Neurosurgical operations with the patient in sitting position: analysis of risk factors using transcranial Doppler sonography

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\textbf{Background.} One major risk factor of the sitting position for neurosurgery is air embolism, especially in patients with persistent foramen ovale (PFO). The first aim of this prospective study was to evaluate a bedside method for detecting PFO using transcranial Doppler sonography (TCD) with contrast medium. A second aim was to address intraoperative monitoring, patient positioning and the occurrence and clinical relevance of air embolism.

\textbf{Methods.} Ninety patients with a mean age of 56.5 yr (range 14–81 yr) undergoing surgery in sitting position were investigated by TCD with contrast agent to detect functional PFO, that is PFO that can be provoked with a Valsalva manoeuvre. In patients in whom TCD was not possible, transcranial duplex sonography, duplex sonography of the carotid artery at the neck or transoesophageal ECG was performed.

\textbf{Results.} In 26 patients PFO was detected. Thirteen of them presented a persistent PFO with high-intensity transient signal in both middle cerebral arteries without Valsalva manoeuvre. The intraoperative positioning in these patients was adapted to the risk for a paradoxical air embolism, although, after surgical recommendations, three patients with a persistent PFO underwent surgery in sitting position. Intraoperative air embolisms were seen in 8 of 80 patients in sitting or semi-sitting position with air aspirable through the central venous catheter.

\textbf{Conclusion.} To address the risk of a paradoxical air embolism, especially in patients undergoing surgery in sitting position, preoperative detection of PFO is advisable. If surgery is performed in seated PFO patients, additional monitoring and special care are warranted.

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Since 1913, when the first surgery with the patient in sitting position was performed, the debate concerning this positioning has continued.\textsuperscript{1–3} The sitting position is thought to be the best for surgical access to the posterior fossa or to dorsally located parietal lesions. Gravity facilitates drainage of blood and other fluids and an optimal view over the pathology is possible with lowered intracranial pressure and increased venous reflux. However, the seated position carries significant risks,\textsuperscript{4} and these have led to a dramatic reduction in the numbers of operations in this position.\textsuperscript{5} Venous air embolism may occur in the presence of persistent foramen ovale (PFO). In patients with PFO surgical opening of veins can lead to a paradoxical air embolism with critical cerebral and cardio-pulmonary complications. PFO was found in 28% of adult patients using transoesophageal ECG\textsuperscript{6} as diagnostic procedure. This is stated to be the most sensitive investigation currently available,\textsuperscript{7} although post-mortem studies have revealed a higher incidence.\textsuperscript{8} Transoesophageal ECG has some disadvantages. Many patients have to be anaesthetized or sedated. Furthermore, complications such as broken teeth and oesophageal
The aim of this study was to apply a transcranial Doppler sonography (TCD)-based method of detecting PFO in patients undergoing surgery in sitting or semi-sitting position. A second focus was on intraoperative monitoring, patient positioning and the occurrence and clinical relevance of air embolism.

Methods

In addition to the routine preparatory procedures before intracranial surgery, all patients were investigated for PFO. Ninety consecutive patients were recruited. All patients were to undergo surgery in sitting or semi-sitting position. Informed consent was obtained in accordance with the guidelines of the local ethics committee.

A MultiDop® X4 (DWL, Sipplingen, Germany) TCD device with bidirectional CW/PW Doppler probe and for duplex ultrasound an HDI 3500 (ATL, Solingen, Germany) device, were used. While performing the ultrasound investigation we administered i.v. contrast agent Echovist®-300 (Schering, Berlin, Germany). The established TCD investigation is able to detect a foramen ovale over 2 mm in diameter; smaller PFOs are thought to have no clinical relevance.

As the first step, the patients learned to perform Valsalva manoeuvre to raise the pressure in the right atrium to open a latent open septum. The Doppler probes were then fixed and both middle cerebral arteries were insonated at a depth of 48–53 mm. The signal was recorded continuously during the whole investigation. Ten millilitres of the ultrasound contrast agent was given into a vein of one arm; the recording time was 4 min for each patient. A second investigation was done while the patient performed Valsalva manoeuvre, also recorded over 4 min. ECG proof of the efficacy of Valsalva manoeuvre was obtained (elevated cardiac frequency). PFO was identified on the basis of an acoustic and a visual signal, the so-called high-intensity transient signal (HITS; Fig. 1). Physiological HITS should be visualized within 10 heart cycles after injection, although some authors describe physiological HITS after 15 cycles. A right-to-left shunt was deemed to be present if three HITS were registered within 10 heartbeats after injection of the contrast agent. The HITS were defined as per the Consensus Committee of the 9th International Cerebral Homodynamic Symposium 1995 and were accepted if they had the following consistent signs:

—The Doppler signal lasted for no more than 300 ms.
—The signal was louder than the background noise (difference at least 3 dB).
—The signal moved in one direction.

![Fig 1 Detection of HITS on scanning the left middle cerebral artery by TCD. The upper frame shows single HITS (arrows). The lower frames indicate timing of injection of contrast agent (arrows) and the presence of several HITS (arrows).](image_link)
The visible HITS were combined with an acoustic sign (click).

