DOI: 10.23934/2223-9022-2019-8-2-138-144

Jugular Bulb Pressure in Surgery of Patients in Sitting Position

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BACKGROUND The pressure in brain sinuses (BSP) is used to monitor the effectiveness of various methods of prevention and treatment of venous air embolism (VAE) during surgeries in patients in the sitting position. A simpler and more approachable way is to measure the pressure in the superior bulb of the jugular vein (JBP), which accurately reflects the BSP. The dependence of the frequency and severity of VAE in JBP, however, has not been investigated, and the data on the effect of various methods of prevention and treatment of VAE on JBP are either insufficient or contradictory. The study was aimed to determine the dynamics of the JBP when bringing the patient to a sitting position, its relation with the severity of the VAE and to assess the effect of right atrium pressure (RAP), positive end expiratory pressure (PEEP) and decreased minute pulmonary ventilation (MPV) on it.

MATERIAL AND METHODS The prospective study included 66 people who underwent intracranial surgery in a sitting position. In addition to the standard monitoring under general anesthesia with artificial lung ventilation, the superior bulb of the jugular vein and the right atrium were catheterized, and the esophagus was intubated with transesophageal echocardiography sensor. JBP was measured in a supine and sitting position and examined in relationship to RAP. In patients with JBP≤0 mm Hg, its dynamics was evaluated at PEEP≤0 cm H_20 and MPV with end-tidal carbon dioxide ($etCO_2$)=44 mm Hg, PEEP=15 cm H_20 and MPV with $etCO_2$=36 mm Hg. The Tuebingen scale (Tuebingen VAE) was used to determine the severity of VAE.

RESULTS After bringing the patient to the sitting position the JBP significantly (W=2137.5; p<0.001) decreased by an average of 8 mm Hg, while in 11 (16.7%; 95% CI: 8.6–27, 8) cases it remained positive. No correlation was found between the RAP and JBP in the supine position (Z =-0.08225; p=0.9344) and in the sitting position (Z=1.2272, p=0.2198). The VAE frequency was 51% (95% CI 38.8–64). In patients with JBP ≤0 mm Hg, the frequency and severity of VAE was significantly higher than with JBP≥1 mm Hg (chi-square=4.37; df=1; p=0.036 and Z=2.47, p=0.015, respectively). Significant changes of JBP when PEEP 15 cm H_20 and MPV with $etCO_2$=36 mm Hg were not found (Z = -0.9784, p=0.3964 and Z=-1.3324, p=0.2305 respectively).

CONCLUSION 1. The negative JBP after bringing the patient to the sitting position is accompanied by an increase in the frequency and severity of VAE. 2. In patients in a sitting position, the correlation between RAP and JBP was not found. 3. Isolated PEEP and changes in ventilation do not lead to an increase in JBP.

Keywords: sitting position, head-up position, venous air embolism, jugular bulb pressure, transesophageal echocardiography

For citation Averyanov D.A., Lakotko R.S., Shchyogolev A.V., et al. Jugular bulb pressure in surgery of patients in sitting position. *Russian Sklifosovsky Journal of Emergency Medical Care.* 2019; 8(2): 138–144. DOI: 10.23934/2223-9022-2019-8-2-138-144 (In Russian)

Conflict of interest Authors declare lack of the conflicts of interests

Acknowledgments The study had no sponsorship

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ALV – artificial lung ventilation
AVM – arteriovenous malformation
BP_m – mean blood pressure
BP_s – systolic blood pressure
BSP – brain sinuses pressure
CVP - central venous pressure
IBPM – invasive blood
JBP – jugular blood pressure
MPV – minute pulmonary ventilation
PEEP – positive end-expiratory pressure
RAP – right atrial pressure
TEE – transesophageal echocardiography
VAE – venous air embolism

INTRODUCTION

Performing neurosurgical operations in a sitting position has long been a subject of discussion, both in the foreign and domestic literature [1-3]. Despite the known disadvantages of this position, it has a number of distinct advantages [4]. Moreover, the refusal to use it does not completely prevent developing one of the most serious complications of neurosurgical operations performed in a sitting position, venous air embolism (VAE), but leads only to its decreased incidence [5]. Considering the fact that in some cases the benefits of sitting position may be greater than the risks of serious complications, such as VAE in particular, surgeons will not completely abandon this method. This is why we need to study of the issue of VAE and learn the ways of solution.

