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Venous and Paradoxical Air Embolism in the Sitting Position. A Prospective Study with Transoesophageal Echocardiography

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Summary

This prospective study investigates the frequency of patent foramen ovale (PFO), venous air embolism (VAE) and paradoxical air embolism (PAE) by transoesophageal echocardiography (TOE) in neurosurgical patients operated on in the sitting position. The risk of PAE after exclusion of PFO is assessed. A PFO was identified by pre-operative TOE and VAE and PAE by continuous intraoperative TOE. Sixty-two patients were divided into two groups, 22 patients were studied in group 1 (posterior fossa surgery) and group 2 (cervical surgery) contained 40 patients.

Pre-operative TOE demonstrated a PFO in 5 of the 22 patients in group 1 (23%). Patients with proven PFO were excluded from the sitting position. Two further patients of this group (12% of 17 patients), in whom a PFO had been excluded pre-operatively, nevertheless had PAE, air occurring in all cavities of the heart. In group 2 the incidence of PFO was 4 out of 40 patients (10%). No PAE was observed in this group. Three morphological types of VAE with different haemodynamic and ventilation changes were demonstrated. VAE was observed in 76% of all posterior fossa operations and in 25% of cervical laminectomies. We conclude that a pre-operative search for PFO is mandatory considering its incidence of 23% in group 1 and of 10% in group 2, and the risk of PAE. If a PFO is detected, the sitting position should be avoided. A residual risk for PAE remains despite exclusion of PFO because the reliability of TOE is limited. TOE is the method of choice for detecting VAE and PAE.

Keywords: Neuroanaesthesia; sitting position; complications; paradoxical air embolism monitoring, transoesophageal echocardiography.

Introduction

Numerous neurosurgeons prefer the sitting position for operations in the posterior fossa or on the cervical spine. This is associated with an increased risk of venous (VAE) or paradoxical (PAE) air embolism [2, 11, 14]. The main points of entry for aspirated air are the diploic and the emissary veins as well as dural vessels. Veins of the cervical muscles and bridging veins may also serve as way of air a entry[9, 11, 14]. Depending on the monitoring method, the incidence of air embolism amounts to between 25 and 60%[2–4, 9, 11, 14]. If air enters the venous system, the situation may be aggravated by PAE since, according to the literature, a PFO can be expected in 10 to 30%[1, 3, 5, 8].

The present prospective study investigates the risk of PAE despite pre-operative exclusion of PFO, and the echocardiographic findings of venous air embolism in connection with different changes in haemodynamics and ventilation.

Methods

Sixty-two patients aged 20 to 70 years (Table 1) were studied. Twenty-two were submitted to surgery in the posterior fossa (group 1) and 40 underwent cervical surgery (group 2) in the sitting position. Surgical diagnoses are shown in Table 2.

Following induction of anaesthesia, testing for PFO was done in the supine as well as in the sitting position by means of transoe-

Table 1. *Biometrical Data and ASA Classification (n = 62)*

Age (yrs)	49 ± 13
Sex:	
male	29
female	33
Height (cm)	168 ± 8
Weight (kg)	70 ± 15
ASA:	
I	35
II	20
III	7

sophageal echocardiography (TEE) using a 5 MHz monoplane electronic Doppler transducer (Hewlett Packard 77020 A).

A bolus of 10 ml agitated human albumin as 20% solution was injected within 2 sec into the right atrium via the central venous port of a Swan-Ganz pulmonary artery catheter (group 1) or a central venous catheter with its tip in the right atrium (Group 2). The injection was monitored over the entire ventilation cycle, special attention being given to the early phase of expiration[4, 5]. Passage of the solution was considered as proven if at least five echo-dense structures were observed in the left atrium.

Testing to detect PFO was done with zero end-expiratory pressure (ZEEP) and a positive end-expiratory pressure (PEEP) of 15 cm H_2O after releasing of positive airway pressure according to the method described by Cucchiara[4]. If, with the patient supine, no shunt was visible at ZEEP, testing was done at a PEEP of 15 cm H_2O. If testing was negative again, it was repeated in the sitting position with a PEEP of 15 cm H_2O.

