

Original Article

Venous air embolisms and sitting position in Helsinki pineal region surgery

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Abstract

Background: Nowadays, the sitting position has lost favor among neurosurgeons partly due to assumptions of increased complications, such as venous air embolisms (VAEs) and hemodynamic disturbances. The aim of our study is to describe the importance of some anesthetic considerations and the utility of antigravity trousers as well, together with a skillful neurosurgery and an imperative proper teamwork, in order to prevent the risk of severe VAE during pineal region surgery. We routinely use them for the variant of the sitting position we developed, the “praying position.”

Methods: A retrospective review of 51 pineal lesions operated on in the “praying position” using antigravity trousers was carried out. In the “praying position” the legs of the patient are kept parallel to the floor. Hence, antigravity trousers are used to generate an adequate cardiac preload.

Results: VAE associated to persistent hemodynamic changes was nonexistent in our series. The rate of VAE was 35.3%. VAEs were diagnosed mainly by monitoring of the end-tidal CO₂ (83.33%). A venous system lesion was the cause in most of the cases. When VAE was suspected, an immediate reaction based on a good teamwork was imperative. No cervical spine cord injury nor peripheral nerve damage were reported. The average microsurgical time was 48 ± 33 min.

Conclusions: The risks of severe VAE during pineal region surgery in the “praying-sitting position” may be effectively prevented by some essential anesthetic considerations and the use of antigravity trousers together with a skillful neurosurgery, and an imperative proper teamwork.

Key Words: Air embolism, antigravity trousers, hemodynamics, microneurosurgery, pineal region lesions, sitting position

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INTRODUCTION

Pineal lesions are challenging because of their location deep inside the intracranial space and their proximity to critical neurovascular brain structures. Several advantages may be offered by the use of the sitting position for pineal region surgery such as: lower intracranial pressure, good venous outflow, gravitational retraction, and straight anatomical orientation.^[2,7,10,17,18,21,22,26,32] On the other hand, the sitting position may oblige the surgeon to a nonergonomic tiring position, and may cause potential dreadful complications such as severe venous air embolism (VAE) associated to general hypotension.^[1,14,25,29]

A variant of the classic sitting position, the praying position, was developed in our department with the aim to reduce the rate of severe complications, while allowing an ergonomic posture for the surgeon. In the praying position, remarkably, it is not required to elevate the legs of the patient above the level of the heart. Conversely, we routinely use antigravity (G-suit) trousers in order to reduce the risk of complications due to a decreased cardiac preload.^[8,10,26]

The objective of this paper is to describe the importance of some anesthetic considerations and the utility of antigravity trousers as well, together with a skillful neurosurgery and an imperative proper teamwork, to prevent the risk of severe VAE during pineal region surgery, while offering an ergonomic surgical positioning.

MATERIAL AND METHODS

Study design and ethics

This is a single-center retrospective study regarding the evaluation of VAE during the surgical treatment of consecutive pineal region lesions operated on in sitting position. Following the Institutional Review Board approval, data were collected from hospital records, and neuroradiological imaging was reviewed. The patients consent was not required as this is a retrospective study, and the research data analysis had no effect on the participants or their medical care.

Participants and study size

Patients with pineal lesions that were operated on in the “praying position” using G-suit trousers by the senior author (JH) between January 2008 and October 2015. Patients with missing information were excluded.

During the study period, 64 patients with pineal lesions were treated. Of these, 51 met the study inclusion criteria (25 men and 26 women). Mean patient age was 37.2 years (range, 8–79 years).

Variables

Venous air embolism

We defined VAE as any of the following: 1) an embolic heart sound by precordial Doppler ultrasound; 2) a

0.7 kPa (5.25 mmHg) or greater decrease in the end-tidal PCO₂; 3) identification of the air leak at the surgical site.^[22] Severe VAE was defined as the presence of VAE associated with persistent hemodynamic instability (i.e., a reduction of the systolic blood pressure in more than two controls in a 5-min interval) or a related change in the minute ventilation. According to some authors a reduction of the systolic blood pressure of 20% or more from the preoperative baseline is required to define a VAE as severe.^[17,22,27] However, we believe that a persistent hemodynamic instability, in other words a difficult management of a severe hypotension, is more important than only a deep but quickly reversible reduction of the systolic blood pressure.

