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Arterial and Venous Brain Reactivity in the Acute Period of Cerebral Concussion

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Transcranial color duplex scanning of the cerebral vessels was used to study arterial and venous reactivity in 38 patients in the acute period of cerebral concussion (CC) and in 32 healthy volunteers. Arterial flow was assessed in the middle cerebral artery (MCA) and venous drainage in the basal vein of Rosenthal (BV). Cerebrovascular reactivity was assessed using hypercapnic and orthostatic tests. These studies showed that CC was not accompanied by marked changes in cerebral hemodynamics in the state of rest. During the acute phase of CC, about 20% of patients showed increases in peak blood flow velocity in the MCA, typical of cerebral hyperperfusion. Increases in the peak blood flow velocity in the BV were seen in 25% of patients with CC, compensating for impaired drainage via the superficial cerebral system. In normal subjects, cerebral venous reactivity to hypercapnia was greater than arterial reactivity, while reactivity to orthostasis corresponded to the magnitudes of arterial changes. The absence of quantitative differences in the responses of arterial and venous blood flow to hypercapnia and the predominance of venous reactivity to orthostasis in patients with CC indicates that these patients had impairments in the regulation of venous tone.

KEY WORDS: color duplex scanning, cerebral concussion, cerebrovascular reactivity.

Cerebral concussion (CC) accounts for about 80% of cases of cerebral trauma. CC is a functionally reversible form of craniocerebral trauma (CCT) with diffuse brain injury, when mechanical energy leads to microstructural changes in the brain and transient functional CNS disorders [4]. There are certain difficulties in establishing the clinical boundaries of this form of craniocerebral trauma, particularly in older patients and persons in the stage of alcoholic intoxication [7]. The mail instrument-based methods for the diagnosis of CCT (echoencephalography, computerized tomography) are not well suited to the diagnosis of mild CCT [4].

The 1980s saw the development of a noninvasive ultrasonography for studies of cerebral blood flow, i.e., transcranial Doppler ultrasonogrpahy. In subsequent years, the main direction of Doppler ultrasonography and color duplex scanning (CDS), as a state-of-the-art development of this technique, was in the investigation of cerebral blood flow in a variety of pathologies, including severe CCT, subarachnoid hemorrhages, and cerebral edema [12, 14, 15]. Post-traumatic vasospasm has been shown to have significant influences on the course of the long-term sequelae of moderate and severe CCT [5, 8]. However, studies addressing cerebral blood flow in mild CCT are few in number and do not allow systematic description of cerebral blood flow reactions in patients with CC. Doppler ultrasonography studies have demonstrated that patients in the acute period of CC have moderate increases in blood flow velocities in the middle cerebral artery [3]. Our literature search yielded no reports of changes in venous hemodynamics in mild CCT.

The informativeness of cerebral blood flow studies in CC can be increased significantly by using functional tests to assess cerebrovascular reactivity. We elected to use the hypercapnic and orthostatic tests for the following reasons. CO_2 is regarded as one of the most effective cerebral vasomodulators at all ages. The physiological effects of hypercapnia on arteries have been well studied and include dilation of cerebral arterioles, resulting in decreases in cerebral

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vascular resistance and increases in cerebral blood flow [9, 12]. However, there are only occasional published data on the use of hypercapnia to assess the state of the venous bed. Thus, Valdueza et al. [17] used Doppler ultrasonography and found that the blood flow velocity in the middle cerebral artery and sphenoparietal sinus increase in hypercapnia, though venous reactivity was significantly greater than arterial reactivity. The orthostatic test allows the reactivities of both the arterial and venous beds to be assessed [6, 11]. We found no studies using complex assessment of arterial and venous cerebral reactivity in the orthostatic test, including in CC.

The aim of the present work was to undertake complex assessment of arterial and venous cerebral reactivity in the hypercapnic and orthostatic tests in patients during the acute period of CC.

MATERIALS AND METHODS

Transcranial CDS of the cerebral vessels was performed in 38 patients (26 men and 12 women) aged 18–47 (mean 26.8 ± 7.0) years undergoing treatment in the Department of Neurosurgery for diagnoses of CC (study group). All patients underwent complex investigations including neurological assessment, whole-head craniography, echoencephalography, and fundoscopy; CT brain scans were performed in 75% of patients. Severe brain lesions were excluded in all patients. The duration of trauma at the time of investigation was 3–6 days. Headaches were reported by 93% of patients, nausea, vertigo, or general weakness alone or in combination were present in 74–78%. The control group consisted of 32 healthy volunteers (16 men and 16 women) aged 18–50 (mean 25.5 ± 8.3) years. All subjects gave informed consent to take part in the study.