Monitoring for VAE and PAE was done by continuous TEE. Typical changes in the 2-D echocardiographic image in the short axis view at the aortic level (Fig. 1), where the fossa ovalis, right atrium and left atrium are visible, were considered as a proof of air embolism[6, 13]. Routine noninvasive monitoring in group I comprised electrocardiography (ECG), capnography, relaxometry, body temperature and urine output. Direct arterial blood pressure and pulmonary artery pressures were also monitored. In case of air embolism air was aspirated via the central venous port of the catheter.

In group 2 the pulmonary artery catheter was omitted, but a central venous catheter was inserted. In cases of AE, the catheter with its tip located in the right atrium was used for air aspiration. The position of the catheter was checked by intracardiac ECG (alpha card) and subsequently by TEE.

Table 2. *Surgical Diagnosis*

Group 1 posterior fossa surgery (n = 22)		Group 2 cervical surgery (n = 40)
Acoustic neuroma	12	disc prolapse = 40 C4/5, 5/6, 6/7
Cerebellopontine angle meningioma	5	
Infratentorial spongioblastoma	1	
Cerebellar arteriovenous malformation	2	
Basilar aneurysm	2	

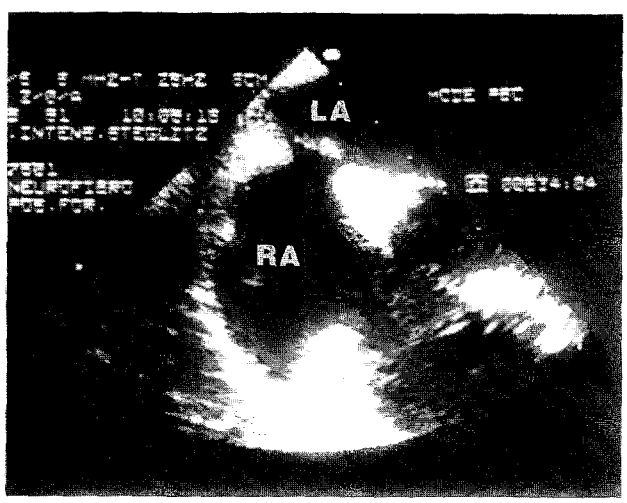

Fig. 1. Short axis view. *RA* right atrium, *LA* left atrium

Posterior Fossa Surgery

The patients were premedicated orally with 2 mg flunitracepam and pre-oxygenated following the onset of intravenous infusion of isotonic electrolyte solution (Sterofundin^R). Anaesthesia was induced with 12.5 mg droperidol, 0.4 – 0.6 mg fentanyl and 5 mg/kg b. w. sodium thiopentone, 0.1 mg/kg b. w. pancuronium bromide, and maintained with 0.1–0.2 mg fentanyl every half hour and 5 – 7.5 mg droperidol every two hours. If train-of-four was $\geq$ 25%, 1 mg pancuronium bromide was repeated.

The patients were hyperventilated so as to maintain a P_aCO_2 of 4.0 kPa. Ventilation was with a F_IO_2; fresh gas flow of $1 l O_2/2 l N_2O$; V_T of 10 ml/kg b.w., I:E ratio 1:2 through a semi-closed system. Following routine catheterization of the frontal horn of the lateral ventricle on the non-dominant side, the patients were placed in the sitting position and N_2O was discontinued. A continuous Propofol (Disoprivan^R) infusion was commenced at 5 mg/kg b.w./h with an injection pump. Ventilation was continued with a F_IO_2 of 0.3 through a semi-open system (Narkosespiromat 656, Drägerwerk). In order to optimize haemodynamics in the sitting position, each patient received an infusion of 15 ml/kg b.w. of 6% hydroxyethyl starch (HES) so as to render central venous pressure (CVP) positive. Volume and electrolyte losses were balanced intra-operatively so as to ensure constant CVP, PCWP and CO values.

