistants, trainees, pharmacists, transport personnel, physical therapists, patients and family members are aware of their roles in AE-prevention.

● Educate patients and families about the risks, complications, the importance of AE prophylaxis, and the symptoms of AE.

Technology Plan

Suggested technologies are limited to those proven to show benefit or are the only known technologies with a particular capability. Other technology options may exist or emerge after the publication of this APSS, please send information on any additional technologies, along with appropriate evidence, to info@patientsafetymovement.org.
With regard to VTE, there are a few novel technology platforms that offer a low entry cost that work alongside the Electronic Health Record (EHR). These technology platforms are secure with multimedia functions and can host checklists, education and much more to improve best practices and engagement across the care continuum. There is also technology that is important in the prevention of blood clots, like compression devices. Examples of those devices and technology solutions are detailed below and may be helpful in VTE prevention.

- “ASA Standard Monitors” should be used and watched carefully in every procedure done under general, regional, or local anesthesia. Particular attention must be paid to end-tidal CO2, which may provide early detection.

- High AE Risk Cases (e.g. sitting craniotomy): Use the following additional detection and treatment technologies when possible:
  - Precordial Doppler Ultrasonography: Early detection.
  - Trans-Esophageal Echocardiography (TEE): Early detection.
  - Pulmonary Artery Catheter: Potential treatment by aspiration from right atrium and ventricle.
  - End-tidal nitrogen (N2) monitoring: If there is no nitrogen in the inspired gas, then sudden appearance of end-tidal N2 implies AE until proven otherwise.

- Use air removal from infusion precautions with all intravenous cannulas, especially central venous (CVP).
  - Consider ClearLine® or equivalent technology for detecting and removing air from infusion fluids.
  - Ensure that all central venous catheters (CVP, PA, “triple lumen”, etc.) use Luer-Lock or other secure locking technology to guard against inadvertent disconnection. A disconnected CVP in a sitting, spontaneously breathing patient can be rapidly fatal.

- Electronic Health Record (EHR)
  - Web-based/EHR predictive algorithms that elicit specific data such as but not limited to vital signs (BP, Temp, HR, RR, and SpO2) lab values, nurses notes, and event reports.
  - The EHR can be a key component of a VTE prevention program by enabling computerized decision support to ensure that every patient has a valid VTE prevention plan at all times during their hospitalization (Morrison and England, 2015; Doyle and Hospital, n.d.).
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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. Some of the APSS recommend technologies offered by companies involved in the Patient Safety Movement Foundation that the workgroups have concluded, based on available evidence, are beneficial in addressing the patient safety issues addressed in the APSS. Workgroup members are required to disclose any potential conflicts of interest.

*This Workgroup member has reported a financial interest in an organization that provides a medical product or technology recommended in the Technology Plan for this APSS. References