Comparison of Cerebral Autoregulation Above and Below the Tentorium of the Cerebellum In Neurosurgical Patients with Transtentorial ICP Gradient

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ORIGINAL WORK

Comparison of Cerebral Autoregulation Above and Below the Tentorium of the Cerebellum In Neurosurgical Patients with Transtentorial ICP Gradient

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Abstract

Introduction: Cerebral autoregulation is an essential mechanism for maintaining cerebral blood flow stability. The phenomenon of transtentorial intracranial pressure (ICP) gradient after neurosurgical operations, complicated by edema and intracranial hypertension in the posterior fossa, has been described in clinical practice but is still under-investigated. The aim of the study was to compare autoregulation coefficients (i.e., pressure reactivity index [PRx]) in two compartments (infratentorial and supratentorial) during the ICP gradient phenomenon.

Methods: Three male patients, aged 24 years, 32 years, and 59 years, respectively, were involved in the study after posterior fossa surgery. Arterial blood pressure and ICP were invasively monitored. Infratentorial ICP was measured in the cerebellar parenchyma. Supratentorial ICP was measured either in the parenchyma of the cerebral hemispheres or through the external ventricular drainage. Cerebral autoregulation was evaluated by the PRx coefficient (ICM +, Cambridge, UK).

Results: In all patients, ICP was higher in the posterior fossa, and the transtentorial ICP gradient in each patient was 5 ± 1.6 mm Hg, 8.5 ± 4.4 mm Hg, and 7.7 ± 2.2 mm Hg, respectively. ICP in the infratentorial space was 17 ± 4 mm Hg, 18 ± 4.4 mm Hg, and 20 ± 4 mm Hg, respectively. PRx values in the supratentorial and infratentorial spaces had the smallest difference (− 0.01, 0.02, and 0.01, respectively), and the limits of precision were 0.1, 0.2, and 0.1 in the first, second, and third patients, respectively. The correlation coefficient between the PRx values in the supratentorial and infratentorial spaces for each patient was 0.98, 0.95, and 0.97, respectively.

Conclusions: A high degree of correlation was established between the autoregulation coefficient PRx in two compartments in the presence of transtentorial ICP gradient and persistent intracranial hypertension in the posterior fossa. Cerebral autoregulation, according to the PRx coefficient in both spaces, was similar.

Keywords: Cerebral autoregulation, Pressure reactivity, Fossa posterior, Transtentorial gradient, Intracranial hypertension, Gradient intracranial pressure

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Introduction

Cerebral autoregulation is a crucial mechanism for maintaining stable cerebral blood flow [1, 2]. Impaired cerebral autoregulation in patients with brain injury and cerebrovascular accidents is often complicated by cerebral ischemia and unfavorable outcome [3, 4]. Compromised

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cerebral autoregulation is a key element in secondary brain damage and is often associated with intracranial hypertension [3–5].

Currently, clinicians have access to various methods for assessing the status of autoregulation [6, 7]. According to Consensus (expert opinion), none of the existing techniques can be considered a standard for autoregulation assessment [8]. Nevertheless, the most straightforward and most accessible method of surrogate evaluation of cerebral autoregulation in patients with acute cerebral injury remains the pressure reactivity index (PRx) [3, 6–8]. PRx calculates as a moving correlation coefficient between intracranial pressure (ICP) and arterial blood pressure (ABP) signals [9].

Treatment of intracranial hypertension in acute cerebral pathological conditions, including brain injury and cerebrovascular accidents, remains the cornerstone of neurointensive care [4, 10, 11]. The development of intracranial hypertension is also possible in neurosurgical patients with complicated courses of disease [4, 10, 11]. Interestingly, neurosurgical intervention on the posterior cranial fossa (PCF) often leads to the development of a very unusual phenomenon—transtentorial ICP gradient. Edema in the area of surgical intervention, mass effect (hematoma, bleeding), venous stasis, and compression of the cerebrospinal fluid pathways in the PCF area lead to the formation of compartment syndrome and transtentorial ICP gradient, with a predominance of ICP values in the infratentorial space [12, 13]. The phenomenon of transtentorial ICP gradient is described in experiments on animal models and in clinical practice [12–17].