Cervical Laminectomies

Patients scheduled for cervical laminectomy (group 2) were anaesthesized with 0.1 mg fentanyl and isoflurane, normoventilated with a fresh gas flow of $1 l O_2/2 l N_2O$, at a V_T of 10 ml/kg b.w., I:E ratio 1:2 via a semi-closed system, and received an infusion of 15 mg/kg b.w. 6% HES.

Measures in Cases of Air Embolism

If signs of venous air embolism were observed, the surgeon was informed immediately, ventilation was changed to 100% O_2 and aspiration of air was attempted through the atrial catheter or the central venous port of the pulmonary artery catheter. Surgical measures, such as rinsing of the operative field with saline solution or coagulation of suspect vessels, application of bone wax, and short-term jugular compression were additionally resorted to.

Results

Table 3 shows the data of VAE, PFO and PAE.

Patent Foramen Ovale

PFO was detected pre-operatively in 5 out of 22 patients (23%) in group 1, and in 4 out of 40 patients (10%) in group 2 ($p > 0,5$ Fischer-Exakt-Test)

Table 3. *Incidence of a Patent Foramen Ovale (PFO) Detected Preoperatively*

PFO	Group 1 posterior fossa surgery (n = 22)	Group 2 cervical surgery (n = 40)
Supine, PEEP: 0 cm H_2O	2 (9%)	–
Supine, PEEP: 15 cm H_2O	2 (9%)	4 (10%)
Sitting, PEEP: 15 cm H_2O	1 (5%)	–
S	5 (23%)	4 (10%)

Incidence of Venous (VAE) and Paradoxical (PAE) Air Embolism

	(n = 17)	(n = 36)
VAE total	13 (76%)	9 (25%)*
Single VAE	2 (12%)	7 (19%)*
Multiple VAE	11 (65%)	2 (6%)*
PAE total	2 (12%)	

* = $p < 0{,}001$.

(Table 3). Patients with proven PFO were excluded from the study and operated on in the modified "park bench position" in group 1 or in the supine position in group 2.

Venous Air Embolism (VAE)

The incidence of VAE differed in the two groups (Table 3). VAE was diagnosed in 13 (76%) of the remaining 17 patients in group 1. Multiple AE occurred in 11 of these patients (65%). Altogether, 36 episodes were observed in 13 patients. TEE showed three different morphological groups of AE with specific behaviour of haemodynamics and ventilation.

In 21 episodes, VAE presented as a "beadlike" embolism without changes in haemodynamics, $P_E'CO_2$ or P_aCO_2. The only measures taken in such cases were volume substitution to establish a CVP > 0 and notification of the surgeon. In 10 episodes, VAE had the appearance of a "pearl string", associated in 2 cases with a decrease of $P_E'CO_2$ and an increase in P_aCO_2 by more than 1 KPa. One patient had a decrease of MAP by more than 20 mm Hg. Five cases showed a "snow flurry" picture (following damage of major veins), associated with tachycardia, a decrease in MAP by more than 20 mm Hg, a fall of $P_E'CO_2$, and an increase in P_aCO_2 by more than 1.5 KPa. Episodes of air embolism were not attributable to specific surgical steps.