According to the literature, the prevalence of VAE ranges from 6% to 56% [6, 7]. Some techniques have been suggested for the prevention and treatment of VAE [8–10]. BSP (brain sinuses pressure) is calculated to assess of the effectiveness of these methods indirectly [11–14], which disadvantages are high invasiveness and difficulty in providing access, which limits its widespread use. It is more simple and affordable for an anesthesiologist to measure pressure in the superior bulb of the jugular vein (JBP) [11, 15, 16]. The dependence of VAE frequency and severity on JBP, however, has not been investigated, and the efficacy of various methods of prevention and treatment of VAE are either insufficient or controversial [9].

The aim of study is to determine the dynamics of JBP when bringing a patient to a sitting position, its relation to the severity of the VAE and to assess the effect of pressure in the right atrium, positive end-expiratory pressure and decrease in minute pulmonary ventilation (MPL).

MATERIAL AND METHODS

After the approval by the local ethics committee, the prospective study included 66 patients from the Neurosugregy Clinic of S.M. Kirov Military Medical Academy from 2017 to 2018. The criterion for inclusion into the study was the planned neurosurgical intervention in a sitting position on the operating table. Characteristics of patients are presented in Table 1. Exclusion criteria were repeated craniotomy with the presence of a bone defect in the area of operation and the patient's refusal to participate in the study.

Table 1

The characteristics of patients

Age (years)		44 (36; 58)
Height (cm)		166.5 (162; 175)
Weight (kg)		70.5 (61.25; 82)
Gender	Male, n (%)	29 (44)
	Female, n (%)	37 (56)
Trepanation method	Resection trepanation, n (%)	37 (56)
	Osteoplastic trepanation, n (%)	29 (44)
Reason for surgery	Neoplasm of the cerebello-pontine angle, n (%)	11 (16.6)
	Cerebellum neoplasm, n (%)	10 (15.1)
	Neoplasm in the 4 ventricle, n (%)	10 (15.1)
	Meningioma of the posterior cranial fossa, n (%)	7 (10.6)
	Neuroma of the cerebello-pontine angle, n (%)	7 (10.6)
	Neoplasm of the occipital lobe, n (%)	6 (9.1)
	Neurovascular conflict, n (%)	6 (9.1)
	Arnold-Chiari anomaly, n (%)	4 (6)
	Neoplasm of the pineal region, n (%)	2 (3)
	AVM of the occipital lobe, n (%)	1 (1.5)
	AVM of the cerebellum, n (%)	1 (1.5)
	Meningioma of the middle third of the falx, n (%)	1 (1.5)

Note: AVM – arteriovenous malformation

To determine the limits of the physiological permissibility of flexing the trunk and extremities of patients prior to the sugrery, we asked the patient to take a position identical to the sitting position on the operating table, and clarified complaints about numbness, tension, myalgia, etc. In the morning of the surgery day, standard premedication was used: Tramadol 100 mg, Diphenhydramine 10 mg, Seduxen 10 mg intramuscularly.

Upon admission of a patient to the operating room, the standard monitoring was provided: electrocardiography in three leads, pulse oximetry and invasive blood pressure measurement (IBPM). One of the radial arteries, which was catheterized under ultrasound guidance with a 20G peripheral catheter, was used as an access for IBPM. The IBPM sensor was set at the level of the phlebostatic axis in the supine position and at the level of the external auditory canal in the sitting position. In order to correct dehydration due to nighttime liquid deprivation and reduce the negative hemodynamic effect of sitting, intravenous infusion of physiological saline 0.9% 800 ml and colloid solution Voluven 500 ml were administered before anesthesia. Target figures at the time of surgery were IBP_m (mean) more than 65 mm Hg or $IBPM_{syst}$ (systolic) more than 100 mm Hg. If necessary, hypotension was managed with noradrenaline infusion.

