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Perioperative anesthetic management for neurosurgical operations in a lounging, sitting or semi-sitting position

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In neurosurgery, positioning the patient in a lounging or (semi-)sitting position is used for surgical treatment of processes in the area of the posterior cranial fossa, as this can offer a number of advantages compared to other forms of positioning, e.g., good drainage of blood and cerebrospinal fluid as well as potentially better preservation of cranial nerve function. At the same time, this positioning requires vigilant perioperative anesthesiological monitoring. In addition to ensuring adequate cerebral blood flow, it is crucially important to recognize and treat a venous air embolism (VAE). The underlying mechanism of VAE is due to the elevated surgical area in relation to the heart and the resulting hydrostatic pressure difference between an open vein and the heart. If the incoming air enters the pulmonary arterial vascular bed, the effects are primarily equivalent to a pulmonary artery embolism and can lead to right heart failure and the need for resuscitation. It should be emphasized that the effects of a VAE are not primarily depending on the total volume of air entering the vasculature, but rather on the volume entering per time. Especially patients presenting with a persistent foramen ovale (PFO) are at high risk during operations in a (semi-)sitting position. In the case of VAE, this can lead to a direct passage of air bubbles from the right heart to the left heart, leading to cerebral and coronary vascular embolism with subsequent stroke or myocardial infarction. Therefore, there is a need for anesthesiologists to recognize and assess both a PFO before the start of positioning and an intraoperative VAE, as well as to treat this in a targeted manner in communication with the surgeon. Using transesophageal echocardiography (TEE), VAE can be directly visualized and objectively graded according e.g., to the "Tuebingen Venous Air Embolism Grading Scale". Depending on the severity of the VAE, various measures must be taken: information of the surgeon, avoidance of further air entry, treatment of the hemodynamic depression, evaluation of the grade of VAE and, if necessary, aspiration of the entered air or the so-called "air lock". Here, the authors discuss advantages and disadvantages, implementation, as well as special risks of this neurosurgical positioning, physiological changes caused by the sitting position itself, hemodynamic monitoring of the patient and intraoperative ventilation. A special focus is on pathophysiology, incidence, and TEE diagnosis of VAE in lounging or (semi-)sitting position, including discussion of the question of a PFO.

KEYWORDS

hydrostatic pressure difference, persistent foramen ovale, sitting position, transesophageal echocardiography, venous air embolism

1 Introduction

In neurosurgery, a sitting, semi-sitting, or lounging position might be beneficial for posterior fossa procedures because it facilitates access to the cranial nerves and thus helps to preserve their function (1). However, surgery in the sitting, semi-sitting, or lounging position continues to be met with pronounced skepticism because of the specific risks associated with it like pneumocephalus and venous air embolism (VAE). At the same time, there appears to be renewed interest in this positioning lately, as its advantages may actually outweigh potential risks (2–4). Based on extensive clinical experience, we put forward the present work in order to stimulate the debate and to provide guidance for the safe performance of neurosurgery in sitting, semi-sitting, or lounging position.

It is important to note that many of the recommendations in this article can also be applied for the safe care of patients in other surgical disciplines, as elevated upper body positioning is also used, for example, in the “beach chair” position for shoulder surgery or stabilization in the upper cervical spine.

In order to achieve the best possible result for the patient during surgical treatment, complex forms of positioning have been and are being used in several surgical specialties. This implies a critical role for anesthesiology in ensuring optimal vital parameters and mitigating complications arising from positioning, either by preventing them or by recognizing them at an early stage and administering appropriate treatment.

In the domain of neurosurgery, the patient’s positioning in a lounging or (semi-)sitting position for surgical intervention is a prevalent practice, particularly in posterior fossa procedures (2–4). This approach might offer several advantages over alternative positioning methods (1). In addition to the specific risks associated with the positioning itself, ensuring adequate cerebral perfusion and recognizing and treating VAE are of particular importance with these forms of positioning. In the context of anesthesia, transesophageal echocardiography (TEE) is important for the early detection of VAE, facilitating a targeted treatment approach in collaboration with the surgical team.

2 Definition and effects of lounging or (semi-)sitting position

2.1 History and current status

The utilization of the sitting position for surgical interventions on the cervicodorsal spine and for procedures within the posterior fossa was documented in the literature, particularly during the 1960s and 1970s (5). However, since the 1990s, there has been a decline in its frequency of use in the Anglo-American world by more than 50% (6). On the other hand, there appears to be renewed interest in this positioning recently, as its advantages may actually outweigh potential risks (2–4).

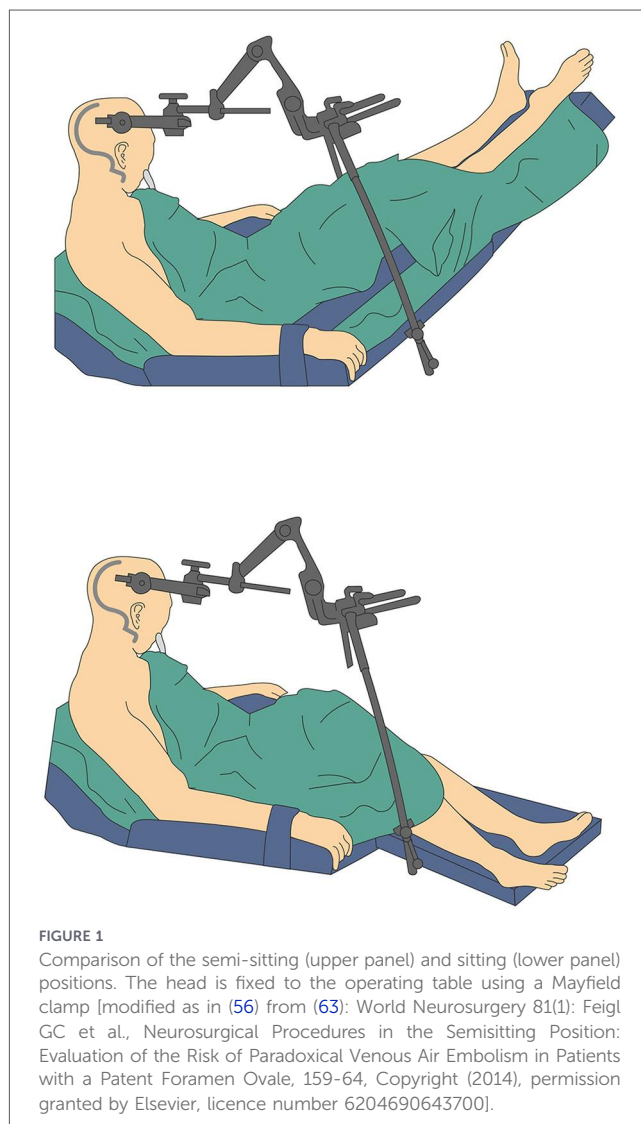
2.2 Implementation and risks of the (semi-)sitting position

In order to achieve the best possible access to the surgical area, the head of the patient in the supine position is connected to the

operating table by means of a three-point screw clamp (“Mayfield clamp”), thus fixing the cervical spine together with the head in the required position. The patient’s upper body is then elevated to form an angle of approximately 90°–100° with the horizontally positioned legs.

In the **sitting position**, the operating table is tilted as a unit to further expose the surgical site, with the patient’s legs pointing towards the floor and positioned well below the surgical area.

The **semi-sitting position** is intended to prevent the latter. In order to execute this positioning, it is necessary to flex the hips and bend the knee joints by approximately 30°. Subsequently, the operating table is tilted to an inclination that places the patient’s feet at the same level as their head, thereby ensuring the transverse sinus is also at the same level. In order to optimize the exposure of the surgical area, it is necessary to perform an anteflexion at the cervical spine level. This anteflexion should be more pronounced in the semi-sitting position than in the sitting position. In particular, if a lateral approach to the posterior fossa is chosen, the patient’s cervical spine must undergo not only notable flexion but also rotation in the sense of a lateral twisting movement. A sketch of the sitting and the semi-sitting position is displayed in [Figure 1](#).