HITS without Valsalva manoeuvre indicate large PFO with a functional shunt volume,14 labelled persistent PFO. More than 20 HITS after Valsalva manoeuvre are also classified as having haemodynamic relevance.15 named significant PFO. HITS after Valsalva manoeuvre are considered to show the presence of a latent open foramen ovale.

Whenever a good temporal bone window was not possible for TCD, unilateral colour-coded duplex sonography was used. If there was no usable signal the left carotid artery was investigated at the neck. The final means of ruling out PFO was transoesophageal ECG.

According to the preoperative findings the positioning during surgery was chosen. Patients without PFO underwent surgery as planned in sitting position. Patients with a PFO during the Valsalva manoeuvre were positioned to meet the surgeons’ requirements. In patients with PFO without Valsalva the positioning was finally chosen after considering all different surgery related aspects. If there were surgical strong reasons for the sitting position (brain oedema, or special anatomical considerations) in patients with a proven persistent PFO, the decision was made balancing the risks with the benefits. Emphasis was placed on the meticulous prevention of venous bleeding, especially originating from opened venous vessels.

Intraoperative management and anaesthesiological monitoring included the routine procedures. To allow air aspiration and in order to prove air embolism during surgery a central venous catheter was placed with the aid of contrast agent under radiographic control in the cardiac atrium/vena cava entrance. In addition, a precordial Doppler sonography probe was placed over the heart. No transcranial Doppler was used during surgery. Special care was taken with patient positioning, ensuring that the legs were placed at the level of the heart, with the knees bent (Fig. 2).

An embolism encountered during surgery was classified as confirmed if air could be aspirated. An air embolism was suspected if no air was aspirated but one of the following criteria was fulfilled:

—sudden decrease in end-tidal carbon dioxide;
—sudden increase in heart rate;
—sudden decrease in blood pressure.

The patient’s clinical-neurological status was reevaluated after operation and computed tomography (CT) was carried out within 12 h after surgery to detect any areas of hypoperfusion.

Results

Ninety patients (43 female and 47 male) with a mean age of 56.5 yr (range 14–81 yr) underwent surgery and were

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebellopontine angle</td>
<td>26</td>
</tr>
<tr>
<td>Cerebellar hemisphere</td>
<td>24</td>
</tr>
<tr>
<td>Occipital lobe</td>
<td>13</td>
</tr>
<tr>
<td>Cervical spine, dorsal approach</td>
<td>7</td>
</tr>
<tr>
<td>Parietal lobe</td>
<td>6</td>
</tr>
<tr>
<td>Brainstem and adjacent structures</td>
<td>6</td>
</tr>
<tr>
<td>Parieto-occipital lobe</td>
<td>4</td>
</tr>
<tr>
<td>Cranio-cervical junction</td>
<td>3</td>
</tr>
<tr>
<td>Pineal region</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
</tr>
</tbody>
</table>

Fig 2 Optimized sitting position—the legs are elevated to the level of the heart.
included in the study. The intracranial pathologies were located mainly in the posterior fossa (Table 1). Seventy-two patients had TCD investigation successfully; two were not able to perform the Valsalva manoeuvre correctly. These two patients underwent no further investigation to detect a latent PFO and were considered to have no PFO. In total, 23 of the 72 patients showed a right-to-left shunt (PFO) as detected by TCD; 13 had a persistent PFO and the other 10 had latent PFO (HITS after Valsalva manoeuvre). Of the 18 patients who could not be investigated by TCD, 16 underwent duplex sonography, where three additional latent PFOs were found. The remaining two patients without temporal bone window required transoesophageal ECG to exclude a right-to-left shunt before operation (Table 2).

In 64 patients (71.2%) right-to-left shunt could be ruled out and surgery was performed with the patient in sitting or semi-sitting position as planned before operation.

In total, 26 patients (28.8%) with right-to-left shunt were identified before surgery (Table 3); 13 had persistent PFO (Fig. 1) and the remaining 13 had latent PFO. Eight of the thirteen patients with persistent PFO underwent surgery in sitting position; four in semi-sitting position and one patient was placed in a different position for optimal access to the lesion (Table 3).

Four of the thirteen patients with persistent PFO also underwent surgery in sitting or semi-sitting position. Nine patients underwent surgery in different positions (Table 3). Eight proven and seven suspected events of air embolism were seen during surgery. The confirmed embolisms with aspiration of air through the venous catheter all occurred in patients in sitting position; the suspected embolisms were seen in four patients in sitting position, two patients in semi-sitting position and one patient in a different position (Table 2).

Only one confirmed air embolism (aspiration of air through the venous catheter) occurred in a patient with a latent PFO. This patient developed a short period of cardiovascular depression and required catecholamines. No other patient with proven air embolism was diagnosed to have a PFO. Furthermore, no other reasons for the development of an air embolism were detected but the surgical procedure. No other complications occurred. The remaining seven confirmed air embolisms occurred in patients without PFO; none of them showed signs of cardiovascular instability.

