Death by “air”ror
How much is too much?

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LINE UP
1. Case Reports
2. How lethal is air? When air turns bad
   It’s invisible- how do you know?
3. How’s the air getting in?
4. Stop the air flow!
5. No air allowed!
What is an AIR EMBOLISM?

- Air embolism is a rare, potentially catastrophic and often underappreciated complication of vascular access devices.
- Entry of air into the venous or arterial vasculature.

Case Reports

- 8 mth old; jugular IV started for hydration
- Family reported to nurse air bubbles seen in the line, after nurse squeezed IV bag.
- Baby then screamed, turned blue, arrested and died
- Cause of death: cerebral air embolism

Kendyll Bliss

http://www.sptimes.com/2003/02/09/Columns/A_couple_s_loss_may_0.shtml
4 wk. old infant, peripheral IV infusion via pump started

- 1 minute later, IV set seen to be 2/3 empty
- Cyanotic, with grunting, mottled skin and unmeasurable BP
- Full recovery
- Causation: **inadequate priming of administration set**

14 y.o. boy received 2 infusions of pantolac in 100mL NS & lactated ringers via peripheral IV.

- Autopsy revealed copious fine frothy red blood found in svc, ivc, neck veins, heart; sc emphysema over upper parts of body
- Cause of death: venous air embolism following **iv infusion**

62 y.o. female with long-term PN via tunnelled silicone catheter

- Turned in bed and “suddenly felt generally uncomfortable with severe air hunger” and became cyanotic but no other signs/symptoms
- Recovered rapidly with O2 8L/m and placement in left lateral decubitus position
- **Catheter was torn** in 2 at a point between the sutures and the catheter hub

72 year-old patient **unintentionally disconnected the cvad**

- Found unresponsive with severe tetraparesis and akinetic mutism with stable cardiopulmonary status
- No neurologic improvement 3 months later
65 y.o male, 20 min. after I.J CVAD removed, up to bathroom to defecate.

Found on floor unconscious, ↑HR↑P↑BP, diffuse wheezes & crackles

Intubated, Hyperbaric oxygen (Patent foramen ovale)

Hours later, ↑cardiac output, ↑R, ↑T° >hematemesis, IJ site bleeding> DIC

Several days later, patient discharged home


53yo male treated for stomach cancer

Dialysis catheter removed

Patient died from air embolism during CVAD removal

Nurse prepared to remove CVAD used to deliver antibiotics

Nurse inadvertently pulled catheter out causing air embolism

Patient resuscitated; catastrophic brain damage

http://www.romeomedia.com/category/Legal%20Marketing?page=5


HOW LETHAL IS AIR?

Air Embolism
DEATH BY AIR


Is it common?

- Mortality rates due to catheters range from 5-30% \(^{\text{Natal, Bessereau}}\)
- Mortality associated with CVAD-related cerebral air embolism is 23% \(^{\text{Heckmann}}\)
  - 35% survived with severe neurologic deficits
  - 38% with good or complete recovery
- True incidence unknown. Crude prevalence 2.65 cases per 100,000 admissions \(^{\text{Bessereau}}\)
- Prognostic factors of mortality: cardiac arrest, ICU admission \(^{\text{Bessereau}}\)

Incidence

Figure 1. Air Embolism Reports to the Pennsylvania Patient Safety Authority, June 2004 to December 2011

- 15 (20%): Confirmed cases of air embolism
- 10 (20%): Suspected cases of air embolism
- 4 (5%): Situations creating high potential for an embolism

https://www.youtube.com/watch?v=oZ1_TA wCUWw
Right Heart Outflow Obstruction

- ↓ cardiac output
- Cardiovascular collapse/ MI

Pathophysiology...

Air in RV ventricle → Turbulence → Inflammatory response → RBC, platelets, fibrin & fat globules → Endothelial damage → Ischemia → Pulmonary edema


How Much is Too Much?

It depends...

**Location**
- Point of entry
- Embolus lodges

**Volume & Rate**
- High volume
- High rate

**Patient Variables**
- Position
- Cardiac & lung fx
- + pressure gradient

Size (& rate) matters!
4.8% PIVs flushed with saline demonstrated small air emboli on CT in right heart, pulmonary trunk and L brachiocephalic vein.

Source: air in syringe or cannula.

- Upright position
- Dyspnea
- Deep inspiration
- Hypovolemia

Air entry is more likely if pressure in veins is below atmospheric pressure.

