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Essay

Venous air embolism in neurosurgery[☆]



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ABSTRACT

Venous air embolism is a potentially serious neurosurgical complication. Every neurosurgical procedure is at risk of developing the condition but the sitting and semi-sitting position represent a higher risk. The neuroanesthesiologist plays a key role in the management of the venous air embolism, from diagnosis to treatment. This article reviews the literature on air embolism in terms of its incidence, etiology, diagnosis and therapy.

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Embolismo aéreo venoso en neurocirugía

RESUMEN

El embolismo aéreo venoso es una complicación de neurocirugía que puede llegar a ser potencialmente seria. Todos los procedimientos neuroquirúrgicos tienen riesgo de presentarlo, siendo las posiciones sentada y semisentada las que mayor riesgo conllevan. El neuroanestesiólogo forma parte primordial en el manejo del embolismo aéreo venoso, desde su diagnóstico hasta el tratamiento. Este artículo revisa la literatura relacionada con el embolismo aéreo en cuanto a incidencia, etiología, diagnóstico y terapéutica.

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Introduction

Venous air embolism (VAE) is a potentially serious neurosurgical complication. Its incidence ranges between 16% and 86%, depending on the literature model studied^{1,2}; however, in most cases, it has no relevant clinical manifestations. This broad range in the incidence on VAE is probably due to the ample variety of surgical and anesthetic techniques reported and even more so, to the different diagnostic methods used.

VAE-related mortality in neurosurgery is unclear, but there are some case reports of fatal outcomes following the occurrence of a massive air embolism.³

The risk of developing a VAE exists for all kinds of neurosurgical procedures; however, its incidence is higher for procedures requiring the patient to be in a sitting⁴ or semi-sitting position.^{5,6} The incidence of air embolism in the sitting position is variable but has been described in up to 45% of the cases.⁷ It may also occur with the patient in lateral decubitus, supine or prone position.⁸ The procedures more commonly associated with VAE are craniotomy in the sitting position, surgery of the posterior fossa, and craniostomy repair.^{9,10}

In pediatric neurosurgery the incidence reported has ranged between 9.8 and 0.42%.^{11,12} The incidence reported in neuroendoscopic procedures is low, but it may also occur.¹³

Although it is infrequent, patients with severe pulmonary disease or obese patients may benefit from the semi-sitting or the sitting position for neurosurgery.¹⁴

Pathophysiology

Air embolism occurs in the presence of a pressure differential at two different sites of the venous system, which in turn causes a negative pressure or sub-atmospheric gradient between the right atrium and the cranial venous sinuses. When the venous system of the central nervous system is exposed to environmental pressure and there is a difference of at least 5 cm of H₂O between the two sites, there will be air inflow.^{15,16}

Several factors contribute to the clinical impact of air embolism, including air volume, the patient's position and the type of surgical procedure.⁹

In humans, the lethal dose of air embolism is 3–4 mL/kg.¹⁷ The volume of air in the venous system that may trigger clinical manifestations is around 100 mL for the adult.¹⁵ Once the air gets into the circulation it lodges inside the superior vena cava and the right atrium. Some of that air volume may pass through the tricuspid valve and reach the pulmonary artery. When the amount of air is small the pulmonary capillaries have the ability to filtrate it, but when the air volume is larger, the air passes into the pulmonary capillaries causing vasoconstriction and impairment of the ventilation and pulmonary perfusion ratio.¹⁵ This air may obstruct the pulmonary artery flow resulting in a drop in cardiac output, either due to acute right heart failure (obstruction of the right ventricle outflow tract) or due to a reduced left ventricular filling (decreased pulmonary veins flood flow).¹⁸