Sitting position

In our department, the sitting positioning style for pineal region lesions, regardless of the surgical approach (supracerebellar infratentorial or occipital interhemispheric route), is a standardized protocol that ends in a somersault position (“praying-sitting position”) with the horizontal axis of the tentorium parallel to the floor, with less than 90° in relation to the axis of the surgeon [Figure 1].^[7,8]

In the classic sitting position as illustrated by Porter *et al.*, both legs are raised as high as possible in order to prevent the risk of complications.^[25] On the other hand, in the “praying sitting position” the surgical table is bent around 90–100°, thus elevating the upper torso of the patient. As a consequence of this maneuver, the legs of the patient are kept parallel to the floor. Hence, G-suit trousers are used to generate an adequate cardiac preload. Anesthetic considerations for the praying sitting position are described in the Table 1.^[20]

Antigravity trousers

The G-suit trousers are applied at the lower limbs of the patient up to the level of his/her hips (the G-suit trousers are applied when the patient is in supine position, intubated, with peripheral venous access and with urinary catheter). Patients are dressed in antigravity



Figure 1: Sitting praying position in Helsinki neurosurgery. Photo provided by professor Martin Lehecka from Helsinki Neurosurgery

trousers (Trousers ANTI-G, NATO No 8475-99-1300180, Beaufort, Belfast, UK), which are inflated with compressed air up to a pressure of about 40 mmHg. There is a potential risk for peripheral nerves and/or blood vessels injuries, but the shape of the trousers allows the positioning of the patient without intense compression of critical points. Flexible positioning of lower extremities joints is possible. Effective blood gas test, hemodynamic monitoring, and precordial Doppler ultrasound are mandatory [Figure 2].

Thanks to their side zippers, antigravity trousers can be applied in less than 5 min for normal weight adult patients. Their main physiological effect is to increase the peripheral resistance, thus redistributing the blood to body areas above the suit and improving the cardiac preload.^[26]

Microneurosurgery

As previously described, microneurosurgery of the pineal region in Helsinki Neurosurgery is performed according to the following protocol.^[20]



Figure 2: Antigravity trousers for sitting position in Helsinki Neurosurgery

Table 1: Anesthetic considerations for the sitting position in our department

Conventional use of fentanyl, thiopental propofol (or rarely inhaled anesthetic), and rocuronium or vecuronium.

Administration of a bolus of intravenous Ringer's acetate (RAC) or hydroxyethyl starch (HES) just before the positioning of the patient, being HES slightly more effective than RAC in achieving comparable hemodynamics.

In adults, the target mean arterial pressure - measured at the level of the foramen of Monro is 60 mmHg or higher, and/or the systolic arterial pressure 100 mmHg or higher.

The precordial Doppler ultrasonography probe is placed over the right fifth intercostal space.

The patients are normoventilated (target $\text{PaCO}_2 = 4.4\text{-}5.0$ kPa [33.0-37.5 mmHg]) with 100% inspired oxygen, without positive end-expiratory pressure, by volume controlled ventilation. N_2O is not given. Arterial blood gases are analyzed after the induction of anesthesia and as needed.

The surgical strategy is routinely planned based on MRI and CT. Digital subtraction angiography is occasionally used in highly vascularized lesions to determine the main feeders of the lesion. The study of the deep venous system is the most valuable factor in planning the surgical strategy. The paramedian supracerebellar suboccipital approach is the preferred route in our center, as described in a previous paper.^[7] However, the occipital interhemispheric approach and the subtemporal approach are also usable in particular situations.