Upright position particularly favours the rapid entry of air bubbles.

The minimum volume of air lethal to humans is not yet known. Two cases of 100-200 mL air, with one author stating lethal volume may be greater if normal cardiac function.

Infusion of 50 mL in healthy patients has been reported to cause hypotension, dysrhythmias and sometimes death.

It has been estimated from studies with dogs that as little as 20 mL/sec of air will be associated with symptoms of air embolism, and 70 to 150 mL/sec or 3-5 ml/kg of air can be fatal. ECRI, Minski, Natal, Wilkins, Pant.

- It has been suggested that the heart may be able to withstand large quantities of air if injected slowly, as dogs have been able to withstand up to 1,400 mL of air over a several-hour period.
- Exposing an opened IV line for only a second (i.e., when disconnecting tubing or changing the needleless connector) can let in 100mL of air.
- The closer the entry into the venous system to the right heart is and the faster the air entry, the smaller the amount of air is needed to cause a fatal outcome.
How Much is Too Much....

**Infusion-related Air Embolism**

- Little available data in relation to how much air is tolerated through an infusion system. The passage of a few air bubbles into the patient is a common occurrence, with no substantial evidence of adverse consequences.
- Pump air detector standard = 0.5mL/7.1mm
- Suggested lethal volume of ~225 mL in healthy adult is equivalent to >1 mL air bubble in standard IV tubing. Wilkins

**Volume**

Tiny but lethal:

- A small air embolus can be fatal

- As little as 0.5 mL of air in a coronary artery can cause ventricular fibrillation.

Natal, von Jurgenson, Levy

**Arterial Air Embolism**

- The lungs are able to filter air to prevent the air from travelling from the venous to arterial circulation up to a threshold of about 0.35 mL/kg/min,
- after which air cannot be filtered and may enter arterial system, with arterial bubbles detected in 50% of patients where air entry exceeds this threshold. Wilkins

**Patent Foramen Ovale (PFO)**

- 10-35% of patients have a subclinical PFO
Arterial Air Embolism

PFO: Increasing the risk of air embolism

- 40% of 26 cases of cerebral air embolism: patients had a patent foramen ovale;
- 15/31 patients with neurological symptoms following air embolism had right-to-left shunting via intrapulmonary shunt or patent foramen ovale. Wilkins, Besserau
- 0.5 mL has been reported as lethal in the left-side arterial circulation. Pant

How Much is Too Much....

Infusion-related Air Embolism

“If 1:4 healthy adults has a patent foramen ovale [likely asymptomatic], may be no safe maximum volume of air, although it is emphasized that clinically significant infusion-related air embolism is rare.” Wilkins

IT’S INVISIBLE- HOW DO YOU KNOW?

Air Embolism
Signs & Symptoms

Respiratory
- Dyspnea
- Tachypnea
- Cough
- Hypoxia
- Wheezing

Cardiac
- Chest pain
- Hypotension
- Cyanosis
- Tachycardia
- Tachyarrhythmia/bradyarrhythmia
- PAH

Ward, Armstrong, Haavik, Natal, Ruakin, Pant, Andrews, Odowd

Signs & Symptoms...

CNS (cerebral arterial embolism) ¹Heckmann
- Sense of impending doom
- Encephalopathic
- Sense of impending doom
- Focal Lesions
- Hemiparesis
- Loss of vision

High mortality rate - 36%

Ward, Haavik, Heckmann Odowd Natal, Odowd, Fail

Signs & Symptoms...

Likely to suffer long-term neurological deficits if present on ICU admission with:
- focal motor deficits
- Babinski sign
- On mechanical ventilation of 5 days or more

(OR = 12.78, 3.98–41.09; OR = 6.76, 2.24–20.33; OR = 15.14, 2.92–78.52, respectively) ⁰Bessereau

CNS

Ward, Haavik, Heckmann Odowd Natal, Odowd, Fail

Financial Consequences


Sources:
In et al. 2000, Nishi et al. 2007, Sjogren 1998
Mann et al. 2003, Boto-Barton et al. 2004, Tuck et al. 1994
Anesthesiology legal claims:
- Peripheral vascular catheters =2% of claims
  - Air embolism one of the most common complications – 8%
  - Air embolism claims had highest median payment and a rate of 100% payment-per-claim ($325,000, 2007 with a range of $25,800–$4,120,200)

Financial Consequences...