The aim of our study was to evaluate the state of autoregulation above and below the cerebellar tentorium in patients with complicated courses after neurosurgical interventions on the PCF and developed transtentorial ICP gradient.

Materials and Methods

In this work, we present retrospective data from three patients after neurosurgical intervention on PCF (Table 1). Before surgery, all patients had moderate bulbar palsy, cerebellar symptoms, headache, and dizziness. These patients had a high degree of vascularization at the surgical site, revealed by angiography, suggesting the likelihood of venous congestion in the trunk region, a risk of increased bulbar dysfunction, and prolonged intensive care. Monitoring of ICP in the supratentorial and infratentorial space in two patients was performed immediately after the operation (the first and third patients). In one patient (the second patient), supratentorial ICP monitoring was done through the external ventricular drainage (EVD) that was installed 3 days after the surgery, followed by PCF decompression to attenuate the edema in PCF, hydrocephalus, and neurological impairment.

The ICP monitoring indicated a high probability of edema and intracranial hypertension in the PCF. The Codman probes were installed at the end of the surgery after preliminary calibrations. In all three patients, the infratentorial transducers were implanted in a sitting position into the cerebellar hemisphere to a depth of 1.5 cm. The dura mater was sealed by suture, the bone flap was placed in place and fixed, and soft tissues were sewn in layers. After that, the patient was transferred to a horizontal position. The second transducer was installed supratentorial (in two patients) through the trephined hole at the Kocher point to a depth of 2 cm. Each transducer was connected to an "ICP Express Codman" monitor (Codman & Shurtleff Inc., Raynham, MA), connected to the bedside Philips IntelliVue MP60 (Philips Medical Systems, Best, The Netherlands). In one patient (the second), ICP measurement in supratentorial space was performed through the EVD that was installed due to hydrocephalus.

Table 1 General characteristics of patients

Patients #	Sex	Age (years)	DS	DC of fossa posterior	EVD	Duration of stay in NICU (day)	Duration of stay in hospital (day)	Outcome/ Karnofsky performance scale [22]
1	Male	32	Hemangioma of the caudal parts of the IV ventricle	No	No	6	64	Survived/ 60
2	Male	24	Malformation of the right cerebellar hemisphere. Chronic hematoma of the right cerebellar hemisphere	Yes	Yes	16	20	Died / 0
3	Male	59	Hemangioblastoma of brainstem	No	No	51	97	Survived / 80

DS: Diagnosis, *DC* Decompression, *EVD* External ventricular drainage, *NICU* Neurosurgical intensive care unit

Data Acquisition

Arterial blood pressure was recorded through arterial lines connected to pressure transducers. ICP was acquired from an intraparenchymal strain gauge probe (Codman ICP MicroSensor; Codman & Shurtleff Inc., Raynham, MA). All data were recorded using digital data transfer and sampled at a frequency of 100 Hz using the ICM + software (Cambridge, UK). Signal artifacts were removed by using both manual methods before further processing or analysis. Duration of intracranial hypertension was measured to summarize the time when ICP was more than 20 mm Hg from all times of monitoring and is presented as percentages. The length of impaired autoregulation was calculated as the time when PRx was more than 0.2 and is presented as percentages.

Signal Processing

Ten-second moving averages (updated every 10 s to avoid data overlap) were calculated for signals: ICP and ABP. PRx was calculated as the moving correlation coefficient between 30 consecutive 10-s mean windows of ICP and ABP, updated every minute using the ICM + software (Cambridge Enterprise Ltd, Cambridge, UK, http://icmplus.neurosurg.cam.ac.uk) [9]. The threshold of the PRx was set to 0.2. Mean values more than the recording period were calculated.

Autoregulation status was considered as preserved if $PRx \leq 0.2$. Autoregulation status was deemed to be non-preserved or impaired if $PRx > 0.2$.