Anesthesia was initiated with Propofol 1–1.2 mg/kg, Fentanyl 3-5 μg/kg, Rocuronium 0.4–0.6 mg/kg (as a muscle relaxant). Artificial ventilation of the lungs (ALV) was provided in the normal ventilation mode so that the pressure of end-tidal exhaled carbon dioxide ($etCO_2$) was 35–38 mm Hg. Medication sleep was maintained by Sevoflurane inhalation (MAC 0.9–1.0), and analgesia by fractional administration of 0.1 mg of Fentanyl every 30 minutes. If necessary, Propofol 4–8 mg/kg/min was used as the main anesthetic for monitoring of transcranial electrical motor induced potentials. Before bringing the patient into a sitting position, we intubated the esophagus by a transdural esophageal echocardiography sensor *TEExi* 8–3 MHz *(Fujifilm Sonosite)* and performed the diagnosis of blood bypass from right to left according to the previously described method [17]. Subsequently, TEE in the bicival position (2D mode) was used to diagnose the VAE during the operation. Catheterization of the superior bulb of the jugular vein was performed with a 14G catheter under ultrasound guidance on the side of the surgical intervention or on the right side in case of midline access. It it was inserted 14–15 cm in the cranial direction against the stop, then pulled backwards 0.5–1 cm and checked for free blood flow [18]. The right atrium was catheterized to measure the pressure under ultrasound guidance. The accuracy of the location of the tip of the catheter was confirmed by TEE.

The desired position of patients was achieved due to pillows and adjustments of parts of the operating table. To increase the reduced preload of the heart due to the sitting position the legs were lifted in accordance with the physiological level determined in the preoperative period (Fig. 1). Knees and ankles above the level of the heart chambers was considered optimal.

Fig. 1. A patient in a sitting position

To determine the dynamics in a stable state before and after bringing the patient to the sitting position, we measured JBP. The condition was considered as stable if an obvious trend to increase or decrease JBP, mean blood pressure (BP_m) systolic blood pressure (BP_{syst}), right atrial pressure (RAP), heart rate (HR), $etCO_2$, hemoglobin oxygen saturation (SpO_2), and their fluctuations were either absent or insignificant (no more than 2 mm Hg for IMBP; 1 mm Hg for JBP, RAP and $etCO_2$; 2 beats/sec for HR; 1% for SpO_2). To assess the effect of RAP, positive end-expiratory pressure (PEEP), $etCO_2$ on VAE in patients with VAE in a sitting position below 1 mm Hg, we consistently recorded these figures first with PEEP 15 cm mmAq and $etCO_2$ 36 mm Hg, then with a PEEP of 0 cm mmAq and $etCO_2$ 44 mm Hg. To determine the severity of VAE, the Tübingen scale *(Tübingen VAE)* [19] was used.

Statistical processing was performed using *R* version 3.5.1 (*RStudio* version 1.1). Quantitative and qualitative ranking data are presented in the form of medians and quartiles, nominal in the form of percentages and 95% confidence interval (95% CI) (the exact Klopper – Pearson method). For comparative studies, the Wilcoxon test was used for paired samples, the Wilcoxon test in the Pratt modification (the *"coin"* package *R* version 3.5.2) in the presence of repeated values with the calculation of the exact value of the probability, the Wilcoxon criterion for unpaired samples using χ^2 Pearson with Yeats corrected for continuity. The significance level at which the null hypothesis of the absence of differences in the groups was rejected was considered 0.05. Correlation analysis was performed with Spearman test (package *«coin» R* version 3.5.2) with the calculation of the exact value of the probability of the presence of duplicates (*«mid-ranks»* method*).*

RESULTS

In patients in the supine position, JBP was 5 (3; 7) mm Hg. In 61 (92.4%; 95% CI 83–97) patients, it was positive. The change to the sitting position was accompanied by a statistically significant decrease in the JBP by an average of 8 msustained only in 11 (16.7%; 95% CI 8.6–27.8) patients. These patients were excluded from further analysis of the effect on JBP, RAP, PEEP and ventilation.

