Air Embolism

Definition
Vascular air embolism is the entrainment of air (or exogenously delivered gas) from the operative field or other communications with the environment into the venous or arterial vasculature, producing systemic effects [Mirski et al. 2007].

Causes
Air embolism principally is caused by the entry of air into the vascular system (Fig. 1). Many different causes are described and most are of iatrogenic nature [Gabriel 2008, Wittenberg 2006, Josephson 2006, Patel 2000, Booke et al. 1999, Obermayer 1994].

Pathophysiology
The embolism is propelled into the heart, creating an intracardiac air lock at the pulmonary valve and preventing the ejection of blood from the right ventricle of the heart. The right side of the heart overfills with blood because less blood is ejected from the right ventricle. The force of myocardial contractions increases in an attempt to eject blood past the air lock. The forceful contractions cause small air bubbles to break loose from the pocket (Fig. 2). These small bubbles reach the pulmonary circulation system, creating an obstruction to forward blood flow and tissue hypoxia. Pulmonary hypoxia leads to vasoconstriction of the lung, which further increases the workload of the right ventricle and reduces blood flow out of the right side of the heart [Perdue 2001, Phillips et al. 1997].
Fig. 1: Air embolism is principally caused by the entry of air into the vascular system.

Fig. 2: Air within the right heart. The air can arrive at the heart and then cause an intracardiac air lock. The beating heart can also disintegrate the trooped air into smaller bubbles. These bubbles bear the risk of impairing blood circulation in smaller vessels. This is specially critical for the pulmonary circulation system.

Causes

- open IV systems
- not properly filled and vented infusion lines
- parallel infusions
- disregard of products’ instructions for use
Air Embolism

Causes

**Common causes for air embolism include:**
- Entering of air through open IV access and infusion systems (e.g. open stop cock, deconnection, leakage due to product failure). The amount of air entry is influenced by the position of the patient and height of the vein with respect to the right side of the heart [Josephson 2006, Perdue 2001, Muth et al. 2000].
- Not properly filled and completely vented infusion line.
- Parallel infusions, where gravity infusions and infusion pumps are connected together and interact through the infusion lines (Fig. 3). Such systems can develop a beading (fluid-air-fluid etc.), when the gravity infusion runs dry (Fig. 4) [Obermayer 1994].
- Incorrect execution of procedures for pressure infusion [Gray et al. 1999].
Fig. 3: Parallel infusion. Combinations of gravity infusion and pump driven infusion (blue) in parallel bears the risk of air embolism, when gravity infusion runs dry.

Fig. 4: Beading (fluid-air-fluid) in parallel infusion.
### Possible symptoms* / Clinical signs

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Source(s)</th>
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<tr>
<td>Anxiety [Josephson 2006]</td>
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<tr>
<td>Dyspnea [Mirski et al. 2007, Perdue 2001]</td>
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<tr>
<td>Chest pain [Mirski et al. 2007, Perdue 2001]</td>
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<td>Agitation or disorientation [Wittenberg 2006]</td>
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<td>Cyanotic appearance [Perdue 2001]</td>
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<td>Sudden loss of consciousness, circulatory shock or sudden death [Wittenberg 2006, Josephson 2006]</td>
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</table>

### Symptoms and clinical signs

The symptoms and clinical signs of air embolism are related to the degree of air entry into the circulation system. They usually develop immediately after embolization [Mirski et al. 2007, Wittenberg 2006, Josephson 2006, Perdue 2001].

### Complications

It is generally accepted that any amount of air that might enter the patient must be considered critical. The impact is directly correlated with the patient's condition, the volume of air and the rate of accumulation [Gabriel 2008, Mirski et al. 2007, Josephson 2006, Booke et al. 1999, Orebaugh et al. 1992].

Clinical complications are diminished cardiac output, shock and death [Wittenberg 2006, Josephson 2006].

* The symptoms are associated with vascular collapse and can be nonspecific.
** The cardiac “mill wheel” murmur (or cog wheel murmur) is a loud, churning murmur heard over the apex of the heart, sounding like machinery (a late sign).
Possible symptoms* / Clinical signs

- Anxiety [Josephson 2006]
- Tachycardia [Mirski et al. 2007, Wittenberg 2006]
- Dyspnea [Mirski et al. 2007, Perdue 2001]
- Tachypnea [Mirski et al. 2007, Wittenberg 2006]
- Chest pain [Mirski et al. 2007, Perdue 2001]
- Altered level of consciousness [Wittenberg 2006]
- Agitation or disorientation [Wittenberg 2006]
- Severe hypotension / shock [Wittenberg 2006]
- Shortness of breath [Perdue 2001]
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- Sudden loss of consciousness, circulatory shock or sudden death [Wittenberg 2006, Josephson 2006]

Consequences

Air Embolism

Risk related costs for the healthcare institution

Even non-fatal episodes of venous air embolism lead to extensive involvement for diagnostic (e.g. blood-gasanalyses, echocardiography, ultrasonography) and therapeutic interventions (e.g. oxygen, intravascular volume expansion, catecholamines) [Mirkhi et al. 2007, Muth et al. 2000, Booke et al. 1999].