How's the air getting in?
Type of VADs

CVAD ➔ PIV

Table: Reports to the Pennsylvania Patient Safety Authority of Confirmed or Suspected Air Embolisms Related to Central Venous Access Devices, by Identified Associated Factors, June 2004 through December 2011

<table>
<thead>
<tr>
<th>CONTRIBUTING FACTORS IDENTIFIED</th>
<th>NUMBER</th>
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<tbody>
<tr>
<td>Insertion</td>
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<tr>
<td>Venous catheter placed in artery</td>
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<tr>
<td>Injection of air</td>
<td>1</td>
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<tr>
<td>Line exchange with head elevated</td>
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<td>Lines not clamped or capped</td>
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<td>No Yohosha maneuver</td>
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<tr>
<td>Not specified</td>
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<tr>
<td>Total</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure 1. Air Embolism Reports to the Pennsylvania Patient Safety Authority, June 2004 to December 2011

Besserreau

Causes of Air Embolism

- VADs accounted for 1/4 gas embolism (n=29/125 at Hyperbaric oxygen center)
  - Removal (n=9)
  - Accidental removal (n=8)
  - Manipulation and usual care (n=7)
  - Insertion (n=5)
  - Peripheral venous catheterization (n=2)
ACCIDENTAL DISCONNECTION

- Cause of almost half of cerebral air embolism cases in a review of 14/26 published case reports (1975-1998) \(^\text{Heckmann}\)

- Air embolism due to catheter disconnection has a mortality rate between 29% and 43% \(^\text{Pearson}\)

Air embolism caused by a laceration to central venous catheter during shaving \(^\text{Pearson}\)

Causes of Air Embolism...

http://www.fda.gov/MedicalDevices/Safety/AlertsandNotices/TubingandLuerM isconnections/ucm313275.htm
CASE STUDY
An ER patient had an IV heparin lock but no IV fluids had been started. The patient also had a noninvasive automatic BP cuff placed for continuous monitoring. The BP cuff tubing was disconnected when the patient went to the bathroom. When she returned, her spouse mistakenly connected the BP cuff tubing to the IV catheter and approximately 15 mL of air was delivered to the IV catheter. The patient died from a fatal air embolus, despite resuscitation efforts.

Infusion-related Air Embolism
- Improper priming of administration set (4 fatal cases in literature)
- Air vented bottles
- Fluid infusions that are finished
- Fluid infusions with rapid infusion through an air-filled drip chamber and the administration set remains open pose threats for air entry. Sing, Gardner, von Jurgenson
- (A one-litre sized crystalloid IV infusion bag can contain up to 60 mL of air) Schnoor

STOP THE FLOW!

Treatment
- Early detection and treatment are critical to prevent or minimize cardiovascular, pulmonary and neurologic damage. Andrew
- Stop air entry Wilkins, Garg, Heckman
- Notify MD; Call 911 if in alternate care setting; stay with patient and provide reassurance. von Jurgenson, Natal
- Left lateral decubitus and trendelenburg position
Air Embolism

**PREVENTION**

- **Education, practice guidelines & protocols**
- **Insertion of VADS**
  - Hydrate patient prior to insertion to correct hypovolemia whenever possible
  - Occlude needle hub and catheter during insertion/removal

**Treatment...**

- **100% O₂ artificial ventilation with airbag/endotracheal intubation**
- **CPR/ closed cardiac massage**
- **Fluid resuscitation (to increase intravascular volume, venous pressure and venous return)**
- **Inotropic support (e.g., dobutamine) if cardiovascular collapse to increase CVP**
- **Aspiration of air through distal lumen of CVP line or pulmonary artery catheter if catheter already in place**

**Hyperbaric oxygen therapy**, which is the main therapy for massive arterial air embolism, preferably initiated **within 3-5 hours** of the event (reduces size of air bubbles, accelerates nitrogen resorption and increases oxygen content of arterial blood)

**Diagnostic measures include:** ABGs, CXR, EKG, pulse oximetry, ventilation-perfusion scan, CT of chest and head, echocardiography, pulmonary artery catheter

**LONG TERM CARE PHARMACY SERVICES**
During CVAD insertion, stop ventilation during insertion of needle; increase right atrial pressure during tunnelling of catheter.

During peripheral cannulation and removal, place the arm below the level of the heart.

Minimize IV manipulations and management of scalp vein infusion;

Always use luer-lock connections to avoid accidental disconnections.