To avoid damage caused by this special positioning, the following should be considered:

- The use of muscle relaxants may increase the likelihood of positioning injuries (7).
- Excessive flexion at the hip joint can result in a number of adverse consequences, including damage to the sciatic nerve and circulatory disorders due to compression of the iliac and femoral vessels.
- In the presence of degenerative spinal changes, such as osteophytes, the patient's positioning can cause these structures to protrude into the spinal canal, resulting in increased pressure and potential damage to the spinal cord.
- In addition to the swelling of the tongue, flexion of the cervical spine can also result in tetraplegia due to traction on the spinal cord and compression-induced spinal hypoperfusion, a condition known as midcervical flexion myelopathy (8–11). Nevertheless, this type of damage manifests itself with equal frequency in (semi-)sitting positions as in the prone position (11).

To avoid the problems described above one could perform a trial positioning of the awake patient beforehand (Figure 2). However, the usual alternative in clinical practice for detecting neurological abnormalities is to position the patient under electrophysiological intraoperative monitoring (IOM), which includes the recording of somatosensory evoked potentials. This method is employed to identify potential damage to the spinal cord at an early stage, thereby facilitating the avoidance of this severe complication (11–13). When interpreting the recorded evoked potentials, it should be noted that their amplitudes and latencies depend, among other things, on the depth of anesthesia and the degree of relaxation (14). Therefore, it is recommended to strive for a consistent depth of anesthesia using a processed electroencephalogram (EEG) monitoring device from the induction of anesthesia, without re-relaxing the patient, and a “baseline survey” of the evoked potentials before starting the positioning measures.

In addition to the standard visual positioning evaluation, it is important to ensure that two fingers can be comfortably placed

between the chin and sternum of the patient to prevent excessive anteflexion. Any circulatory disorders of the leg vessels might be readily identified by periodically assessing the capillary refill time at the toes.

In the “beach chair” position, a common approach in shoulder surgery, the patient's head is not secured to the table using a Mayfield clamp. Instead, it is placed in a neutral position and fixed with straps over the bony facial skull to prevent the head from slipping out of the head holder. In shoulder surgery, it is important to ensure not only the secure fixation of the head but also to avert increased lateral movement of the cervical spine due to intraoperative traction of the patient's arm. Such movement can lead to nerve damage and should therefore be avoided.

2.3 Advantages and disadvantages of the (semi-)sitting position

In a conventional position, such as supine or prone, the surgical area and the heart are on almost the same level, with no notable difference in height. Given that the intravascular pressure is consistently higher than the ambient pressure, the leakage of blood from an opened vein would impede the entry of air. In the event of surgical site bleeding, the surgeon's vision is compromised, thereby hindering the ability to accurately localize the bleeding source. In contrast, elevating the upper body changes the hydrostatic pressure difference between the surgical site and the heart, causing blood to drain out of the surgical site under the influence of gravity, thus improving the surgeon's view. The principle has found application in other surgical disciplines as well. For instance, urology has adopted it for robot-assisted prostatectomy, utilizing a reinforced Trendelenburg position. Similarly, trauma surgery has incorporated it to facilitate shoulder surgery when using the beach chair position. Likewise, in the field of neurosurgery, an operation in a sitting or semi-sitting position can offer similar advantages (6, 15). Among other things, the intracranial pressure (ICP) decreases and the cerebrospinal fluid outflow is improved. In neurosurgery, the gravitational separation of the tissue structures often results in improved surgical conditions, especially for operations in the area of the cerebellum or the 4th ventricle.

Even from the perspective of an anesthesiologist, a (semi-)sitting position presents certain advantages when compared to a supine or prone position. In obese patients in particular, the compliance of the thorax and lungs is increased by the descent of the abdominal organs and thus the diaphragm, making ventilation easier. In the context of airway management in a (semi-)sitting position, access to the patient's face and neck is less restricted, especially compared to prone position. Likewise, when using electrophysiological monitoring, motor responses, such as those of the facial nerve, can be seen more clearly on the patients' face. These advantages must be weighed against the potential risks (Box 1).

In addition to the occurrence of positioning injuries, venous air embolism (VAE) is a particular risk of the sitting or semi-sitting position. The severity of VAE can range from asymptomatic incidental findings to circulatory problems requiring catecholamines, and even to right ventricular failure with fatal consequences. In the presence of a patent foramen ovale (PFO), paradoxical VAE events can lead to cerebral and myocardial infarctions due to air-related arterial vascular occlusion.



FIGURE 2
Trial positioning on an awake patient.

BOX 1 Advantages and disadvantages of surgery in the (semi-)sitting position.

Advantages

- Improved ergonomics for the surgeon
- Improved exposure of the surgical site, especially for operations in the posterior fossa
- Improved cerebrospinal fluid and blood drainage
- Lower intracranial pressure
- Less blood loss and tissue trauma
- Easier positioning and ventilation, especially in obese patients
- Better access to the patient's face and neck
- Better access to patients in emergency situations
- Facilitated observation of motor response with IONM

Disadvantages

- Tongue swelling due to excessive flexion of the cervical spine
- Nerve damage (e.g., of the sciatic nerve or even tetraplegia)
- Cranial nerve damage
- Postoperative pneumocephalus
- VAE with hemodynamic effects that may cause right heart failure
- VAE with consecutive coagulopathy
- Paradoxical VAE with stroke and/or coronary artery occlusion in the presence of a PFO

IONM, intraoperative neuromonitoring; PFO, persistent foramen ovale; VAE, venous air embolism.

The presence of intracranial air, termed pneumocephalus, has been observed in a substantial proportion of postoperative imaging studies following intracranial surgery, both in the supine and (semi-)sitting positions. However, the occurrence of a tension pneumocephalus, necessitating surgical intervention, is a rare phenomenon, manifesting in approximately 3% of cases (16).

Taken together, the type of surgical positioning necessitates a meticulous risk-benefit analysis, which must be conducted from a surgical and anesthesiological perspective. Finally, it is imperative that patients are informed of the risks associated with the positioning to ensure their informed consent.

2.4 Physiological changes due to the (semi-)sitting position

Moving the patient from a supine position to a sitting position is regularly associated with hypotension (17). The underlying cause of this phenomenon is believed to be orthostatic dysregulation, characterized by the redistribution of blood volume to dependent body parts, a process known as venous pooling. This is associated with a reduction in cardiac preload. Studies on neurosurgical patients devoid of preexisting cardiovascular conditions have demonstrated that elevating the upper body is accompanied by a substantial reduction in atrial pressure and mean arterial pressure (18). Furthermore, there is a decrease in intrathoracic blood volume and cardiac output (19, 20). The use of anesthetics is known to reduce the reaction rate and effectiveness of the baroreceptor reflex as a physiological adaptation mechanism to

these positioning-related hemodynamic effects, thus exacerbating the risk of hypotension.

Cerebral blood flow is largely determined by mean arterial pressure (MAP), which serves as the driving force, and intracranial pressure (ICP), which functions as the downstream, post-capillary pressure. In the MAP range of approx. 60–160 mmHg, cerebrovascular autoregulation ensures sufficient blood flow to the brain via cerebral vasodilation or constriction. In the event that the blood pressure falls below the lower limit of the autoregulation range, there is a precipitous decline in cerebral blood flow and, consequently, in the cerebral oxygen supply, possibly resulting in neuronal damage. A deterioration in cerebral perfusion has been reported in patients with congestive cardiac failure when the MAP falls below the lower limit of cerebral autoregulation (21).