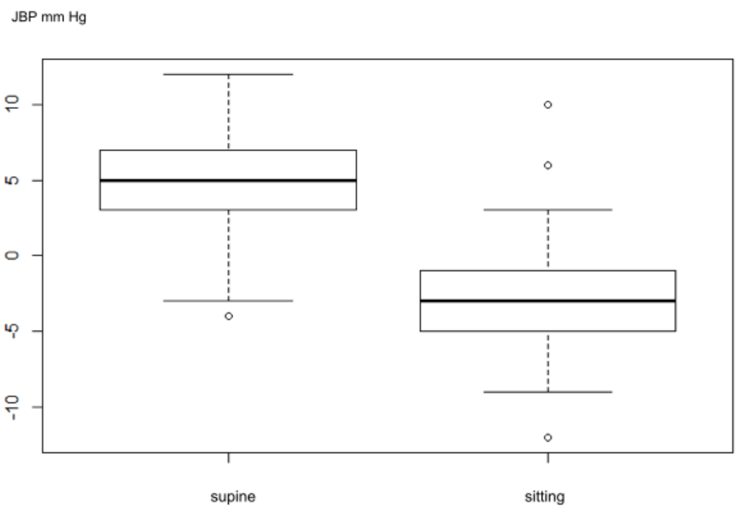

Fig. 2. The pressure in the superior jugular vein bulb (JBP) in patients in a sitting and supine position

The incidence of VAE was 51% (95% CI 38.8–64). To assess the effect of JBP on the severity of VAE, patients were divided into two groups: group 1 with JBP equal or more than 1 mm Hg and group 2 with JBP equal or less than 0 mm Hg. The severity of VAE in group 1 was 0 (0; 0) and statistically significant (Z=2.47; p=0.015) differed from the severity in the group 2-1 (1; 0). Thus, in group 1, only two patients (18%; 95% CI 2,2-51,7) had VAE with Tubingen score 1. At the same time, VAE was found in 32 patients of the the group 2 (58 %; 95% CI 44.1–71.3). The difference in the incidence of VAE in groups was statistically significant (χ^2= 4.37; df=1; p=0.036). The VAE severity is presented in Table 2.

Table 2

The severity of VAE depending on JBP

VAE severity		Group 1	Group 2
Tubingen 0 (n)		9	23
Tübingen 1 (n)		2	21
Tubingen 2 (n)		0	6
Tubingen 3 (n)		0	4
Tubingen 4 (n)		0	1
Tubingen 5 (n)		0	0
Total (n)		11	55

RAP in patients in the supine position was 4 (2; 4) mm Hg , and in the sitting position it was -3 (-5; 1) mm Hg. The change in RAP due to a change in the patient's position on the operating table was statistically significant (V=1,778; $p<0.001$). There was no correlation between RAP and JBP, both in the supine position (Z=-0.08225; $p=0.9344$) and sitting position (Z=1.2272; $p=0.2198$).

When comparing JBP before and after a change in PEEP, no statistically significant differences were found (Z=-0.9784; $p = 0.3964$). Also, there were no statistically significant differences in JBP and when ventilation (Z=-1.3324; $p=0.2305$) of the lungs was changed.

DISCUSSION

The problem of VAE, arising from operations on the head and neck in a sitting position, is currently unresolved and is one of the main reasons to abandon the sitting position in neurosurgical practice. The prerequisites for the development of VAE are the communication of a non-collapsible vein with the external environment and the negative pressure in it. Such non-collapsible venous vessels for neurosurgical interventions are most often diploic veins, emissary veins and sinuses. The prerequisite for creating a negative pressure is the location of the operating wound above the heart level with the formation of a gravitational gradient up to 20 mmAq in adults [20].

If the opening of non-collapsible vessels cannot be avoided in cases where it is an integral part of the surgical approach, then preventing the formation of negative pressure in these vessels seems to be quite feasible. In order to directly or indirectly influence pressure in them, many methods have been suggested. However, the direct monitoring of the effectiveness of all these methods remains a challenge.

The most accurate approximation of pressure in non-collapsible veins is the measurement of BSP. However, such monitoring is too invasive and obviously not suitable for routine use. A simpler way to obtain the necessary information is JBP. Catheterization of the superior bulb of the jugular vein in routine practice is simple, and the relation between JBP and BSP is obvious, since the jugular vein is a continuation of the sigmoid sinus, and its superior bulb is the closest area to it. The difference between the BSP and JBP is about 1–2 mm Hg [11]. *Meyer et al*. revealed a direct correlation between RAP and JBP in children [16]. Later, this fact was even used as a reason to abandon the measurement of JBP. According to the results of the analysis of the data obtained, no correlation was found between RAP and JBP in adults. The reasons for which this discrepancy exists, is apparently the contingent of patients (the gravitational gradient is obviously higher in adults) and the method of calculation. To build a regression model, *Meyer et al.* used JBP and the RAP obtained before and after bringing the patients to a sitting position, which is incorrect from the point of view of statistical analysis. The reason why there is no correlation between JBP and RAP seems to be two factors: the presence of valves in the internal jugular vein and the operation of this vein as a Starling resistor [14].