Once the quadrigeminal cistern is opened and the lesion reached, at the beginning we use to take tumor samples for histopathological analysis, and then we endeavor to progressively accomplish a complete resection. In case of vascular pineal lesions, the analysis of their angioarchitecture is crucial in order to attempt their complete removal. During the intradural stage, it is essential to distinguish the deeply located veins from the dark blue-colored cisterns. Along the supracerebellar approach, the precentral vein is recognized and, if needed, it is coagulated and cut. The microsurgical dissection starts laterally following the cleavage plane between the lesion and its vicinity. An internal debulking is performed by using aspiration, as well as the mechanical and thermal effect of the bipolar forceps. Once the posterior third ventricle is reached, additional cerebrospinal fluid is released. The tumor is carefully dissected from the surrounding veins with the help of water dissection to complete the microsurgical excision. Ultrasonic aspirator is rarely used during this surgery in Helsinki.

The angle below the posterior commissure requires extreme care. The slightest bleeding could determine fatal consequences and small residual tumors as well. Microsurgical mirrors or endoscopes may help to visualize this area. After complete resection, careful hemostasis is imperative. In case of malignant and infiltrative tumors, radical decompression is mostly offered. However, if possible, we try to remove the lesion completely. In case of vascular malformations, a careful microsurgical dissection should take into consideration their anatomic features such as the feeding arteries arising from the vertebrobasilar system, and the tectal and superior cerebellar draining veins into the straight sinus.

Statistics

Correlations between independent variables and the occurrence of VAE were analyzed using the Fisher, Chi square, and Mann-Whitney U test. P values <0.05 were considered significant. SPSS version 22 (SPSS Inc., Chicago, IL, USA) was used.

RESULTS

Participants and descriptive data

Sixty-one patients with pineal lesions were consecutively operated on by the senior author (JH) between March

2008 and October 2015. Three patients were not operated on in the sitting position. Other three patients were not included due to missing data (anesthetic information, preoperative images, or appropriate follow-up). Four pediatric patients did not use antigravity trousers but elastic bandages, and were excluded from the study as well. Characteristics of the remaining 51 patients are presented in the Table 2.

Outcome data and main results

The rate of VAE was 35.3% (18 patients). VAEs were diagnosed mainly by monitoring of the end-tidal CO₂ (83.33%). Only three cases were recognized by direct vision during the surgery; however, the retrospective surgical video analysis revealed a venous

system lesion also in other five patients. In nine patients with no evident venous damage, we highly suspected the presence of microvenous lesions due to the vascular manipulation during the dissection of the pineal lesion and/or small openings of the venous sinuses during the dura opening. No analyzed surgical variable was associated with the presence of VAE [Table 2].

Severe VAE was absent in our series. However, three adult patients (respectively harboring a pineal cyst, a solitary fibrous tumor, and an arteriovenous malformation) presented a very short period (one measurement in a 5-min interval) of low systolic blood pressure associated with VAE, which was rapidly corrected with

Table 2: Characteristics of the pineal region lesions operated on in the praying sitting position using antigravity trousers between 2008 and 2015