Three patients with before operation diagnosed right-to-left shunt showed signs of a suspected air embolism during operation. One of these patients was in the sitting position, one semi-sitting and one in a different position.

None of the patients with confirmed or suspected embolic events showed a neurological deficit. All patients underwent postoperative CT; there were no signs of hypoperfusion or infarction after operation.

**Discussion**

The aim of this study was to evaluate the usefulness of a bedside method for the preoperative diagnostics of PFO using TCD. To visualize the intracranial vessels by means of TCD, a usable temporal bone window is required. No such window was present in 18 (20%) of the patients studied; other authors have described the failure rates between 10% and 50% in elderly patients. With respect to measurement time, time resolution, positioning and use of contrast agent, several authors have stated that TCD is equivalent or superior to other procedures.

TCD using ultrasound contrast agent was shown to detect PFO in 95% of cases, using transoesophageal ECG as reference examination recent studies have found it to be equivalent to transoesophageal ECG if the right settings are used. The presence of HITS is not a certain sign of PFO, but PFO is a more likely cause of HITS than other factors (e.g., a lung fistula). Error may be minimized by counting 10 heart cycles while recording, but confident differentiation is not possible using this procedure. Overall, the right-to-left shunt is a possible danger in case of an air embolism regardless of the underlying reason.

In this study a total of 26 (28.8%) of the 90 patients examined were found to have either persistent or a potential right-left shunt caused by a foramen ovale, a frequency similar to previously reported findings. The Valsalva manoeuvre has been proven to be the most sensitive means of identifying a PFO as it increases the number of PFOs detected by around 50%. In this study 100% more cases of PFO were detected after Valsalva manoeuvre. Only two patients were not able to perform the manoeuvre because of their clinical condition.

The risk of suffering an air embolism during surgery in sitting position has been stated between 25 and

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**Table 2** PFO as diagnosed by investigation modality. TCD, transcranial Doppler sonography; TOE, transoesophageal ECG

<table>
<thead>
<tr>
<th>Modality</th>
<th>Persistent PFO (n)</th>
<th>Latent PFO (n)</th>
<th>No PFO (n)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCD</td>
<td>13</td>
<td>10</td>
<td>49</td>
<td>72</td>
</tr>
<tr>
<td>Duplex</td>
<td>0</td>
<td>3</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>TOE</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>13</td>
<td>64</td>
<td>90</td>
</tr>
</tbody>
</table>

**Table 3** Incidence of air embolism during surgery in different positions and the presence of PFO

<table>
<thead>
<tr>
<th>Position during operation</th>
<th>Patients (n=90)</th>
<th>Proven air embolism (n=8)</th>
<th>Suspected air embolism (n=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No PFO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting</td>
<td>51</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Semi-sitting</td>
<td>13</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>PFO on Valsalva Manoeuvre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting</td>
<td>8</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Semi-sitting</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Different</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Functional PFO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Semi-sitting</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Different</td>
<td>9</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
The wide range is attributable to different means of detection and forms of monitoring. In this study air embolisms occurred in 8 patients (10%). Adding the patients with suspected air embolism \((n=7)\), the proportion increases to 18.8\%, which is still lower than the previous reports.\(^2^6\) We believe that the care taken while positioning the patient and the meticulous prevention of bleeding from surgically opened venous vessels were responsible for the lower air embolism rate.

Some studies have stated relative and absolute contraindications for the sitting position.\(^3\) Alongside age, hypertension and obstructive lung disease, diagnosed PFO is one of them.\(^3\) In a study by Kwapisz and colleagues,\(^2^7\) the semi-sitting position chosen before operation was changed into supine position after diagnosing PFO to avoid complications. In this study no other contraindication to the sitting position was present, so right-to-left shunt was the only possible reason for changing the patient’s intraoperative position.

Four patients in this study underwent surgery in sitting or semi-sitting position in spite of proven PFO because of the topography of the pathology and strong neurosurgical reasons. Patients with a PFO usually undergo surgery in positions other than sitting if the pathology and anatomical considerations allow. The knowledge of a PFO with the accompanied risk of a paradoxical air embolism should ensure meticulous surgical management of bleeding, and exact positioning of the patients.

Sitting position according to the surgeons’ requirement is possible as the number of proven PFO and the numbers of patients suffering an air embolism are two different aspects that need to be evaluated separately. The results of this study indicate that a strong relationship between PFO, either persistent or latent and the risk of an air embolism is not existent. The main reason for an air embolism during surgery is the surgical procedure itself. Therefore the decision to avoid the sitting position based solely on the presence of a diagnosed PFO should be reconsidered. In these patients, the sensitivity of detecting air embolism can be improved by using a central venous catheter integrated with an ultrasound probe.\(^2^8\)

In summary, if surgeons are accustomed to performing surgery with the patient in sitting or semi-sitting position and intraoperative monitoring is adapted to the possible risk factors, preoperative investigation for PFO further reduces the risk to the patient, in that knowledge of the presence of PFO will heighten the surgeon’s degree of care and focus attention on alternative positions for surgery.

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