Methods that allow for a safer increase of JBP and, accordingly, BSP may neutralize one of the two mandatory factors for the development of VAE and, probably, reduce the risk of its development or reduce the severity. Indeed, for the purpose of bringing a patient into a sitting position, it decreases. *Meyer et al.* showed that in children such a decrease averages 10 mm Hg. [16] In the data obtained in adults, the decrease was also significant (8 mm Hg). It should be noted that, due to negative values, the need for an increase in JBP after bringing the patient into a sitting position exists in most, but not all, patients. Based on the data obtained, in 16.7% of cases JBP was above zero. The other researchers give the similar data [15, 16].

Increasing BSP against the background of constant cerebral cerebral blood flow suggests, one way or another, the struggle with the gravitational pressure gradient between the heart and the operating wound. Methods of influence may be divided into three groups: the creation of an obstacle to the free flow of blood through the jugular veins, the creation of increased pressure in the right atrium and an increase in the volume of cerebral blood flow.

Among the methods of the 1st group, the simplest one currently suggested is manual two-sided compression of the jugular veins. This is a way to significantly increase JBP and the BSP above atmospheric, regardless of its initial values [11, 13]. Unfortunately, in the absence of routine control of JBP, insufficient compression will be ineffective, while excessive compression may reduce cerebral blood flow due to compression of the carotid arteries [9]. Alternatives to manual compression are various versions of neck tourniquets and intragular cylinders [8, 21]. However, all these methods should be considered as short-term and therapeutic, aimed at preventing further entry of air into the circulatory system and facilitating the surgeon's search for the source of its penetration. Due to the obvious effectiveness of this method, the data on its effect on the JBP are not given in this work.

As methods of the 2nd group, an increased infusion load, PEEP and antishock trousers are known [16, 22]. Among these methods, the least effective is the infusion load, since its ability to increase RAP in patients in the sitting position is insignificant [22]. In this regard, the patients in this study decided not to expand the infusion volume. *Meyer et al.* recommended the use of antishock trousers [16]. Thus, with their use, the central venous pressure (CVP) in adults in the sitting position increases from an average of -2 to 8 mm Hg. [23]. A simple, not requiring any additional tools way to increase RAP is PEEP [24, 25]. However, an increase in peep to prevent VAE should be viewed critically. *Giebler et al*. cite evidence that PEEP reduces the frequency of VAE, but reducing the preload may lead to undesirable hemodynamic effects [26]. According to them, the use of PEEP up to 15 cm mmAq has no such effects. Unfortunately, its isolated application is not able to cope with the gradient and significantly affect JBP, as demonstrated in this study.

The use of reduced minute ventilation of the lungs with $etCO_2$ target numbers at the upper limit of the allowed reference interval (35–45 mm Hg) is a method of the 3rd group influencing the gradient. It is known that due to coupling "etCO $_2$ - cerebral blood flow" in the range from 20 to 80 mm Hg, $etCO_2$ directly contributes to an increase in cerebral blood flow, which ultimately leads to the leveling of negative BSP [10]. The isolated use of this method in the presented work, however, did not lead to a significant increase in JBP.

The study indicates that the isolated application of any one method of dealing with a gravitational gradient (in particular, in the framework of the presented research - PEEP and changes in the ventilation mode), which inevitably arise in patients in a sitting position, will not have success due to the lack of effect of each of them separately. It appears, however, that their combinations, taking into account the possible negative effects of a particular technique, may have good results and require further study.

FINDINGS

1. The negative pressure in the upper bulb of the jugular vein is formed when the patient is put to the sitting position and accompanied by an increase in the frequency and severity of the venous air embolism.
2. In patients in the sitting position, the correlation between the pressure in the right atrium and the superior bulb of the jugular vein was not found.
3. Isolated application of positive pressure at the end of exhalation and changes in ventilation mode did not lead to an increase in pressure in the upper bulb of the jugular vein.

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Received on 01.02.2019

Accepted on 25.03.2019