Etiology

As was already mentioned, VAE may occur during any neurosurgical procedure. The procedure with the highest risk of VAE occurrence is when the patient is required to be in the sitting or semi-sitting position; however, it is important to note that the fact of being in the supine position does not rule out the probability of VAE.^{19,20} For this reason it is increasingly less frequent to have the patient in the sitting or semi-sitting position in neurosurgery,²¹ not just because of the high incidence of VAE, but also because of the risk of other complications including sciatic nerve injury, macroglossia, and tension pneumocephalon, inter alia. These positions are increasingly less popular in North America, although in Europe they are still being used as a routine, particularly for surgery of the posterior fossa.²²

Surgery to correct craniostomy is one of the procedures with the highest incidence of VAE and represents an important cause of morbidity – mortality in the pediatric population.²³

Recently, surgery for deep brain stimulation with the patient awake for the treatment of Parkinson and other motion disorders has been associated with a high risk of developing VAE. Chang et al, found an incidence of 1.3% of VAE in a retrospective series of 467 patients undergoing deep brain stimulation.⁵ Other recently published trials have reported an incidence of VAE of 3.2% for deep stimulation surgery in a retrospective series of 287 cases, and an incidence of 4.5% in a prospective series with 22 cases.²⁴

Air embolism has also been reported in stereotactic surgery.²⁵ A Series with 36 stereotactic surgeries reported 3 cases of symptomatic air embolism (8.3%) and in 5 cases there was radiographic evidence of air embolism in postop CTs (13.8%). This study showed a relationship between the elevated head position and the occurrence of air embolism, even when the air volume did not affect the patient's hemodynamic stability.

Clinical manifestations

When the patient is awake during the surgical procedure, the VAE may manifest as a coughing episode associated with arterial oxygen desaturation, arterial hypotension,²⁶ dyspnea, chest pain and nausea. Furthermore, a de novo heart murmur may be identified at auscultation.^{27,28}

During the postoperative period patients may develop neurological impairment ranging from focal neurological lesions to coma.²⁹ Cardiovascular disorders may also develop, including acute right heart failure, pulmonary hypertension, myocardial ischemia, associated pulmonary edema,³⁰ and cardiovascular collapse.³¹

The presence of coagulopathy and reduced platelet count have also been reported following a VAE, apparently triggered by the effect of air bubbles on the pulmonary microvasculature that causes the release of inflammatory factors and platelet activation.^{27,32} However, Duda et al in his trial found no evidence of inflammatory markers when comparing patients in the sitting position versus supine position in neurosurgery.³³

Diagnosis

Capnography

A sudden drop in the end tidal CO₂ level associated to hypotension is highly suggestive of air embolism.⁸ Capnography is a readily available and economic diagnostic tool, with moderate sensitivity and specificity for diagnosing air embolism when the patient is awake or under general anesthesia.

Precordial Doppler

Precordial Doppler may detect the presence of air in the blood. It is highly sensitive as compared to capnography and conventional hemodynamic monitoring for the diagnosis of VAE. However, being a subjective, non-quantitative method, it may result in diagnostic false negatives. The transducer should be placed in the right atrium when the patient is already in the final surgical position.³⁴ A routine test should be done prior to starting the procedure: an amount between 0.25 and 1 mL of air or 3–5 mL of stirred saline solution is injected through the central catheter. The anesthesiologist should be familiar with the sound of the precordial Doppler when the air flows into the heart cavities in order to have a reference prior to starting the procedure.

Transesophageal echocardiography

Transesophageal echocardiography (TEE) has the advantage of making a precise diagnosis with the potential to render considerable information,³⁵ in addition to diagnosing the air embolism. Its use is essential for diagnosing the patent foramen ovale³⁶ that may be patent in up to 35% of the population and result in central nervous system embolism.³⁷ TEE is the most sensitive invasive method for diagnosing air embolism,⁹ in addition to the ability to diagnose paradoxical air embolism.³⁸ TEE allows for the diagnosis of small air volumes in the heart – between 0.01 and 0.19 mL/kg.³⁹