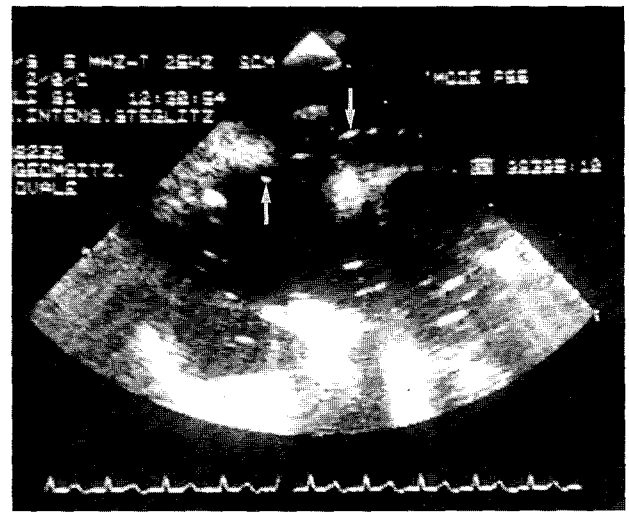

Fig. 2. Paradoxical air embolism (passage of air through a patent foramen ovale)

In group 2 a total of 12 "pearl-string" VAE occurred in 9 out of 36 patients (25%). Neither decreases in MAP, nor tachycardia, fall of $P_E'CO_2$ or increase of $PaCO_2$ were observed.

Paradoxical Air Embolism (PAE)

Although pre-operative TEE had not revealed a PFO two of the 17 patients (12%) in group 1 had PAE air being visible in all cavities of the heart. It was demonstrated that air passed from the right to the left atrium through the foramen ovale (Fig. 2). In the first case, surgery had to be interrupted after fruitless efforts by the surgeon to stop the entrance of air. In the second case, air entrance was stopped and surgery could be continued. Paradoxical air embolism was not demonstrable in any case of group 2. Due to the small number of patients it is not possible to compare the incidence of air embolism in both groups. None died, and none had postoperative neurological deficits attributable to intra-operative AE.

Discussion

As expected, the incidence of VAE differed between the two groups of patients (76% in group 1, and 25% in group 2, $p < 0{,}001$). Incidence of multiple VAE occurred in 65% of group 1 and in 6% of group 2

($p < 0{,}001$). On the other hand, simple VAE were demonstrated in 12% of group 1 and in 19% of group 2 ($p < 0{,}001$). This is explained in part by the difference in venous pressure gradients between the operative site and the right atrium. Also, different ventilation modes (hyperventilation in group 1 and normoventilation in group 2), with a different P_aCO_2, may have an effect on incidence of air embolism. The considerable differences (between 25 and 60%) reported for the rates of AE during surgery in the posterior fossa alone are probably attributable to the different monitoring methods used by various authors[2–4, 9, 11, 14]. While methods such as precordial Doppler sonography or capnography may yield false-positive or false-negative results, transoesophageal echocardiography is, at present, the most reliable technique for detecting air embolism[9]. As little as 0.2 ml of air are already detected as an echodense structure[7]. Since air embolism may occur at any time during surgery, monitoring must be continued throughout[10].

In 2 patients of group 1, passage of air was demonstrated intra-operatively from the right to the left atrium through a PFO, despite pre-operative exclusion of a patent foramen ovale. Black *et al.*[3] also report one case of intra-operative PAE during an episode of VAE despite pre-operative exclusion of PFO by transthoracic (Valsalva's manoeuvre) and transoesophageal echocardiography (PEEP = 20 cmH_2O). It must, thus, be assumed that the conditions under which pre-operative exclusion of a PFO takes place are not comparable to those that follow intra-operative AE, as well as to changes in CVO and in airway pressure[6, 13]. From the fact that in one of our patients PFO was identified only in the sitting position and with a PEEP of 15 cmH_2O we conclude that PEEP may predispose to the opening of a PFO and, thus, to PAE.

The incidences reported in the literature, based on TEE and/or transthoracic contrast echocardiography, amount to between 6 and 18%[3, 5, 8]. This is clearly below the incidence of about 30% of a PFO as verified at autopsy[8].

Our data demonstrate a persistent risk of paradoxical air embolism despite pre-operative exclusion of a PFO. Therefore, the usefulness of TEE for screening for PFO is limited. However, as a continuous intra-operative monitoring method, TEE provides helpful information about the extent echocardiographic findings of VAE and the appearance of PAE during surgery in the sitting position.

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