It should be emphasized that the lower point of the cerebral autoregulation range is shifted to the right (i.e., to higher MAP values) by pre-existing conditions, including but not limited to chronic arterial hypertension or atherosclerosis. In patients with cerebral ischemia, traumatic brain injury or subarachnoid hemorrhage, cerebral autoregulation may even be completely eliminated, so that cerebral blood flow is directly dependent on MAP. Intraoperative hypotension has been associated with a risk of myocardial or cerebral ischemia, even though the extent and duration of hypotension determine the specific effects (22–24). A retrospective study by Wachtendorf et al., analyzing data from over 300,000 patients, demonstrated an increase in the probability of delirium with increasing duration of hypotensive episodes, defined as a fall below a mean arterial pressure of 55 mmHg (25). Despite its clear risks to patients and the importance of blood pressure measurement for targeted therapy, a universal definition of intraoperative hypotension remains elusive. There is a general consensus, however, that a decrease of more than 20% in the baseline blood pressure as measured in an awake patient should be classified as hypotension (26).

2.5 Hemodynamic management of the patient for surgery in the (semi-)sitting position

2.5.1 Arterial blood pressure measurement

As the (semi-)sitting position favors arterial hypotension, meticulous monitoring of blood pressure is paramount. The process of accurately measuring blood pressure is not a simple task and is susceptible to various medical and technical challenges. The result depends on the location, the method and the shape of the pulse wave. Invasive blood pressure measurement has been demonstrated to exhibit superior temporal resolution and validity in comparison with non-invasive methods. The measurement of mean arterial pressure as the geometric mean of the pulse wave is the least prone to error (27). Indeed, the mortality rate is lower in patients who undergo invasive blood pressure measurement than in the comparison group who receive non-invasive measurements. This discrepancy is likely attributable to enhanced ability to identify hypotensive phases (28). In addition to the visualization of the absolute values, the varying amplitude of the arterial pressure curve can

be observed to discern a “swing” of the curve in the sense of a pulse pressure variation (PPV) for the purpose of assessing the patient’s volume status.

For a reliable measurement of cerebral blood pressure during surgery in a (semi-)sitting position, special attention should be paid to the correct positioning of the pressure transducer, which converts the mechanical signal of the arterial blood column into an electrical signal. The skull base or external auditory canal is widely accepted as the reference level for blood pressure in the brain; therefore, the arterial pressure transducer should be positioned at this level. In the context of noninvasive blood pressure measurement, e.g., on the upper arm, the hydrostatic pressure difference based on height differences must be taken into account when estimating arterial blood pressure in the brain. It should be noted that a height difference of 1.34 cm corresponds to a pressure difference of 1 mmHg. For example, if the mean arterial pressure (MAP) is measured using a cuff on the upper arm at 65 mmHg, a difference of 20 mmHg must be assumed at a height difference of 26.8 cm, which would correspond to a MAP in the brain of only 45 mmHg. The level of the pressure transducer should also be observed postoperatively during transport and during the stay in the post anesthesia care unit—all the more so, as the degree of upper body elevation varies more in these situations than during the operation itself.

2.5.2 Treatment of hypotension in (semi-)sitting position

In principle, any therapeutic intervention should address the underlying cause of the hypotension. Compensating for hypovolemia is of particular importance, given that even in the absence of blood loss, a (semi-)sitting position can result in relative hypovolemia due to the redistribution of blood to dependent body parts. A positive response to the administration of volume is indicated by an increase in blood pressure and a reduction in stroke volume variability (29). The application of α -sympathomimetics (e.g., norepinephrine or phenylephrine) to augment peripheral vascular tone can be advantageous as a supplement (30). However, it is important to acknowledge that an increase in systemic vascular resistance may be associated with a decrease in cardiac output. Consequently, this may result in reduced regional oxygenation of the brain and other organs.

By contrast, the maintenance of blood pressure using β -sympathomimetics is primarily achieved by increasing cardiac output, a process that appears to be beneficial in terms of cerebral oxygenation. However, this may lead to pronounced tachycardia, especially in the presence of hypovolemia (31, 32). In a nutshell, it is important to both maintain blood pressure and to ensure adequate cardiac output to secure sufficient brain perfusion. The necessary information for a differentiated and cause-oriented therapy of hypotension can be obtained by using TEE during neurosurgical operations in a (semi-)sitting position, in accordance with up-to-date guidelines.

Measures to prevent and treat intraoperative arterial hypotension in (semi-)sitting position are:

- Preoperative cardiac evaluation
- Close monitoring of mean arterial blood pressure (invasive measurement)
- Gradual positioning under close blood pressure monitoring
- Reduction of venous pooling through

- Compression of the lower extremities (stockings or alternating pressure cuffs)
- Positioning the lower legs at the level of the right atrium
- Adequate volume administration
- Use of a norepinephrine or phenylephrine as vasopressor
- Extended, differentiated catecholamine therapy depending on the TEE findings.

2.5.3 Central venous catheter

Historically, the central venous pressure (CVP) has frequently been used as a surrogate marker for the venous filling state. It was hypothesized that a normal to high CVP is equivalent to a normal volume status or mild hypervolemia. However, in many cases CVP may not provide a valid statement about the patients’ volume status. Consequently, the implementation of a central venous catheter (CVC) exclusively for the purpose of measuring central venous pressure (CVP) does not appear to be a valuable clinical practice.

At the same time, the CVP can be used to draw conclusions about the pumping function, especially of the right heart, or about the presence of a pulmonary artery embolism when observing trends or a sudden increase of CVP. Besides, a differentiated catecholamine therapy may be guided by determining the central venous oxygen saturation. Furthermore, the CVC facilitates the intravenous administration of medications such as catecholamines and osmotic agents in a safe manner. Given the rationale outlined, we suggest that all patients undergoing surgery in a (semi-)sitting position be administered a central venous line.

The desired positioning of the CVC tip can be achieved during the advancement of the catheter, either by means of intracardial ECG lead or by direct visualization in the TEE. In clinical practice, two distinct philosophies can be identified when positioning the tip of the CVC:

- A) CVC tip in the right atrium: Here, the aspiration attempt of an “air lock” (foamy, partially clotted blood that obstructs venous inflow into the right heart) is primarily via the terminal lumen.
- B) CVC tip in the superior vena cava: In this case, an air lock aspiration attempt may be carried out via lateral lumen openings. This procedure has been recommended in animal studies (33–35).

Both approaches can be considered equally safe in daily practice of anesthesiological care of patients in the (semi-)sitting position. The approach should be based on local conditions and the individual risk for a VAE. Note, that in the case of VAE, a multi-orifice catheter increases the probability that an orifice will be located where an air-fluid interface exists, thereby maximizing the chance of successful air aspiration (2, 36).

When selecting the catheter size, it should be noted that, according to the Hagen-Poiseuille formula for laminar flows, the volume of fluid that flows through a tube system (such as a CVC and connected extension set) per unit of time is highly dependent on the inner diameter and length of this tube system. This fundamental principle might also be applicable to turbulent flows of blood-air mixtures and to both passive flow and active

aspiration (37). If aspiration of the air-blood mixture is considered a therapeutic option for severe VAE, we suggest using a catheter with a large lumen and the shortest possible distance from the catheter opening to the end of the line. However, these large-lumen and stiffer catheters are also associated with a higher risk of injury to the myocardium. Therefore, it is advisable that they remain in the terminal section of the superior vena cava with the catheter tip, and not be advanced into the right atrium.

2.6 Intraoperative ventilation and application of positive end-expiratory pressure in the (semi-)sitting position

While large, randomized trials on the use of lung-protective ventilation strategies have been conducted in recent years for e.g., abdominal surgery (38), only few and small studies on the (semi-)sitting position exist.