Cerebral blood flow parameters were measured using a Vivid-3 Pro (GE, USA) ultrasound system with a sectored phasic probe with a frequency of 1.5–3.6 MHz. Arterial flow was assessed in the middle cerebral artery (MCA) and venous drainage in the basal vein of Rosenthal (BV). Studies were performed in accordance with the requirements of depth of location, color scale, and scanning angle correction. Measurements were made bilaterally. Blood flow parameters were assessed in the proximal (M1) segment of the MCA and the middle segment of the BV. These segments have clear anatomical orientations and are accessible to ultrasound studies in most subjects.

Peak systolic velocity (Vps_{MCA}, cm/sec) and the resistance index (RI_{MCA}, U) were measured in the MCA and the maximum linear blood flow velocity ($Vmax_{BV}$, cm/sec) was measured in the BV. Blood flow measures were recorded with the subjects in the lying position at rest and during functional tests (hypercapnic and orthostatic).

Hypercapnia was created using a special apparatus to increase the CO_2 concentration in alveolar air to 5.7–6.4% by increasing the additional volume of the "dead" space [10]. Blood flow parameters were recorded after 50 sec of respiration using this apparatus. Postural changes were analyzed in subjects 1 min after active transfer in orthostasis (the sitting position). Vessel reactivity in tests was calculated as $CR\% = ((P_{ft}/P_r) - 1) \times 100\%$, where CR% is the coefficient of reactivity, P_r is the value at rest, and P_{ft} is the value in the functional test.

Data were analyzed using standard nonparametric statistical methods. Quantitative parameters were presented as medians (Me) and 25th and 75th centiles. The hypothesis that there were intergroup differences in various measures was tested using the two-tailed Fisher's test. Differences were regarded as statistically significant at $p < 0.05$. Values for the right and left sides were initially compared and were then combined because of the absence of significant differences between them.

RESULTS AND DISCUSSION

Mean Vps_{MCA} in subjects of both groups at rest were consistent with published values [10] and showed no differences between groups (see Table 1). Increases in blood flow velocity in the MCA not associated with local arterial stenosis are known to result from arterial hyperperfusion or spasm, the defining value for this being a Vps_{MCA} of over 120 cm/sec [2, 8]. We found an intergroup difference in the proportions of cases in which Vps_{MCA} was greater than 120 cm/sec: 16.7% of the experimental group and 5.3% of the control group ($p < 0.05$). These data show that CC is associated with an increase in the incidence of increases in the MCA flow velocity to the pathological level, which may be due to cerebral hyperperfusion or spasm of the cerebral arteries.

The hyperdynamic type of cerebral hemodynamics (hyperperfusion) and vasospasm are defined by the ratio Vps_{MCA}/Vps_{ICA}, where Vps_{ICA} is the peak systolic blood flow velocity in the internal carotid artery [12]. Values of this index of less than 3.0 indicate a diagnosis of vasospasm [8, 14]. This criterion did not identify any cases of vasospasm. The Vps_{MCA}/Vps_{ICA} index was significantly different between the groups, at 1.52 in the group of patients with CC (1.3–1.7) and 1.3 in controls (1.1–1.55) ($p < 0.05$). These data provide evidence that CC increases the proportion of cases with cerebral hyperperfusion.

No interhemisphere differences in the MCA were seen in terms of the velocity and index of resistance, which are typical of more severe brain damage. There were no differences in coefficients of brain asymmetry such as Vps_{MCA} (experimental group 5.4–18.2%; control group 4.0–17.7%) and RI_{MCA} (2.0–10.6% and 1.7–6.9%, respectively) between groups.

Analysis of venous hemodynamics showed that in patients with CC, the blood flow velocity in the BV was

TABLE 1. Measures of Blood Flow in the Middle Cerebral Artery and Basal Vein at Rest and in Functional Tests (Me and 25–75%)

Parameter	CC group			Control group		
	at rest	hypercapnia	orthostasis	at rest	hypercapnia	orthostasis
	n=78	n=60	n=54	n=63	n=43	n=33
Vps_{MCA}, cm/sec	100.6	142.0*	94.5*	99.0	133.6*	93.0*
	91.0—114.0	118.6—155.8	84.8—102.7	93.5—113.0	111.4—146.0	80.0—103.2
RI_{MCA}, U	0.54	0.51*	0.55	0.56	0.52*	0.55
	0.51—0.58	0.45—0.57	0.5—0.6	0.52—0.58	0.48—0.57	0.5—0.58
$Vmax_{BV}$, cm/sec	12.2**	16.6*	10.7*	11.4	16.1*	10.3*
	10.5—14.4	13.0—20.6	8.7—12.6	9.4—12.8	12.9—19.0	9.0—11.3
IP_{BV}, U	0.22	0.24*	0.25	0.23	0.26	0.19
	0.14—0.33	0.22—0.33	0.15—0.31	0.18—0.28	0.18—0.3	0.11—0.26

Note: n is the number of vessels studied; Vps_{MCA}, cm/sec, it maximum blood flow velocity in the middle cerebral artery; RI_{MCA}, U, is the index of resistance in the middle cerebral artery; $Vmax_{BV}$, cm/sec, is the maximum blood flow velocity in the basal vein; IP_{BV}, U, the index of phasicity in the basal vein; *significant differences compared with rest, $p < 0.05$; **significant differences between groups, $p < 0.05$.

greater than that in controls (see Table 1), though mean values of $Vmax_{BV}$ in both groups were consistent with published data [16]. Increases in blood flow in the deep venous system are known to indicate outflow obstruction via the superficial cerebral veins and to correlate with elevated intracranial pressure [15, 16]. The proportion of cases in which $Vmax_{BV}$ was greater than normal was significantly greater in the group of patients with CC (23.7%) than in the control group (9.5%) ($p < 0.05$).