In a trial in India with 140 patients undergoing surgery of the posterior fossa, a comparison was made between using ETCO₂ and TEE for the diagnosis of air embolism. The conclusion was that in the presence of a diagnosis of air embolism using TEE with no associated changes in capnography, it is unlikely for the air embolism to cause any hemodynamic imbalances.⁴⁰ The disadvantage of ETT is that it is costly and requires specialized training of the anesthesiologist in order to make a precise diagnosis. Moreover, the routine use of transesophageal echocardiography is not a guarantee to diagnose air embolism in every case.⁴¹

Other diagnostic methods

During the postoperative period, the diagnosis may be done using CT. The presence of air in the dural venous sinuses, in the cortical vein or in the pterygoid plexus is diagnostic.²⁸

Another diagnostic method used is the measurement of expired nitrogen. The presence of nitrogen in the expired gas monitor when the patient is breathing 100% oxygen is highly

suggestive of VAE, but it is not widely used as a routine for neuroanesthesia monitoring.⁹

Because of its high sensitivity, the role of transcranial Doppler in the diagnosis of VAE is limited to the identification of arterial air embolism in the presence of a patent foramen ovale^{42,43}. The use of albumin micro aggregates and technetium for pulmonary ultrasound is one additional method to confirm the presence of air embolism.⁴⁴

Treatment

The treatment for VAE is aimed at stopping the inflow of air into the circulation and managing any complications that may arise.

Having a properly hydrated patient prior to the procedure helps to prevent the occurrence of VAE. Maintaining an adequate volemia (guided by the central venous pressure or dynamic variables such as changes in systolic volume) may reduce the pressure gradient between the right atrium and the venous port of entry.

If venous embolism is suspected, the anesthesiologist must immediately inform the neurosurgeon to start the irrigation of the surgical field and provide coverage to any blood vessels that may be exposed. 100% oxygen should be used and always avoid using nitrous oxide,⁴⁵ or any air/oxygen mixtures.

The head of the patient should be repositioned at the level of the right atrium and, if possible, place the patient in left lateral decubitus (Durant maneuver) so that the air bubbles move toward the right atrium. If the patient has a central venous catheter, any air lodged between the superior vena cava and the right atrium should be aspirated.⁴⁶ In a dog trial having a right atrium catheter available allowed for aspiration of up to 50% of the emboli air volume.⁴⁷

In the case of a massive embolism, advanced resuscitation maneuvers should be quickly initiated.¹⁵ Transient bilateral compression of the jugular veins has been a technique described to reduce the inflow of air through the exposed venous sinuses. By decreasing the cerebral venous flow, the venous retrograde flow increases and the inflow of air is interrupted. This is a controversial maneuver since it may raise the intracranial pressure, reduce brain perfusion and concomitantly compress the carotid arteries.

The use of PEEP is controversial; there is no evidence of improving the VAE in neurosurgery and it may further deteriorate the patient's cardiovascular condition.⁴⁸

The use of hyperbaric oxygen therapy has increased recently.¹⁸ Hyperbaric oxygen reduces the size of the bubbles by promoting nitrogen reabsorption and the passage of dissolved oxygen into the blood.⁴⁹ The use of hyperbaric oxygen has been more common in arterial air embolism in the brain. There are also a few cases reported in the literature using spontaneous ventilation during neurosurgical procedures with the patient in the sitting position and the use of echocardiography with positive results.⁵⁰

Conclusions

Venous air embolism may be a serious neurosurgical complication. The semi-sitting or the sitting position is the most

relevant risk factor. There are various diagnostic methods available, including transesophageal echocardiography as one of the most sensitive methods, but it requires adequate training of the anesthesiologist. The treatment is intended to reduce the airflow when the diagnosis is confirmed and to implement adequate resuscitation measures in case of a massive embolism.

Ethical disclosures

Protection of human and animal subjects. The authors declare that no experiments were performed on humans or animals for this study.

Confidentiality of data. The authors declare that no patient data appear in this article.

Right to privacy and informed consent. The authors declare that no patient data appear in this article.

Conflicts of interest

The authors have no conflicts of interest to declare.

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