Michael Jew PGY-3 | Block 8 – VGH Neuroanesthesia | Jan 13 – Feb 9, 2020

How common is venous air embolism (VAE) in neurosurgery? Is there any evidence for use of a central venous catheter (CVC) for VAE management?

Venous air embolisms (VAEs) are potentially catastrophic events during therapeutic procedures. They are due to air entrainment from a sump-like effect created by a pressure gradient from an operative site that is higher than the heart[1]. In neurosurgery, VAEs are classically associated with posterior fossa cranial surgeries in the sitting or semi-sitting positions[2], which have fallen out of favour due to their inherent VAE risk. Craniotomy procedures are at additional risk due to the presence of non-collapsible venous channels and sinuses in the skull and brain, respectively. Fortunately, clinically significant VAEs are rare. VAE causing hemodynamically significant events due to air lock in the right ventricular outflow tract (RVOT) depends on both the volume and rate of air entrainment. Initial studies in dog and swine models led to consensus estimates of lethal VAE volume in adult humans to be 200-300 mL (3-5 mL/kg)[3]. Air entry into the pulmonary vasculature also activates a systemic inflammatory response and causes hypoxia from increased physiologic dead space[4]. The presence of a PFO and right-to-left intracardiac shunt can also result in cerebral ischemia due to arterial embolization of much smaller volume VAEs.

The true incidence of VAE is unclear given the variable detection modalities and their accuracies. VAE are likely underreported due to subclinical presentation or lack of dedicated monitoring in non-neurosurgical operations. Common VAE detection techniques in descending order of sensitivity include transesophageal echocardiogram, pre-cordial doppler, end-tidal CO2 and hemodynamic changes[1]. VGH utilizes pre-cordial doppler, which while non-invasive and highly sensitive in detecting as little as 0.05 mL/kg air, has poor specificity. Reports of overall neurosurgical VAE incidence range from 1.6-93%[5]. With routine pre-cordial doppler, VAEs were reported as 43-45%, with a 0-1% morbidity and mortality rate in patients undergoing sitting posterior fossa craniotomies[4]. This is in contrast to neurosurgical patients in a horizontal position with VAE detection in 12% of cases[2]. Ammirati et al. conducted a retrospective study in Australia and described 2 out of 41 (4.9%) clinically significant VAE detected by TEE for consecutive neurosurgeries done in the semi-sitting position[6]. In Germany, Jadik et al. applied a standardized protocol to minimize intraoperative VAE in the semi-sitting position over 1999-2004 for 187 consecutive neurosurgical patients[7]. Their protocol entailed strict standardized preoperative and intraoperative TEE monitoring, exclusion of patients with patent foramen ovale, right atrial CVC, PEEP and fluid goals. They reported 3 (1.6%) relevant VAE events leading to decrease in end-tidal CO2 and 1 (0.5%) hemodynamically relevant VAE.

In the event of a clinically significant VAE causing cardiovascular collapse, effective management depends on prompt diagnosis and treatment centered on immediate resuscitation per ACLS algorithms and prevention of further air entrainment. The latter involves repositioning the surgical site below the level of the heart, packing the surgical field with saline-soaked gauze, bone wax application and bilateral jugular compression. The Durant maneuver, partial left lateral decubitus, with Trendelenburg, has also been advocated to dislodge an air lock from the RVOT, despite lack of efficacy in canine studies[1,8]. Likewise, chest compressions with CPR may also facilitate break up of an air lock.

While intuitive, aspiration of entrained air from the right atrium via CVCs has limitations. Evidence on various CVCs in removing VAE come from canine studies from the Artru group at the University of Washington, Seattle in the 1980s[9,10]. Intentional lethal doses of venous air were injected into dogs sited with various sized CVCs, which were compared on their ability to retrieve air. Swan-Ganz catheters showed only 6-16% success rate in air aspiration versus 30-60% by the 14-gauge Cook Bunegin-Albin multi-orifice catheter stocked at VGH. Even with optimal multi-orifice catheter placement 2-cm distal to the superior vena cava-right atrial junction, average aspiration of air has ranged from only 15-20 mL, which may not yield hemodynamic improvement[11,12]. A swine study also showed significant air transit into the right ventricle within five seconds of injection that became unreachable by atrial catheters[13]. Accordingly, albeit routinely taught in crisis resource management, there is no clinical data to support the emergent insertion of CVCs in acute VAE management. This is echoed by anecdotal polling of the VGH Neuroanesthesia group, in which usage of multi-orifice catheters is rare, and likely only pre-emptively inserted for uncommon, high-risk sitting craniotomy cases.

References:

1. Mirski MA, Lele AV, Fitzsimmons L, Toung TJK. Diagnosis and Treatment of Vascular Air Embolism. *Anesthesiol J Am Soc Anesthesiol*. 2007;106(1):164-177.

2. Black S, Ockert DB, Oliver WC, Cucchiara RF. Outcome following posterior fossa craniectomy in patients in the sitting or horizontal positions. *Anesthesiology*. 1988;69(1):49-56.

3. Toung TJK, Rossberg MI, Hutchins GM. Volume of Air in a Lethal Venous Air Embolism. *Anesthesiol J Am Soc Anesthesiol*. 2001;94(2):360-361.

4. Orebaugh SL. Venous air embolism: clinical and experimental considerations. *Crit Care Med*. 1992;20(8):1169-1177.

5. Symons NL, Leaver HK. Air embolism during craniotomy in the seated position: a comparison of methods for detection. *Can Anaesth Soc J*. 1985;32(2):174-177.

6. Ammirati M, Lamki TT, Shaw AB, Forde B, Nakano I, Mani M. A streamlined protocol for the use of the semi-sitting position in neurosurgery: A report on 48 consecutive procedures. *J Clin Neurosci Off J Neurosurg Soc Australas*. 2013;20(1).

7. Jadik S, Wissing H, Friedrich K, Beck J, Seifert V, Raabe A. A standardized protocol for the prevention of clinically relevant venous air embolism during neurosurgical interventions in the semisitting position. *Neurosurgery*. 2009;64(3):533-538; discussion 538-539.

8. Durant TM, Long J, Oppenheimer MJ. Pulmonary (venous) air embolism. *Am Heart J*. 1947;33(3):269-281.

9. Artru AA. Venous air embolism in prone dogs positioned with the abdomen hanging freely: percentage of gas retrieved and success rate of resuscitation. *Anesth Analg*. 1992;75(5):715-719.

10. Colley PS, Artru AA. Bunegin-Albin catheter improves air retrieval and resuscitation from lethal venous air embolism in dogs. *Anesth Analg*. 1987;66(10):991-994.

11. Albin MS. Venous Air Embolism: A Warning Not to Be Complacent—We Should Listen to the Drumbeat of History. *Anesthesiol J Am Soc Anesthesiol*. 2011;115(3):626-629.

12. Hanna PG, Gravenstein N, Pashayan AG. In vitro comparison of central venous catheters for aspiration of venous air embolism: effect of catheter type, catheter tip position, and cardiac inclination. *J Clin Anesth*. 1991;3(4):290-294.

13. Schäfer ST, Lindemann J, Neumann A, Brendt P, Kaiser GM, Peters J. Cardiac air transit following venous air embolism and right ventricular air aspiration. *Anaesthesia*. 2009;64(7):754-761.