Statistical Analysis

Statistical analyses were performed using Statistica10.0 (StatSoft, USA). The Bland–Altman method was used to compare the autoregulation coefficient (PRx) in supratentorial and infratentorial spaces. The correlation between ICP and PRx values in the supratentorial and infratentorial spaces were done by using Pearson's correlation coefficient. All data are presented as means ± standard deviations.

Results

ICP in the supratentorial and infratentorial space was monitored for 103 ± 9.5 h. In all patients, ICP was higher in the PCF. The transtentorial ICP gradient was 5 ± 1.6 mm Hg in the first patient, 8.5 ± 4.4 mm Hg in the second, and 7.7 ± 2.2 mm Hg in the third. ICP in the infratentorial space was 17 ± 4 mm Hg in the first patient, 18 ± 4.4 mm Hg in the second, and 20 ± 4 mm Hg in the third. The total duration of intracranial hypertension in supratentorial space in all patients was minimal: 0.6%, 2.3%, and 0.7%, respectively. The entire period of intracranial hypertension in the infratentorial space was 25%, 34% and 45%, respectively, of the monitoring time (Table 2). All patients showed a high degree of similarity between the ICP and PRx trends in the supra and infratentorial spaces (Supplementary Figs. 1, 4, 7, 10–12). The correlation coefficient between ICP values in the supratentorial and infratentorial spaces was 0.91 in the first patient, 0.64 in the second, and 0.86 in the third (Table 2).

Most of the time, autoregulatory status was preserved in all patients ($PRx \leq 0.2$), despite the ICP gradient and the development of episodes of persistent hypertension in the PCF (Table 3). The PRx in the supratentorial space in each patient was 0.02 ± 0.2, 0.07 ± 0.2, and 0.002 ± 0.2, respectively, and in the infratentorial space was 0.04 ± 0.2, 0.06 ± 0.2, and 0.02 ± 0.2 in the first, second, and third patients, respectively (Table 3). The duration of the impaired autoregulation ($PRx > 0.2$) in the supratentorial and infratentorial spaces was similar in all patients (Table 3), (Supplementary Figs. 3, 6, 9). The correlation coefficient between PRx values in the supratentorial and infratentorial spaces was 0.98, 0.95, and 0.97 in the first, second, and third patient, respectively (Table 3; Supplementary Figs. 2, 5, 8). PRx values in the supratentorial and infratentorial spaces had the smallest difference (−0.01, 0.02, and 0.01) and the limits of precision were 0.1, 0.2, and 0.1 in the first, second, and third patient, respectively (Fig. 1).

Table 2 Comparison of mean ICP in supratentorial- and infratentorial spaces

Pts #	ICP monitoring time (hours)	ICP_{supra} (mm Hg)	ICP_{infra} (mm Hg)	Duration of ICP_{supra} > 20 mm Hg (%)	Duration of ICP_{infra} > 20 mm Hg (%)	Correlation ICP_{supra} and ICP_{infra}
1	114	13 ± 3.4	17 ± 4	0.6	25	0.91
2	96	11 ± 4.5	18 ± 4.4	2.3	34	0.64
3	100	11 ± 2.8	20 ± 4	0.7	45	0.86

Pts – patient; ICP_{supra} – intracranial pressure in supratentorial spaces; ICP_{infra},—intracranial pressure in infratentorial spaces, ICP_{supra}, intracranial pressure in supratentorial spaces, Pts, patient

Table 3 Comparison of PRx in supratentorial- and infratentorial spaces

Pts #	ICP monitoring time (hours)	PRx_{supra}	PRx_{infra}	Duration (%) of PRx_{supra}		Duration (%) of PRx_{infra}		CorrelationCorrelation PRx_{supra} and PRx_{infra}
				≤ 0.2	>0.2	≤ 0.2	>0.2	
1	114	0.02 ± 0.2	0.04 ± 0.2	67	33	66	31	0.98
2	96	0.07 ± 0.2	0.06 ± 0.2	62	38	64	36	0.95
3	100	0.002 ± 0.2	0.002 ± 0.2	61	39	61	39	0.97