If positive end-expiratory pressure (PEEP) is applied during ventilation of a patient in (semi-)sitting position, the CVP normally increases due to the overall increase in intrathoracic pressure. Therefore, the application of increased PEEP had been proposed as a strategy to reduce the risk of VAE. The rationale for this is the idea that, in the presence of euvoemia or mild hypervolemia, bleeding from a venous sinus or vein in the surgical site is more likely to occur than air entering the venous system during (semi-)sitting surgical procedures. However, at PEEP values of up to 15 cm H₂O, neither this effect (39) nor a significant increase in pressure in the sagittal sinus could be observed (40–42). Conversely, an elevated intrathoracic pressure has been observed to potentially reopen a functionally closed foramen ovale, thereby increasing the likelihood of paradoxical VAE (43, 44). Moreover, the rise in intrathoracic pressure can impede venous return to the heart, thus exacerbating cardiovascular dysfunction induced by VAE and intensifying (relative) hypovolemia. In contrast to the lack of benefit of increasing PEEP, hypoventilation can increase the pressure in the venous sinus (45).

The following conclusions can be drawn from the few studies that have been conducted:

- Oxygenation: PEEP of 5–10 cm H₂O has been demonstrated to indirectly enhance oxygenation in the semi-sitting position (46).
- Hemodynamics: PEEP (≤ 15 cm H₂O) can lead to a deterioration of the cardio-circulatory function in the (semi-)sitting position (47).
- Intracranial pressure: Changes in the PEEP (≤ 15 cm H₂O) can lead to an increase in ICP in (semi-)sitting position, particularly if the ICP is already elevated or if the cerebral reserve spaces have been depleted (48).
- Pressure in the venous sinus: PEEP ≤ 10 cm H₂O does not typically result in the intended increase in pressure within the venous sinuses of the brain (39).
- VAE incidence: PEEP (≤ 15 cm H₂O) does not directly prevent VAE in (semi-)sitting position (39, 45).

Consequently, intraoperative ventilation with high PEEP values in the (semi-)sitting position cannot be recommended (49, 50), and some authors explicitly advise against it (39). Standard,

i.e., lung-protective ventilation with a moderate PEEP of 5–10 cm H₂O is therefore the recommended approach.

3 Venous air embolism

The underlying pathological mechanism of VAE during surgery in the (semi-)sitting position is caused by the elevated position of the surgical area in relation to the heart. This difference in height results in a hydrostatic pressure difference between an open vein and the heart, allowing air to enter the venous bloodstream. The more pronounced this pressure difference is, the higher the probability of VAE (51). In neurosurgery, the sigmoid sinus, the transverse sinuses and the occipital sinus are particularly worth mentioning as large venous entry ports in the surgical area, although air can also enter through the emissary veins and diploic veins of the skull bone (52, 53).

Normally, veins collapse as soon as subatmospheric pressure occurs in the venous lumen. This collapse leads to the cessation of (venous) blood flow and prevents air from entering the venous bloodstream. By contrast, the venous sinuses of the brain are connected to the bone by connective tissue and are thus kept open. This anatomical peculiarity is the underlying mechanism that enables the occurrence of subatmospheric pressure in the venous sinuses and veins in proximity to the sinuses, thereby facilitating the entry of air in the event of vascular injury.

The possible predilection sites for venous air entry are as follows:

- a) The galea veins, which are adherent to the calotte and can be opened during preparation, e.g., with the raspatory.
- b) The diploic veins, which are located between the internal and external tabula of the skull bone. Upon opening the skull bone, this vascular system is exposed to the atmosphere and must be surgically closed. Typically, these vessels are sealed with bone wax.
- c) The emissary veins, which run in bony channels and connect the superficial cranial veins with the dura mater sinuses.
- d) The venous sinuses of the brain, which are formed by the dural leaves and also remain open when opened.

3.1 Incidence of VAE

In the literature, incidence values for the occurrence of VAE in the (semi-)sitting position vary widely, ranging from 76% for posterior skull surgeries and 25% for the spine up to 100% for neurosurgical procedures in the sitting position (53, 54). Notably, VAE can also occur during brain surgery in the supine position, e.g., VAE events were identified in 11% of cases with appropriate monitoring via TEE (55). Hurth et al. recently reported a differentiated incidence of VAE according to severity, with 41.2% (detection of air bubbles), 3.6% (drop in etCO₂ by more than 3 mmHg) and 0.8% (drop in blood pressure >20% or increase in heart rate >40%) (56).

However, when interpreting these data, it must be noted that both the definition of the occurrence of a VAE itself and the employed detection methods and their sensitivity are not uniform. This circumstance is reinforced by the fact that the literature regularly fails to provide information on the

underlying environmental conditions and physiological variables. Such variables include, but are not limited to, volume balance, transthoracic pressure, CVP, PEEP, systemic blood pressure, and the height difference between the right atrium and the surgical field. Thus, the true incidence of VAE during surgery in the (semi-)sitting position remains ultimately unclear, but is certainly dependent on the structure being operated on (brain tumor, vascular system, or bone).

3.2 Pathophysiological effects of VAE

Since the intruded air primarily enters the pulmonary arterial blood flow via the right atrium and right ventricle, causing a partial obstruction, the first effects of a VAE correspond to the clinical symptoms of a pulmonary artery embolism. Continued air entry will further impair the ventilation-perfusion ratio of the lung due to the increasing obstruction of the pulmonary vascular system, resulting in an oxygenation and CO₂-elimination disorder. Likewise, pulmonary vascular resistance (PVR) and thus the afterload of the right heart are increased. This effect is further amplified by a series of mechanisms, including the activation of the vascular endothelium, complement activation, cytokine release, production of oxygen radicals, formation of platelet microaggregates, and local as well as systemic inflammatory reactions (57). The increase in PVR in turn leads to an increased pressure in the rather thin-walled right ventricle, resulting in right heart dilatation with possible tricuspid insufficiency and cardiac arrhythmia. The enlargement of the right ventricle in turn leads to displacement of the cardiac septum with increasing compression of the left ventricle. This eventually results in a decrease in arterial blood pressure, coronary perfusion, myocardial contractility and even circulatory arrest. It is important to underscore that the clinical implications of VAE are not primarily dependent just on the absolute volume of air that has entered, but rather on the relative volume of air that has entered per unit of time.

In addition to the scenario of VAE described above, the possibility of paradoxical air embolism should be particularly noted, for which two mechanisms exist:

- a) In the case of continuous air entry, pulmonary arterial obstruction leads to an increasing exhaustion of the filtration capacity of the vascular bed for the air bubbles that have entered, so that these can finally travel through the pulmonary circulation and enter the systemic circulation (52).
- b) To ensure that the fetal circulation can exist until birth bypassing the pulmonary circulation, there is an open connection at the atrial level, the foramen ovale. This foramen ovale typically closes functionally immediately after birth by means of a membrane overlap, which should grow together with the left atrium wall over time. However, a PFO exists in about 25%–30% of the population, which is only functionally closed – i.e., without adhesion of the membrane to the atrial wall (46, 52, 58) – and can therefore reopen when the right atrial pressure exceeds the left atrial pressure, allowing air to directly pass from right to left in the case of VAE.

3.3 Preoperative evaluation of a patent foramen ovale

In order to assess the individual risk of a patient for paradoxical VAE preoperatively, the evaluation of a PFO is highly desirable. A plethora of methods are available for this purpose, including transcranial Doppler sonography (TCD), transthoracic echocardiography (TTE), and transesophageal echocardiography (TEE). Among these, TEE had long been regarded as the preferred technique and the gold standard (59). However, this exclusive position of TEE has recently been called into question (60). Advancements in technology, exemplified by techniques such as “harmonic imaging” and “second harmonic imaging”, have led to the emergence of TTE as a diagnostic modality that is comparable to, and in some cases, superior to TEE. This advancement is particularly notable when contrast agents, such as agitated saline solution are used, and a Valsalva maneuver is performed (61, 62).