	No VAE: 33	VAE: 18	P
Age (years)	M: 34.7±15; Min: 8; Max: 64	M: 43.7±19.9; Min: 13; Max: 79	0.078
Sex	Female: 16; Male: 17	Female: 10; Male: 8	0.771
Bone flap height (cm)	M: 3.9±0.5; Min: 2.9; Max: 5.3	M: 4.2±0.7; Min: 2.9; Max: 6	0.072
Bone flap length (cm)	M: 3.2±0.4; Min: 2.3; Max: 4.2	M: 3.3±0.6; Min: 2.2; Max: 4.6	0.363
Pineal lesion height (cm)	M: 1.9±1.1; Min: 0.5; Max: 5.5	M: 2.2±0.9; Min: 0.7; Max: 4.2	0.104
Pineal lesion length (cm)	M: 2.2±1.4; Min: 0.5; Max: 5.4	M: 2.7±1.2; Min: 0.8; Max: 5.5	0.124
Pineal lesion width (cm)	M: 1.9±0.9; Min: 0.5; Max: 4.8	M: 2.4±1.1; Min: 0.8; Max: 5.4	0.058
Lesion volume (cm ³)	M: 7.3±13.8; Min: 0.06; Max: 71.3	M: 9.9±12.3; Min: 0.3; Max: 12.3	0.092
Skin to skin surgical time (min)	M: 102.1±34.3; Min: 60; Max: 207	M: 120.3±35.5; Min: 68; Max: 201	0.197
Microsurgical time (min)	M: 42.8±26.7; Min: 12; Max: 114	M: 54.2±38.6; Min: 18; Max: 151	0.413
Total resection	30/33	17/18	1.00
Surgical approach	SCIT: 32/33	SCIT: 15/18	0.120
Initial SBP (mmHg)	M: 113.8±12.8; Min: 89; Max: 138	M: 108.7±14.4; Min: 80; Max: 135	0.282
SBP at the positioning (mmHg)	M: 100.7±13.9; Min: 76; Max: 132	M: 96.7±17.8; Min: 68; Max: 133	0.266
VAE diagnosis	-	Decrease of PCO ₂ >0, 7 kPa: 15; Doppler US: 7; direct vision: 3	
SBP at VAE diagnosis (mmHg)	-	M: 91.8±12.1; Min: 60; Max: 113	
Surgical video analysis: (VAE origin)	-	Dissection of a pineal lesion attached to the deep venous system: 5; separation of the torcula from the occipital bone during the craniotomy: 2; transverse sinus damage during the craniotomy: 1; not evident: 9; no video: 1	
SVAE	-	None	
Follow-up (months)	M: 25.6±25; Min: 0; Max: 88	M: 19.9±22; Min: 0; Max: 75	
Diagnosis	Tumors: 30 Ependimoma: 1 Germinoma: 5 Glioblastoma multiforme: 2 Hemangioblastoma: 1 Meningioma: 1 Pineal cyst: 15 PPTID: 5 Vascular lesions: 3 Cavernoma: 1 PChA aneurysm: 1 AVM: 1	Tumors: 17 Pilocytic astrocytoma: 3 Epidermoid tumor: 1 Hemangiopericytoma: 1 Meningioma: 3 Pineal cyst: 7 PPTID: 1 Solitary fibrous tumor of the pineal region: 1 Vascular lesions: 1 AVM: 1	0.171

AVM: Arteriovenous malformation, M: Mean value, Min: Minimum value, Max: Maximum value, PChA: Posterior choroidal artery, PPTID: Pineal parenchymal tumor of intermediate differentiation, SBP: Systolic blood pressure, SCIT: Supracerebellar infratentorial approach, SVAE: Severe venous air embolism, US: Ultrasound, VAE: Venous air embolism

vasoactives and fluid filling. Mean arterial pressure was over 50 mmHg in two cases, and 45 in other one. No change in the ventilation during the surgery, no immediate nor late postoperative complications were observed in these patients.

On the other hand, a patient harboring an epidermoid tumor with a damaged dominant right transverse sinus, which was repaired by direct suturing, presented signs of minor air embolism without consistent reduction of her blood pressure.

In our series three patients had recurrent lesions: only a patient with a recurrent hemangiopericytoma presented a VAE.

As a part of the sitting position protocol, when VAE was suspected, an immediate reaction based on a good teamwork and a proper communication between the anesthesiologist and the surgeon was imperative. The compression of both jugular veins by the anesthesiologist was very effective to find the leak, which was repaired by the surgeon using hemostatic agents or direct suturing. Air aspiration from the central venous catheter was never used.

Postoperative course was uneventful with no complication related to the positioning nor to the use of the antigravity trousers. No cervical spine cord injury, no facial or tongue edema nor peripheral nerve damage were reported.

DISCUSSION

Essential anesthetic considerations and antigravity trousers as well, together with a skillful neurosurgery and an imperative proper teamwork may effectively prevent, the risk of severe VAE during pineal region surgery in the ergonomic “praying-sitting position.”