ICP_{infra}, coefficient autoregulation in infratentorial spaces,

Pts – patient; PRx_{supra}, – coefficient autoregulation in supratentorial spaces, Pts, patient; ICP_{infra}—coefficient autoregulation in infratentorial spaces

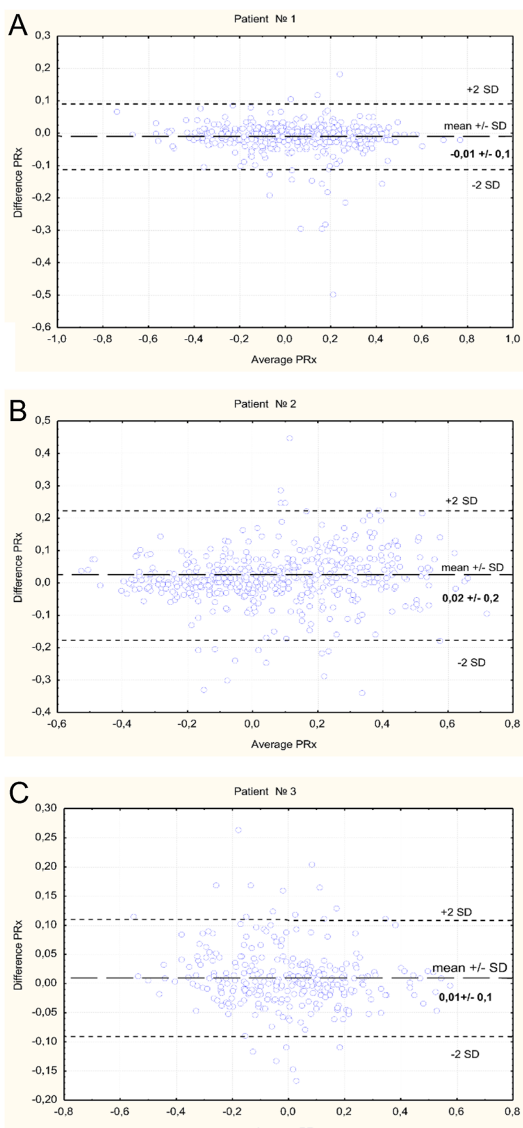

Fig. 1 Bland–Altman plot for comparison of average paired PRx supratentorial and PRx infratentorial space plotted against their mean difference in first (a), second (b), and third (c) patient. **A** Bias was − 0.01, limit of precision was 0.1. **B** Bias was 0.02, limit of precision was 0.2. **C** Bias was 0.01, limit of precision was 0.1. PRx, pressure reactivity index, SD, standard deviation

Discussion

In this study, we evaluated cerebral autoregulation above and below the tentorium cerebelli in neurosurgical patients with a complicated postoperative period, accompanied by edema in PCF and intracranial hypertension development. We observed that all patients had an ICP gradient with a predominance of ICP values in PCF. This phenomenon occurs during the formation of a compartment syndrome in the PCF in various cerebral pathological conditions, as described in the literature [12–17].

We assumed that the ICP gradient is associated with a more prominent impairment of cerebral autoregulation in the PCF. However, our study did not confirm the hypothesis because the autoregulation coefficient PRx was very similar in the supra and infratentorial spaces despite the existing ICP gradient. It should be noted that the relative duration of impaired autoregulation was the same above and below the tentorium in all patients (Table 3). For each individual patient, a minimal difference was found between PRx values (Fig. 1) and a significant correlation of PRx ($p < 0.05$) above and below the tentorium of the cerebellum (Table 3, Supplementary Figs. 1, 2, 4, 5, 7, 8; Supplementary Tables 1–3).