Consequently, TTE is considered a noninvasive procedure that, when utilized appropriately, exhibits adequate diagnostic sensitivity and can be performed on an outpatient basis in advance of a planned operation. Alternatively, in everyday clinical practice, a PFO can also be assessed immediately before the start of surgery, i.e., after the induction of anesthesia in the intubated patient via TEE by an experienced examiner.

In the event that surgery is scheduled in the (semi-)sitting position, the presence of a PFO is considered an elevated risk of paradoxical air embolism, which can potentially lead to neurological impairment and even life-threatening complications. When a PFO is detected, an individual risk-benefit analysis should therefore be carried out prior to surgery and the planned procedure – surgery in a (semi-)sitting position or alternatively in a supine or prone position – should be discussed with the patient. Early preoperative screening for PFO in good time before surgery facilitates timely interdisciplinary consultation regarding the optimal form of positioning for the planned procedure, taking into account the best risk-benefit ratio (Figure 3).

In the event that the examination and the associated diagnosis are not carried out until the patient is under general anesthesia, we suggest that the alternatives be thoroughly discussed with the patient during the informed consent discussion, employing a “what-if” approach.

3.4 Diagnosis of intraoperative VAE

In order to ensure the safety of procedures performed in a (semi-)sitting position it is important to diagnose intravascular air entry as early as possible, because the effects of VAE are determined by the total volume and by the volume per time of the air that has entered the vascular system. The possible detection methods for this vary considerably in terms of their sensitivity (Table 1).

Transesophageal echocardiography (TEE) is currently considered the gold standard for detecting intraoperative VAE due to its high sensitivity, as it can detect even very small amounts of air. In addition to the high sensitivity and specificity for VAE detection, TEE furthermore offers the advantages of direct visualization of air leakage through a PFO into the left

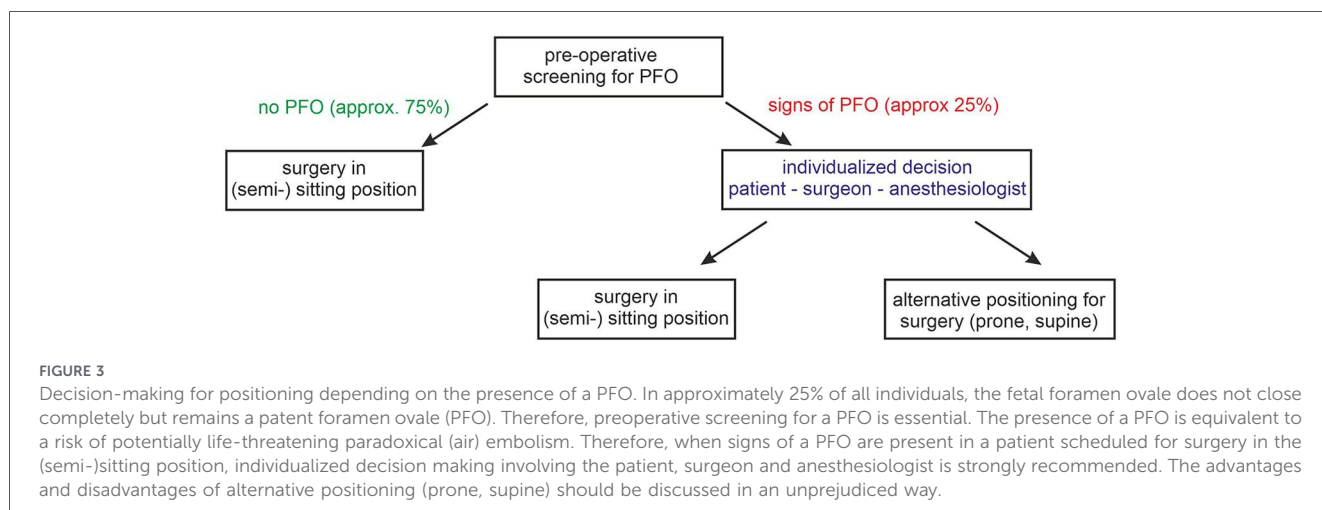


TABLE 1 Monitoring methods for the diagnosis of intraoperative VAE, indicating the volumes for the detection of air [modified according to Ref. (46)].

Monitoring method	Volume (ml/kg)	For a person weighing 70 kg, this corresponds to (ml) (calculated values)	Sensitivity
Transesophageal echocardiography	0.02	1.4	High
Precordial Doppler	0.05	3.5	Moderate
End-tidal CO ₂ measurement	0.5	35	Moderate
Pulse oximetric saturation	1.0	70	Low
Esophageal stethoscope	1.0	70	Low
Arterial blood pressure	1.0	70	Low

atrium as well as its effects on cardiac dimensions and function (54). Therefore, based on available evidence and experience, we strongly recommend using TEE to visualize air in the vascular system in any surgical patient in (semi-)sitting position.

3.5 TEE standard sections for VAE detection

In many publications, the views of TEE examinations are not (13) or at least not unequivocally specified (63). In principle, a standardized complete examination procedure, as practiced in cardioanesthesia, is highly desirable whenever TEE is used (64). In the domain of neuroanesthesia, with a particular focus on potential VAE, the standard views described below are usually sufficient (Figure 4) (65):

- Mid-esophageal 4-chamber view (ME-4-chamber view)
- Mid-esophageal view of the right ventricular inflow and outflow tract
- Mid-esophageal bicaval view (ME bicaval view)

Ideally, atraumatic intubation of the esophagus with the TEE probe is performed via laryngoscopy (66). At an insertion depth of approximately 30–40 cm and with slight retroflexion of the probe the mid-esophageal 4-chamber view can always be obtained. This view serves as a starting point for all subsequent

sections. Even if the position of the probe has changed intraoperatively, this view can be revisited for orientation at any time.

The mid-esophageal 4-chamber view shows both the atria and ventricles of the heart, so that air entering the right atrium and right ventricle and air crossing the left atrium and ventricle can be observed. The dimensions of the heart cavities, the direction of the septal movement and the myocardial contractility (especially of the septal and lateral wall sections of the left ventricle) can also be seen. By using color Doppler, an insufficiency jet might be observed over the tricuspid or mitral valve.

The mid-esophageal 2-chamber view is achieved without changing the probe position by electronically rotating the multiplane TEE transducer by approximately 90°. Left ventricular function can once again be assessed; in contrast to the 4-chamber view, the anterior and posterior wall of the left ventricle can now be visualized.

A subsequent rotation of the multiplane transducer to 120° reveals the inferolateral or posterior and anteroseptal parts of the left ventricle as well as the left ventricular outflow tract with the aortic valve in the mid-esophageal long axis view. Pathology of the aortic valve can also be detected here with the aid of color Doppler and on the basis of morphology and reflex behavior.