Hypercapnic Test

Like other authors [9, 12, 17], we found consistent increases in Vps_{MCA} in response to the hypercapnic test (see Table 1). The increases in MCA blood flow in response to hypercapnia were by 36.8% (17.0–53.6%) in patients with CC and by 22.9% (11.3–45.4%) in controls. However, we also noted paradoxical reactions in both groups, consisting of decreases in Vps_{MCA} in the test (10% of subjects in both groups). The index of resistance, RI_{MCA}, decreased significantly in both groups in the hypercapnic test, which was consistent with the typical reactions of this parameter to hypercapnia [3, 9, 12].

Induced hypercapnia, eliciting dilation and increased blood flow velocity in the cerebral arteries, leads to increased blood flow into the brain and should be accompanied by a corresponding increase in venous drainage. Increased venous drainage is reflected in the $Vmax_{BV}$ values recorded in both groups (see Table 1). The increase in $Vmax_{BV}$ in the test in patients with CC was by 37.7% (18.3–51.0%), compared with 36.2% (19.4–64.4%) in the control group. The results obtained in the control group were comparable to those reported by Valdueza et al. [17]. However, while venous CR% to hypercapnia was significantly greater than the arterial CR% in the control group ($p < 0.05$), these parameters showed no difference in the CC group.

Cerebral vascular tone and cerebral blood flow have been shown to be determined by neuroregulatory mechanisms, and the cerebral veins, including the BV, can take an active part in regulating cerebral blood flow [1]. Increases in the blood CO_2 concentration, acting via direct stimulation of the receptor zones or the vasomotor center, induce increases in the tone of venous structures and increase venous drainage, preventing hyperemia of the brain in these conditions [1, 13]. In addition, intracranial CSF pressure increases in conditions of arterial hyperemia, leading primarily to changes in the volume of the venous bed (its constriction). The cause of passive venoconstriction lies in the thin walls and weak intrinsic tone of the cerebral veins and their location in the CSF space [1].

The decreased venous response to hypercapnia in patients with CC may be the result of the drop in the tone of the venous compartment (impairment to active venoconstriction) or the hindrance of venous drainage into the sinuses.

Orthostatic Test

Transfer to the vertical position led to decreased Vps_{MCA} most subjects in both groups: by 4.9% (–14.6–2.7%) in patients with CC and by 4.0% (–17.6–6.0%) in healthy subjects (see Table 1). These results are consistent with results reported by Osadchii [6], who described decreases in cerebral blood flow by 15–20% in young people on active standing. Cerebral vascular resistance can decrease or remain unaltered [6]. In our study, there were no changes in RI_{MCA} in response to orthostasis in either group.

Decreases in arterial cerebral blood flow lead to the expectation of decreased venous drainage. We recorded decreases in the blood flow velocity in the BV in subjects of both groups. In the experimental group, the decrease in $Vmax_{BV}$ was by 17.3% (5.9–28.3%), compared with 14.8% (2.5–23.6%) in the control group. The direction and extent of cerebral venous reactions to orthostasis were consistent with values reported by other authors [11]. On transfer to orthostasis, arterial, venous, and CSF pressures decreased and the venous drainage velocity was determined by the

reflex constriction of the veins [1]. In the control group, the extent of venous reactivity showed no statistically significant difference from the extent of arterial reactivity, while in patients with CC, venous reactivity was significantly greater than arterial reactivity ($p < 0.05$). This, along with the characteristics of venous responses to hypercapnia, may indicate impairments to venoconstriction in patients with CC.

CONCLUSIONS

Thus, CC was not accompanied by marked changes in cerebral hemodynamics in the state of rest. About 20% of patients in the acute period of CC showed increases in the peak blood flow velocity in the MCA, typical of cerebral hyperperfusion. One in four patients with CC showed increases in the maximum blood flow velocity in the BV, apparently compensating for impaired venous drainage from the superficial cerebral system.

In normal conditions, venous reactivity to hypercapnia was significantly greater than arterial reactivity, while venous and arterial reactivities to orthostasis were similar. During the acute period of CC, cerebral venous reactivity to hypercapnia decreased, while that to orthostasis increased, reflecting impairment to the regulation of venous tone.

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