Additionally, we compared PRx autoregulation coefficients in the supra and infratentorial spaces during periods of normal ICP in the PCF and during periods of increased ICP in the PCF above 20 mm Hg. We purposefully analyzed and compared the state of autoregulation above and below the tentorium of the cerebellum depending on the presence or absence of intracranial hypertension only in the infratentorial space, so the duration of intracranial hypertension in the infratentorial space overlapped in time the duration of intracranial hypertension in the supratentorial space (Supplementary Tables 1–3). However, we did not obtain a significant difference between the coefficients of autoregulation in each compartment during these periods (Supplementary Figs. 1.1–1.3).

Several authors studied the state of autoregulation in healthy volunteers using Doppler sonography in the anterior and posterior parts of the Circle of Willis [18, 19]. They concluded that the damping effects of cerebral autoregulation in the posterior cerebral artery (PCA) are lower than in the middle cerebral artery (MCA) territory and that in the posterior cerebral artery, absolute flow is more tightly regulated, but relative flow regulation is consistent across cerebrovascular territories [18, 19]. They have used a transfer function analysis with a Fourier decomposition of the two waveforms to quantify the effect of spontaneous ABP fluctuations in cerebral blood flow [20]. Our work has some similarities with those described above studies in terms of the assessment of autoregulation above and below the tentorium cerebelli. As opposed to them, we used the PRx coefficient to assess and compare autoregulation. This assessment is feasible with software and invasive blood pressure and ICP measurements above and below the cerebellar tentorium in clinical practice. We noted the similarity in wave characteristics of the ICP (the shape and amplitude of the waves above and below the cerebellum) but have not done a separate analysis.

Moyse et al. [21] observed that supratentorial and infratentorial pulse amplitude, respiratory waves, and slow waves also have a high degree of correlation. At the same time, all other ICP-derived parameters display symmetrical profiles [21].

In our opinion, cerebral autoregulation in patients with transtentorial ICP gradient is underinvestigated, and further study is essential. First, it complements the understanding of cerebral pathophysiology in the development of the transtentorial ICP gradient. Little is yet known about the ICP profiles in the supratentorial and infratentorial compartments in pathophysiology and clinical practice. Second, it will probably allow choosing the optimal blood pressure values during the development of intracranial hypertension in the PCF to prevent cerebral ischemia both above and below the cerebellar tentorium. Third, it may help clarify the indications for decompression of the PCF during intracranial hypertension development in the PCF.

Limitations

The presented work was done only on three patients, as the placement of ICP sensors in both compartments is a very rare case. In one patient (the second), supratentorial ICP measurement was performed through EVD and infratentorial ICP against the background of PCF decompression, which could affect the signal quality and wave characteristics of ICP. Patients were of different ages. The intracranial hypertension profile in each examined patient had specifics, including dominated edema, impaired cerebrospinal fluid circulation, and cerebral ischemia; some were likely to have a venous congestion. It is unclear which of the pathological processes predominated in each patient because of the retrospective character of the study. Magnetic resonance imaging (MRI) and angiography were not routinely performed in patients after surgery. However, all three patients were diagnosed with postsurgical edema in the PCF by computed tomography (CT), and intracranial hypertension was confirmed by invasive monitoring of ICP. All three required targeted intensive therapy (prolonged ventilation, hyperosmolar solutions, sedation, anesthesia, and, in one patient, EVD and decompression of the PCF).

Conclusions

In the presented series of reports, a high degree of correlation was established between the autoregulation coefficient PRx in two compartments in the presence of transtentorial ICP gradient and persistent intracranial hypertension in the posterior fossa. Cerebral autoregulation, according to the PRx coefficient in both spaces, was similar.

Supplementary Information

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Author Contributions

AO performed data collection, assisted in the data analysis, and contributed to article preparation. AG assisted with data collection and contributed to article preparation. IS provided overall study design, assisted with data collection, performed primary analysis, and contributed to article preparation. EA assisted with study design, assisted with analysis. DB assisted with study design, assisted with analysis, contributed to article preparation, and finalized the article. All authors contributed to the article and approved the submitted version.

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Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical Approval

The study conformed to the Declaration of Helsinki standards and was approved by the Burdenko Institute Ethics Committee.

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