The mid-esophageal bicaval view is obtained by slightly rotating the TEE probe clockwise. The superior vena cava (SVC) is visible on the right side of the screen, while the inferior vena

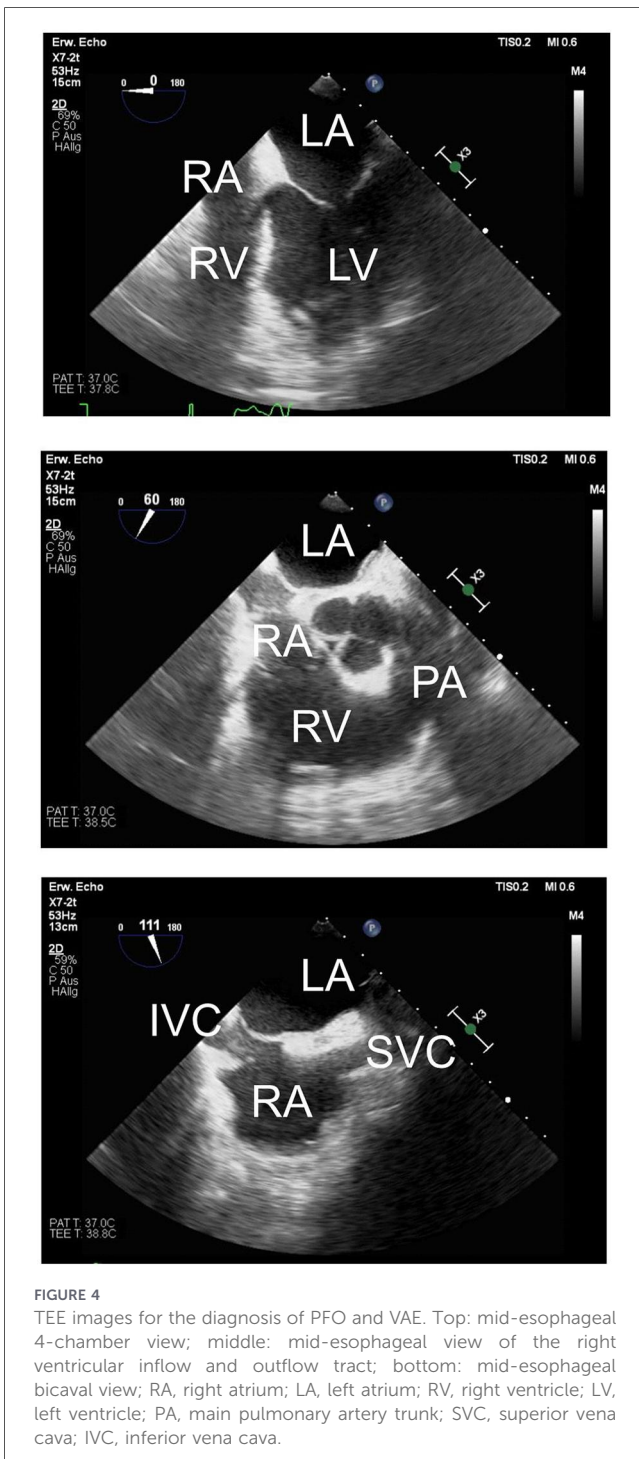


FIGURE 4
TEE images for the diagnosis of PFO and VAE. Top: mid-esophageal 4-chamber view; middle: mid-esophageal view of the right ventricular inflow and outflow tract; bottom: mid-esophageal bicaval view; RA, right atrium; LA, left atrium; RV, right ventricle; LV, left ventricle; PA, main pulmonary artery trunk; SVC, superior vena cava; IVC, inferior vena cava.

cava (IVC) is located on the left side. It should be noted that the IVC frequently exhibits suboptimal visibility. In the center of the screen is the atrial septum, the thinnest part of which is the fossa ovalis. In the area of the SVC, the reflections of an *in situ* central venous catheter might be observed. In this probe position, the entry of air via the vena cava into the right atrium and the passage of air (or contrast medium) into the left atrium can be recognized easily.

To access the mid-esophageal view of the right ventricular inflow and outflow tract, the probe must be rotated

counterclockwise once more, and the multiplane transducer rotated to 80°. In this setting, the right atrium, right ventricular inflow and outflow tract, aortic valve and part of the left atrium can be visualized.

Based on available evidence and experience, we recommend this structured TEE examination to be performed before any positioning measures are taken for the patient because

- The standard views can be obtained with greater reliability in the supine position than when the upper body is upright;
- The correct position of the CVC can be verified;
- A previously conducted evaluation of a PFO can be re-examined;
- Now is the last opportunity to diagnose a PFO;
- Positioning can be reevaluated, or targeted measures can be initiated before positioning to ensure stable hemodynamics if there are other relevant pathological findings such as higher-grade valvular lesions or impaired cardiac function;
- A baseline finding of the heart dimensions is obtained, which can be correlated with any intraoperative changes subsequently.

During surgery, in addition to the B-mode image of the heart, pulsed wave Doppler (PW-Doppler) can be used to visualize the area of the right atrium, whereby an acoustic signal can be obtained to indicate the entry of air, analogous to precordial Doppler. Since the PW Doppler examines a specific, adjustable area, it is preferable to continuous wave (CW) Doppler. This PW-Doppler signal should be tested before surgery begins, e.g., by injecting small amounts of the contrast agent initially used for PFO diagnosis (e.g., 10–20 ml of agitated saline as described below). When making use of PW-Doppler over an extended period, we recommend to employ the lowest possible power gain for the Doppler signal. This precautionary measure is aimed at further mitigating the risk of thermal mucosal damage that might be induced by the TEE probe (67).

3.6 TEE for PFO detection

If a left-to-right shunt is detected in the mid-esophageal bicaval view using color Doppler (Nyquist limit set to 30 cm/s) (Figure 5), this is prove of a PFO (68).

If no left-to-right shunt can be detected by color Doppler, then PFO should be excluded by means of echo-contrast agent and Valsalva maneuver. Echo-contrast agents (“microbubbles”) that are easy to visualize via ultrasound can be produced from autologous patient blood as well as agitated (quickly drawn up) saline or colloid solutions.

The position of the CVC can be verified with an initial administration of a few milliliters. Subsequently, an additional 10–20 milliliters bolus of the solution is administered under standard ventilation conditions to facilitate the detection of an anatomically open PFO. If there is no contrast agent visible in the left atrium within five cardiac cycles, an increase in intrathoracic pressure is induced through a Valsalva maneuver (68) so that the atrial septum adapts to a left convex position (Figure 6). While maintaining a high intrathoracic pressure, contrast agent is again administered so that the right atrium is

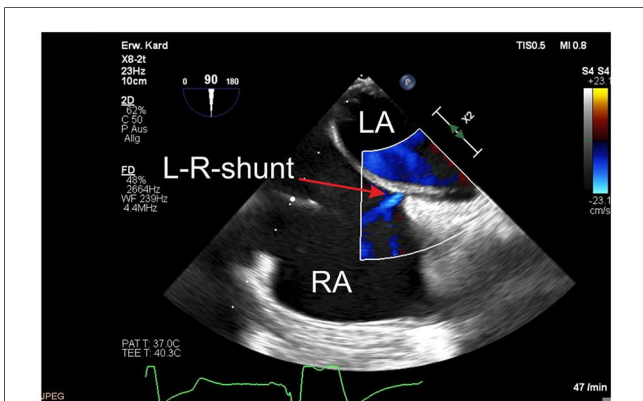


FIGURE 5
Left-right shunt visualized by color Doppler. A left-to-right shunt can be detected via color Doppler. L-R shunt, left-right shunt; LA, left atrium; RA, right atrium.

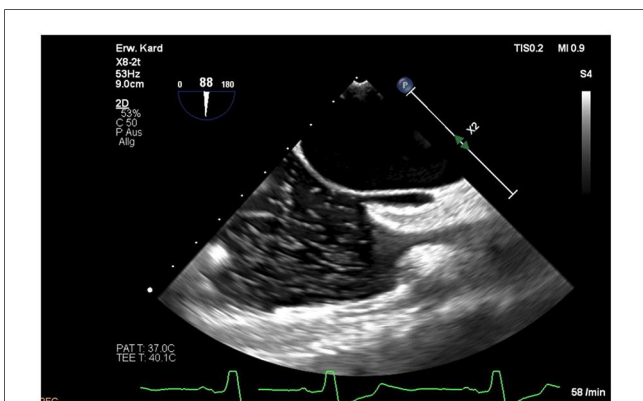


FIGURE 6
Microbubbles as evidence of VAE. Mid-esophageal bicaval view with bubbles as a sign of VAE.

filled with bubbles. After another five cardiac cycles, the adjustable pressure limiting (APL) valve of the ventilator is opened quickly to allow for an increased venous return into the right atrium and simultaneously further contrast medium is administered. The appearance of microbubbles in the left atrium during a Valsalva maneuver performed in this manner is considered definitive evidence of a PFO (Box 2).

