Actionable Patient Safety Solutions (APSS) #12B:

Air Embolism

How to use this guide

This guide gives actions and resources for creating and sustaining safe practices for air embolism. In it, you'll find:

Patient Safety MOVEMENT

Executive summary checklist

Air embolism (AE) is the presence of gas (usually air) in the circulatory system. In the hospital setting, AE is usually the result of inadvertent injection of air into the venous system. Inadvertent AE causes serious mortality and morbidity in hospitalized patients.

Use this checklist to help you prioritize your actions and measure your organization's progress in your efforts to prevent AE:

Create an action plan

- ☐ Healthcare leadership should support the design and use of standards and provider training programs for reducing AE risk:
  - ☐ Ensure all providers perform an AE risk assessment to accurately stratify risk
  - ☐ Measure quality indicators related to AE to determine the best way to close your institution's performance gap
  - ☐ Complete an in-depth chart review for in-hospital AE events to find areas for improvement and address these areas
  - ☐ Adhere to AE best practices from national organizations
  - ☐ Ensure that healthcare professionals receive annual training on AE policies and processes

Ensure best patient care

- ☐ Clinicians should assess and act on AE risk for higher risk groups including:
  - ☐ Patients with right-to-left shunt anatomy, including patent foramen ovale (PFO), patent ductus arteriosus (PDA), atrial septal defect (ASD), etc.
  - ☐ Patients who need large volumes of intravenous fluids, or rapid infusions using pressurized systems (such as major trauma surgery)
  - ☐ Patients who have or need central venous access of any type
  - ☐ Patients who will undergo a high-risk surgical procedure or surgery in a high-risk position (such as a surgery site above the heart)
- ☐ Educate patients and families on AE risks, complications, signs, and symptoms
- ☐ Educate clinicians on technologies that reduce the number of AE by prevent, detect, and actively remove air in intravenous access lines
- ☐ Implement an electronic health records (EHR) system with decision making support to ensure that every patient has an AE prevention and detection plan in place at all times during hospitalization
- ☐ Utilize patient stories – in written and video form – to identify gaps and inspire change in your staff

What we know about air embolism

Causes and symptoms of AE

While AE is often the result of inadvertent injection of air, it can also result from traumatic injuries, surgical procedures, or exposure of venous access systems (such as central venous lines) to the open air. AE can also occur outside of the hospital, such as during SCUBA diving or with blast injuries.

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).

Signs and symptoms of AE in patients can include:
(See also signs and symptoms of VTE, in APSS #12A)

- Chest pain
- Dyspnea
- Shortness of breath
- Unconsciousness or decreased level of consciousness
- Sudden cardiac arrest
- Neurological deficit from transient ischemic attack (TIA) or stroke

In adults with regular circulation, venous AE will enter the pulmonary circulation and become trapped in the lungs. The systems of healthy adults may be able to tolerate small amounts of pulmonary AE – 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.

Right-left shunts increase AE risk

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). The presence of one of these forms of right-left 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.

Because of the high incidence of undiagnosed PFO in adults, it's difficult to 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. Since newborns are far more likely to have right-left shunts, all infants should be treated as high risk for venous AE entering the arterial circulation.

Certain surgeries increase AE risk

The brain is particularly vulnerable to arterial AE, where even a few milliliters of air can cause a major stroke. A retrospective case study by Albin showed that AE 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 AE during surgery is found in (Palmon, Moore, Lundberg and Toung, 1997).

Cannulation increases AE risk

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 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 (Ploner, Saltuari, Marosi, Dolif and Salsa, 1991).

Preventing AE

The literature on the various types of venous or arterial AE 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.

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 Young, 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, Lele, Fitzsimmons and Young, 2007).

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."

Leadership plan

Show leadership's commitment to AE

- Identify senior executive leadership that is committed to a reduction in AE
- Identify team leads, ideally physician and administrative champions, such as the Chief Medical Officer or Chief Nursing Officer
- Gather staff that have an in-depth knowledge base of disease process and prevention of AE such as:
  - Physicians
  - Nursing leaders

- Advanced Practice Providers, such as Physical and Occupational Therapists
- Physicians in training
- Residents
- Bedside nurses
- Quality improvement staff
- Safety/risk
- Pharmacy
- Information Technology team with EMR

Create the infrastructure needed to make changes

- Senior executive leadership and clinical/safety leaders should agree on the best measurable metrics and target actions to close the institution's performance gap
- Senior executive leadership should select a goal and set a timeline and budget to achieve said goal
- Clinical and safety leaders should act as change agents and drive implementation
- Utilize patient stories – in written and video form – to identify gaps and inspire change in your staff

Action plan

Find areas for improvement

- Complete an in-depth chart review of hospital-related AE events and identify trends such as:
  - Service line
  - Physician
  - Diagnosis
  - Risk factors
  - Hospital units
  - Patient mobility
- Identify gaps in care that increase a patient's risk for AE
- Understand your staff's perception of the importance of AE precautions
- Educate care providers in all of the possible causes of AE
- Consider yearly competence in AE prevention, detection, treatment
- Reassess AE risk periodically upon change in level of care, clinicians, and prior to discharge
- 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, and symptoms of AE, as well as the importance of AE prophylaxis

Create protocols to prevent AE

- Ensure interventions are patient-centered
- Incorporate AE Risk Assessment into EHR for all new admissions
- For each potential AE cause, develop a checklist protocol for all caregivers to follow to avoid AE events
    - Example: Pressurized intravenous infusion systems
        - Eliminate all air from IV infusion bags before connecting to a patient
        - Use an air detection technology, such as ClearLine , to detect and eliminate air from infusion tubing
- When possible during surgery, 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

Create protocols to detect and diagnose AE

- Be aware of AE symptoms in a conscious patient:
    - Chest pain
    - Dyspnea
    - Shortness of breath
    - Unconsciousness or decreased level of consciousness
- Be aware of AE clinical signs:
    - Hypotension
    - Decreased end-tidal CO2
    - Rapid or irregular heartbeat
    - "Mill-wheel" murmur
    - Decreased SpO2 (late sign)
    - Peaked P-waves on ECG
- Use special monitors for AE:
    - Trans-esophageal echo (TEE)
    - Precordial Doppler
    - Transcranial Doppler
    - Pulmonary artery catheter
    - End-tidal nitrogen

Create protocols to treat AE

- First, prevent further air entrainment by removing the underlying cause, such as 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"
- If a patient has no palpable pulse, promptly start CPR with chest-compression since 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
- Consider hyperbaric oxygen therapy – note this is unproven but supported by some clinical evidence

Technology plan

These suggested practices and technologies have shown proven benefit or, in some cases, are the only known technologies for certain tasks. If you know of other options not listed here, please complete the form for the PSMF Technology Vetting Workgroup to consider: **patient.sm/dgQogJ**

Consider implementing the following technologies:

System or Practice	Available Technology
ONC Meaningful Use-Certified Electronic Health Record (EHR) System with the following capabilities: • Computerized Provider Order Entry (CPOE) • Drug-drug interaction check • Drug-allergy interaction check • Clinical Decision Support tools (CDS)	
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 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 • **Note:** A disconnected CVP in a sitting, spontaneously breathing patient can be rapidly fatal

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 APSSs recommend technologies that are offered by companies involved in the Patient Safety Movement Foundation. The workgroups have concluded, based on available evidence, that these technologies work to address APSS patient safety issues. Workgroup members are required to disclose any potential conflicts of interest.

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