In a systematic review of craniotomy studies comparing sitting and horizontal positions, the incidence of VAE was respectively 15–45% and 0–12%.^[12,22] The incidence of severe VAE in sitting position was found to be between 1% and 6% in six large studies.^[11,13,16,24,29,30,33]

Previous series from our department reported a rate of minor VAE in patients undergoing pineal lesion removal in sitting position between 19% and 50%, in relation to the considered limit of PCO₂ decrease (0.7 kPa or 0.3 kPa). Precordial Doppler is always used as a part of our protocol for the sitting position in Helsinki neurosurgery. In this retrospective study most of the VAEs were diagnosed by a PCO₂ decrease. Even if we assume that Doppler ultrasound is more sensitive than PCO₂, as reported in the literature, we believe that the changing signal from the Doppler is not so specific. Hence, in our daily clinical practice, VAE is usually reported by the anesthesiologists only when the Doppler changing signal occurs together with an end-tidal PCO₂ decrease, or when end-tidal PCO₂ falls without any change in Doppler.

Nonetheless, VAE was never associated with simultaneous hemodynamic instability nor with a modification in minute ventilation.^[21,22] In other words, systolic blood pressure, heart rate, and respiratory minute volume were comparable in patients with and without VAE. Moreover, no difference in the amount of administered vasoactive agents, intraoperative fluids nor postoperative management in patients with and without VAE was reported. No complication related to a systemic arterial air embolism was observed.^[21,22]

The incidence of VAE in sitting position may be reduced by adopting a careful surgical technique, as well as by maintaining an optimal right atrial pressure. Classically, intravenous fluids, an antigravity suit, and the application of a positive end-expiratory pressure are used for that.^[19]

However, Giebler *et al.* observed that the incidence of VAE did not differ between patients undergoing conventional ventilation and those undergoing ventilation with 10 cm H₂O of positive end-expiratory pressure.^[15] Furthermore, according to Luostarinen *et al.* the sitting position does not require excess fluid treatment compared with the prone position. With goal-directed fluid administration and moderate use of vasoactive drugs, it is possible to accomplish stable hemodynamics in both surgical positions.^[23]

In this regard, we conclude that risk for VAE is directly related to an intraoperative accidental venous structures laceration and to a low cardiac preload due to the surgical position.

Hence, as above mentioned, we strongly believe that an effective surgical teamwork cooperation, together with a skillfull neurosurgery and the use of antigravity trousers, is imperative to reduce the risk for VAE and hemodynamic instability.^[3–7,9,28,31]

Antigravity trousers are commonly used in military airplanes, and they were first used for medical purposes in the 1950s. Compressed air is widely available inside operating theaters: this made easier their use.^[2,10,22,25,26]

Benefits of antigravity trousers in sitting position for neurosurgery were early recognized.^[2,10,17,22,26] However, there is no general consensus about the specific pressure that needs to be used while performing a surgical operation in sitting position. A pressure of 20–40 mmHg has been considered effective and safe by many authors.^[2,10,26] A pressure over 40 mmHg for the entire duration of the surgical procedure may be risky, as it may determine a decrease in renal perfusion and urine output, as well as increased respiratory rate and reduced vital capacity. Nonetheless, the risk of ischemic injuries is connected with long periods of antigravity trousers inflation more than with the pressure of inflation itself. Hence, for example, a pressure of 100–110 mmHg is usually recommended for shocked patients.^[26]

In our department we use the antigravity trousers since 1997. We usually inflate them at a pressure of 40 mmHg, and no complication occurred so far.^[17,22] However, a limitation for their use is represented by the availability of the correct size. In children, often, elastic bandages are wrapped around the lower extremities.^[22]

The average microsurgical time of our surgical series was 48 ± 32 min, and the average surgical skin to skin time was 109 ± 35 min.

CONCLUSIONS

The risks of severe VAE during pineal region surgery in the “praying-sitting position” may be effectively prevented by some essential anesthetic considerations and by the use of antigravity trousers together with a skillful neurosurgery and an imperative proper teamwork.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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