A cost evaluation of the risk can be done by assigning costs to their related clinical treatment and resulting extended length of stay. The cost can be calculated using the average daily cost [Gianino 2007, Bertolini 2005] of the expected clinical treatment. Fig. 5 shows the results of such a calculation for selected examples of complications.

Conclusion

Preventing the entrance of air into the patient’s circulatory system can result in tangible budget savings for the healthcare provider. In the case of severe multiple complications which require full ICU treatment, a hospital may save up to 56,670 € per single case.

Financial impact

Severe complications may lead to an additional financial burden of up to 56,670 € per single case of air embolism.
Air Embolism

Preventive strategies

Fig. 6: Trendelenburg position for the insertion of central venous catheter.

Fig. 7: A siphon (>20 cm) protects against the ingress of air in the infusion set.

Fig. 8: In parallel infusions, the three-way valve of the bypass should be placed in the ascending siphon tube. Use a check valve for gravity infusions.
Preventive strategies

- For the placement of a peripheral cannula, the risk of air embolism can be reduced by ensuring that the selected arm of the patient is kept below the level of the heart during the insertion or removal procedure [Gabriel 2008].
- For the central venous catheter, the best position for its insertion or removal is in the supine or Trendelenburg position. This minimizes the risk of air embolism (Fig. 6) [Gabriel 2008, Mirski et al. 2007, Wittenberg 2006, Josephson 2006, Dougherty 2006, Perdue 2001].
- Follow the instructions for use of the IV equipment and IV containers.
- The incidence of air embolism can also be reduced by the use of Luer-Lock connections. This minimizes the potential for the accidental disconnection of administration sets and syringes from intravenous catheters [Gabriel 2008, Perdue 2001].
- Leaking infusion tubes should be changed immediately to eliminate the risk of air being drawn into the vascular system [Perdue 2001].
- Infusion regimens should always be set up to create a siphon (>20 cm) in the infusion system, which protects against the ingress of air (Fig. 7, 8) [Riemann 2004].
- Modern infusion filters are able to separate 100% of air from infusion lines in addition to the removal of particles and bacteria [Riemann 2004].
- Usage of modern infusion sets featuring an air stop mechanism [Riemann 2004].
**Air Embolism**

**Risk prevention**

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**Intrafix® SafeSet**

The safest and most convenient IV-Set.
A unique airtight 15 μm filter membrane in the drip chamber (AirStop):
- Acts as a barrier, protecting against air infusion.
- Prevents the infusion line running dry and air getting through to the patient.

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**Safeflow / Ultrasite®**

Capless valves for safe and convenient access to the infusion line.
The valve continuously maintains the closed system.
- Closed valve prior to activation.
- Air tight, leak resistant sealing when Luer cone connects to the valve.
- Closure of the valve when Luer connection is disconnected.

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**Discofix® C**

The unique stopcock for premium safety.
- A special material prevents air embolism by eliminating stress cracks.
- The unique Discofix® C resists all pharmaceutical agents even during long-term application.
Intrapur® and Sterifix® Infusion Filters
A whole range of filters for safe infusion therapy.
- Two hydrophobic polytetrafluorethylene (PTFE) membranes ensure reliable air venting elimination of filter position during application.

Mandrins / Stylets
Mandrin / Stylet for B. Braun IV catheters allowing a safe and convenient short-term interruption of IV administration.
- Secure Luer-Lock connection between mandrin and catheter prevents air entrance during interruptions in IV administration.
Air Embolism

Literature


Lamm G, Auer J, Punzengruber C, Ng CK and Eber B. Intracoronary air embolism in open heart surgery – an uncommon source of myocardial ischaemia. Int J Cardiol 2006; 112(3): 85-6


Phillips LD, Kuhn MA. Manual of intravenous medications. Lippincott Williams & Wilkins 1997; 294-95

Riemann T. How many "milliliters" of air will lead to an air embolism? *Die Schwester Der Pfleger* 2004; 8: 594-595


Wong AY, Irwin MG. Large venous air embolism in the sitting position despite monitoring with transoesophageal echocardiography. *Anaesthesia* 2005; 60(8): 811-3
Air Embolism
The summarized scientific information in this document has been prepared for healthcare professionals. It is based on an analysis of public literature and guidelines. The intention is to give an introduction to the risks commonly associated with infusion therapy and to increase the awareness of healthcare workers to these kinds of problems. Due to its summary nature, this text is limited to an overview and does not take into account all types of local conditions. B. Braun does not assume responsibility for any consequences that may result from therapeutical interventions based on this overview.