A Valsalva maneuver can be performed on a ventilated patient as follows: the anesthesia ventilator is set to manual ventilation, and the APL valve is set to a pressure limit of 30 cm H₂O. The pressure within the ventilator system is transferred to the intrathoracic region, resulting in a pressure reversal at the atrial level, and the pressure in the right atrium exceeds that of the left atrium. This can be recognized by a bulging of the atrial septum in the direction of the left atrium. This pressure reversal can cause a foramen ovale - which is closed under physiological conditions - to open. For the Valsalva maneuver, high ventilation pressure should be maintained for approximately 20 s. Longer durations are not recommended, as the Valsalva maneuver has the potential to induce a substantial decrease in systemic arterial blood pressure.

BOX 2 Diagnostic procedure for a right-to-left shunt (e.g., PFO) at the atrial level.

Mid-esophageal bicaval view setting with the following configuration:

- 1) Color Doppler on atrial septum
- 2) Administration of echo-contrast agent under standard (respiratory) conditions
- 3) Administration of echo-contrast agent during Valsalva maneuver (atrial septum will shift into left atrium)

A right-to-left shunt at the atrial level is excluded if, under the above configuration

- 1) The color Doppler signal is inconspicuous **and**
- 2) and 3) no echo contrast agent is seen in the left atrium within five cardiac cycles.

TABLE 2 “Tuebingen venous Air embolism grading scale”, grading of clinically relevant VAE [according to Feigl et al. Ref. (63)].

Degree	Observed change
0	No air bubbles visible in TEE, i.e., no VAE
I	Air bubbles visible in TEE, no drop in etCO ₂
II	Air bubbles visible in TEE, drop in etCO ₂ ≤3 mmHg
III	Air bubbles visible in TEE, drop in etCO ₂ >3 mmHg
IV	Air bubbles visible in TEE, drop in etCO ₂ >3 mmHg, drop in MAP ≥20% and/or increase in HR ≥40%
V	Grade IV and hemodynamic instability requiring resuscitation

TEE, transesophageal echocardiography; etCO₂, end-tidal CO₂; MAP, mean arterial pressure; HR, heart rate.

3.7 Classification of VAE

The “Tuebingen Venous Air Embolism Grading Scale” (63), which further differentiates Jadik’s classification (13), provides a pragmatic clinical classification of the severity of VAE. In addition to the detection of air entry by TEE, the clinical severity is also taken into account (Table 2).

4 Course of action and management in case of VAE

Even though VAE can be observed in a large number of procedures in (semi-)sitting position using sensitive diagnostic tools such as TEE, it usually remains clinically inapparent (69). Depending on the severity of VAE, various measures are to be taken by anesthesiologists and surgeons.

The fundamental procedure in this scenario entails the following:

- Information of the surgical team
- Prevention of further air entry
- Therapy of hemodynamic changes
- Evaluation of VAE severity by blood gas analysis and TEE

- Aspiration of air that has entered (“air lock”) via the central line
- Check coagulation status

The primary objective of all measures is to prevent further air from entering the right ventricle and the pulmonary artery!

4.1 Information of the surgical team

In general, the surgical team should be informed immediately if air bubbles become visible in TEE. Clear and unambiguous communication between the anesthesiology and neurosurgery teams is of utmost importance to ensure the successful management of VAE. Ideally, in the sense of “closed-loop” communication, the surgeon should provide feedback confirming receipt of the information. This precautionary measure seems essential to avert potential misunderstandings or errors during the treatment process. Additionally, the surgeon should articulate whether they are capable of locating the site of air entry and the measures that will be taken to address it, such as the application of bone wax or the draping of the surgical site with neurosurgical micropatties. The anesthesiology team should evaluate repeatedly whether additional anesthesia personnel should be called in (Figure 7).

4.2 Prevention of further air entry

To mitigate the risk of further air entry, it is important to ensure the definitive closure of the open venous entry site. The primary measures for this purpose include, e.g., flushing the surgical field with saline or applying soaked micropatties, as well as sealing the bone edges with wax. In order to facilitate the identification of an open vein and thus a potential air entry point in the surgical area a temporary manual bilateral compression of the jugular veins is recommended. Correct bilateral compression of the jugular veins can increase the pressure in the venous sinus vessels of the brain to such an extent that (further) the entry of air can be reduced or prevented (13, 40, 70–72). In addition, obstruction of the outflow

of venous drainage blood from other cerebral veins results in a retrograde venous blood flow. This causes blood to leak through the open vein, and as a result, it can be identified by the surgeon (73).

In principle, the jugular compression maneuver can therefore be used in two different scenarios:

- During the preparation phase to identify opened, but not collapsed veins and thus seal potential air entry ports;
- During the course of VAE to reduce further air entry in addition to identifying the air entry port by means of venous backflow.

When performing a jugular vein compression maneuver, excessive pressure on the carotid arteries in the immediate vicinity may result in bradycardia and a reduction or even cessation of cerebral perfusion (73). Conversely, the reduced venous outflow resulting from the increase in cerebral blood volume invariably leads to an increase in intracranial pressure (74). To minimize these risks, the pressure exerted on the neck vessels should not exceed 40 mmHg. The appropriate amount of force required to compress the internal jugular vein can be easily determined by an experienced physician from using sonography to place a jugular venous catheter.

The optimal duration of jugular vein compression has not yet been reported in the literature. For instance, while Losasso et al. provide an empirical recommendation of a “15-second limit” for humans, Toung et al. report a safe interval of 20 min in animal experiments (72, 73). The pressure should be applied between the thyroid cartilage and the mandibular bone and thus cranial to the last venous valve in the jugular veins. In everyday clinical practice, a jugular vein compression maneuver is typically performed bimanually. The use of pneumatic neck collars or cuffs has not yet been established beyond clinical studies.

In summary, the bilateral jugular vein compression procedure has been demonstrated to be an effective method for increasing pressure in the venous sinuses, thereby transforming an air entry point into a bleeding point. Given the potential for ICP increase as a consequence, its use should be limited to brief and transient applications, necessitating meticulous collaboration between the operating surgeon and the anesthesiologist.

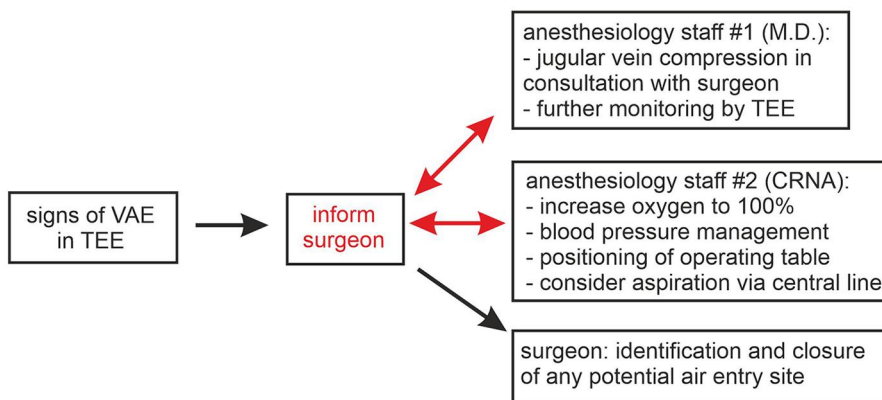


FIGURE 7

Intraoperative best practice of VAE management: in the case of venous air embolism (VAE) a bundle of measures has to be taken in short time. Therefore, the presence of two members of the anesthesiology team (anesthesiologist = MD and nurse anesthetist = CNRA) is highly recommended. A clear assignment of tasks based on tailor-made standard operating procedures is absolutely necessary. Closed-loop communication between the anesthesiology team and the surgeon is the cornerstone of all successful VAE management.