Ensure stopcocks that are not in use are switched off and covered with a Luer-Lok cap/needleless device.

Care & Maintenance of VADS: Air sensors/filters

Air sensors in infusion pumps. Adult infusion systems should be designed to prevent infusion of air >50 μL in normal use and to prevent infusion of volumes of air >1 ml in failure mode. The smallest volume of air possible for neonates, with a maximum air infusion volumes of 10 μL in failure mode.

Careful filling and handling of administration sets and thorough priming of filters (with filter in proper position) as per manufacturer’s guidelines. Gardner, Williams, von Jurgenson.

Check for air bubbles prior to starting the infusion.

Close clamps of the administration set prior to priming, then spike the fluid container and gently squeeze the drip chamber until it is half-filled. von Jurgenson.

If a burette is used, ensure the tubing is clamped off. von Jurgenson.

Remove air from infusion bags when infusing fluids using inflatable pressure infusors. von Jurgenson.
Care & Maintenance: Priming...
- If the set has a roller clamp, move it up to the drip chamber
  - close the clamp;
  - spike the bag;
- half-fill the drip chamber;
- open the clamp and prime the line

http://www.jems.com/article/patient-care/bubbles-air-proofing-your-iv-

Care & Maintenance of VADS: Air in line
- Remove any air bubbles in an infusion system detected during infusion, using a syringe at a downstream injection site (or alternatively by disconnecting the infusion set an allowing free flow to clear the air bubble, although this may increase the infection risk due to the disconnection). On occasion it may be preferable to discard the entire system and start again. In rare circumstances it may be necessary to use a new set to re-spike the infusion bag but this should be avoided. “Infrequent tiny pin head bubbles, even though not desirable, can be left without action, but should be monitored.” von Jorgenson

PREVENTION...
- Inspect all parts of the infusion system, for defects, damage or leakage von Jurgenson
- Ensure administration set junctions are secure, especially before patients get out of bed Gorski
- Check the infusion system regularly for: air bubbles; empty solution container (containers should not run dry); iv tubing that runs dry; leakage or disconnection von Jurgenson
- Close tubing clamps prior to changing fluid containers von Jurgenson
- Clamp off air-vented containers before they are completely empty von Jurgenson

PREVENTION...
- Never using scissors near the venous access device, as this could result in accidental severing of the catheter Gorski
- Avoid the use of hemostats which can crack the catheter hub Andrews
- Careful observation during shaving if a cvad is in the neck Schimp
Care & Maintenance of VADS: Patient Education

- catheter displacement and disconnection
- to properly prime tubing
- to check connections frequently
- to clamp the CVAD at appropriate times
- to avoid the use of sharp objects (such as scissors) near the catheter
- to avoid pulling on the line
- how to manage air embolism

Andrews, INS, Gorski

Removal of VADS

- Place the patient in the Trendelenburg position when possible (although this is somewhat controversial in the literature). If not possible, the supine position is sufficient.

- Position the catheter exit site (e.g., neck, arm) at a height lower than the height of the patient’s heart.

- Instruct the patient to hold his or her breath, and perform a Valsalva maneuver as the last portion of the catheter is removed.

- If Valsalva contraindicated with aortic stenosis, recent myocardial infarction, glaucoma, and retinopathy, ensure that a catheter clamp is present before changing administration sets or needleless connectors and time the removal during patient expiration.

Feil, INS, Schlimp, Natal, Mirski, INS, Feil, Masoorli, Fortrat, Clark
“No medical tragedy is greater than the avoidable iatrogenic death.

Perhaps saddest of all is the occurrence of venous air embolism, which is almost always the result of a therapeutic error or carelessness....

There is no instance in which a needle is placed in the venous system when the hazard of air embolism does not exist” Sowell et al.

SUMMARY

- Incidence of air embolism may be low and likely most cases may be subclinical.
- Potential for severe neurologic, respiratory and cardiovascular morbidity and mortality, with high mortality rates attributed to CVAD-related air embolism, ranging from 23-50%. Feil, Natal. The clinical relevance of a small air embolism is uncertain as is the amount of air required to cause harm.
- Any patient with a vascular access may be at a higher risk than expected due to the incidence of silent patent foramen ovale, increasing the risk of even a small amount of air entry.
- Healthcare professionals and carers manipulating vascular access devices must be aware of the danger of air embolism and adopt good practice to identify and manage air embolism and keep air out of our patients’ lines.

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