If air entry persists despite the implementation of these measures and the point of air entry remains undetectable, it might be necessary to place the surgical site below the level of the patient's heart by tilting the operating table (Figure 7). This possibly facilitates the open vein to be recognized by the retrograde venous flow due to the subsequent blood leakage.

4.3 Therapy of hemodynamic changes

A substantial VAE can potentially lead to right heart failure through a variety of mechanisms. If this occurs, immediate supportive therapy is required to improve myocardial perfusion and support right ventricular function. The treatment of the increase in pulmonary arterial pressure due to VAE involves ensuring adequate oxygenation (by increasing the fraction of inspired oxygen to 100%) and normocapnia, as both hypoxia and hypercapnia significantly increase pulmonary vascular resistance. Inhalation of iloprost or nitric oxide (NO) can also reduce pulmonary vascular resistance. The objective of these measures is to reduce the right ventricular afterload and wall tension, thereby decreasing myocardial oxygen consumption. To increase coronary perfusion and the myocardial oxygen supply, increasing systemic blood pressure by administering norepinephrine or phenylephrine is indicated. In animal studies, it was demonstrated that the administration of norepinephrine, in addition to increasing blood pressure, could also enhance coronary perfusion and, consequently, the right ventricular function (75). An attempt of using positive inotropic substances to achieve a higher right ventricular stroke volume is not particularly promising, as the right ventricular myocardium is thin and less stimulable via β -sympathomimetics. Notably, epinephrine at higher concentrations has a pulmonary vasoconstrictive effect, thereby further increasing the afterload for the right heart (76). The utilization of dobutamine, vasopressin and other medications, such as calcium sensitizers or phosphodiesterase inhibitors, should be carried out in accordance with up-to-date guidelines (77, 78).

Newly emerged cardiac arrhythmias such as tachycardia and extrasystole frequently indicate inadequate myocardial perfusion due to hypotension or air embolic occlusion of a coronary artery and may require additional treatment.

If massive VAE results in circulatory arrest, cardiopulmonary resuscitation should be performed in accordance with the current guidelines of the American Heart Association (79).

4.4 Evaluation of VAE severity via blood gas test and TEE

Repeated arterial blood gas analyses are used to determine the severity and progression of VAE on the basis of the difference between the end-tidal and arterial CO₂ values ($P_{art} - P_{etCO_2}$). TEE can assess the extent of right heart failure by evaluating the heart configuration, contractility, and displacement of the atrial and ventricular septa. For this purpose, it is possible to switch from the bicaval view to the mid-esophageal 4-chamber view with minimal effort.

4.5 Aspiration of air that has entered or the "air lock" via the central line

In the case of circulatory depression due to VAE, an attempt of "air aspiration" can be made via the CVC. Even though there can be no prospective randomized studies on humans for ethical reasons, various animal experiments have yielded positive results in the sense of an increased primary survival rate after induction of a manifest VAE and subsequent air aspiration. However, in these studies, mostly involving only a few cases, catheters exhibiting notable variations in length, diameter and arrangements of openings in the area between the superior vena cava and the pulmonary arteries were used (33, 34, 80–82).

Conversely, pathophysiological considerations indicate that an attempt of air aspiration should be executed as a last resort in case of severe VAE. In this scenario, the newly penetrated air bubbles are not aspirated directly, as these usually flow past the catheter (83). Instead, the therapeutic principle of aspiration aims to reduce the volume of the existing "air lock" (a blood-foam mixture) in the area of the SVC confluence with the right atrium. However, the volume or fraction of entered air that can be effectively aspirated via a CVC placed in an optimal position remains to be elucidated. There is also no scientific evidence that any particular type of CVC tip positioning is associated with a better treatment outcome in humans.

It is important to understand this therapeutic measure because it is typically not large air bubbles that can be aspirated but rather part of a foamy blood-air mixture, the "air lock". Therefore, "air aspiration" should never be considered a substitute for closure of the air entry site by the surgeon. Rather, the aim is to improve venous filling of the right heart by aspirating part of the air lock. The catheter through which the air lock is aspirated in the event of a VAE should have a lumen of at least 14 gauge (2.2 mm). Catheters with a larger lumen (e.g., 12 gauge = 2.8 mm) allow the aspiration of larger volumes each time, however, they are also associated with a higher risk of injury. Consequently, these catheters should not be advanced into the right atrium; rather, they remain with their tip in the final section of the SVC.

4.6 Impact of VAE on coagulation

Research both *in vitro* and in animal experiments has demonstrated that VAE induces the release of mediators such as endothelin, serotonin and thromboxane, which in turn leads to activation of the complement system and thus impairs coagulation (84, 85). In particular, complement factor C3 has been observed to induce the coordinated activation of inflammation and the hemostatic response (termed thrombinflammation) both *in vitro* and *in vivo* (86–89). A number of clinical case reports have documented a protracted and severe inflammatory reaction subsequent to VAE (90, 91). Whether the administration of C3 inhibitors would be useful in these situations is the subject of current research (89).

In addition, the adhesion of air bubbles to platelets was revealed *in vivo* and was accompanied by a 50% decrease in the platelet count. This thrombocytopenia could be due to a coating of the platelets by the air bubbles or to aggregation and venous pooling in the pulmonary vessels (84, 85, 92, 93).

Consequently, intraoperative VAE has the potential to induce significant coagulopathy.

Particularly in procedures in the posterior fossa, even a small volume of postoperative bleeding might exert pronounced pressure on the brain, causing deleterious consequences for the patient. Therefore, in the event of severe VAE (grade ≥ 4 according to the Tuebingen VAE grading scale) or recurrent events (\geq grade 3 according to the Tuebingen VAE grading scale), based on available evidence and experience we recommend to repeatedly monitor the coagulation situation, employing thrombelastography and determining platelet count and function, as substitution of coagulation factors or platelet transfusion might be necessary (93).

5 Use of the (semi-)sitting position in pediatric neurosurgery

Apparently, a subatmospheric pressure in the venous sinuses of the brain occurs less frequently in children than in adults in the (semi-)sitting position. Obviously, the smaller body size plays a pivotal role here, which presumably leads to a smaller hydrostatic pressure difference between the brain and the right atrium. In any case, Iwabuchi et al. did not find negative pressures in the confluence of sinuses in any of the children under 6 years of age examined, and Grady et al. reported subatmospheric pressures in only one-third of children aged 5–15 years (40, 41).

Although the sitting position is employed less frequently in pediatric neurosurgery than in adult patients, it is nevertheless part of the standard clinical routine in some centers (94–96). In principle, the advantages and disadvantages are consistent with those observed in other forms of positioning. Still, particular attention must be paid to the relative instability of the child's skull and spine during positioning and fixation. When using size- and weight-adapted catheters and TEE probes the neuroanesthesiological management closely resembles that employed for adult patients.

6 Final remarks

Following careful research and discussion, this article summarizes current knowledge on perioperative anesthesiologic management for neurosurgical operations in a lounging, sitting or semi-sitting position. One must note however, there are very few scientific studies on this topic. To this end, studies on general surgical patients and animal experiments were also consulted to obtain evidence when no specific studies on patients in the (semi-)sitting position were available. This underscores the necessity for further scientific studies on this topic.

Author contributions

PM: Writing – original draft, Writing – review & editing. MS: Writing – original draft, Writing – review & editing. WK: Writing – original draft, Writing – review & editing.

AB: Writing – original draft, Writing – review & editing. BD: Writing – original draft, Writing – review & editing.

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Conflict of interest

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