Cerebral Autoregulation in Orthostatic Hypotension
A Transcranial Doppler Study

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Background and Purpose
Transcranial Doppler measurements of blood flow velocity permit an assessment of variations in intracranial hemodynamics in response to acute arterial pressure variations. The purpose of this study was to scan healthy volunteers and patients with autonomic failure for differences in cerebral hemodynamic patterns under an acute hypotensive stimulus.

Methods
We used transcranial Doppler monitoring of blood flow velocity in the middle cerebral artery and noninvasive monitoring of arterial blood pressure and heart rate before, during, and after acute arterial hypotension induced by reactive hyperemia of the lower limbs.

Results
After maximum hypotension, the mean blood flow velocity was higher in the healthy volunteers than in the patients. In the healthy subjects mean velocity rose significantly \((P<.01)\) higher than arterial blood pressure after 30 seconds and 60 seconds; in the patients mean velocity and arterial pressure moved in parallel fashion. The diastolic blood flow velocity increased more in the control group than in the patients during the early stages of the test; furthermore, only in the healthy volunteers did it increase significantly more than arterial pressure after 30 seconds and 60 seconds. Regarding the pulsatility index, the differences between the two groups were similar to the diastolic velocity results.

Conclusions
(1) Monitoring of mean blood flow velocity showed the ability to maintain an adequate cerebral blood flow in healthy subjects; this mechanism was not efficient in the patients with autonomic failure. (2) Diastolic velocity and pulsatility index values clearly showed that only in healthy subjects were cerebral hemodynamics relatively independent of pressure values.

Key Words
- autonomic nervous system
- cerebral circulation
- Doppler
- ultrasonics

Cerebral autoregulation is the ability to maintain an adequate blood flow in the organ under conditions that may cause regional changes, such as lowered perfusion pressure (systemic hypotension or local stenosis) or the presence of chemical stimuli (eg, changes in \(P_{CO_2}\)). This functional adaptation takes place in the microcirculation through adjustments in arteriolar resistance. Transcranial Doppler (TCD) ultrasound scanning\(^4-6\) has recently been accepted as a method for investigating cerebral autoregulation because it allows the recording in real time of functional parameters that are significant indexes of variations in cerebral blood flow (CBF) and cerebrovascular resistance.\(^7-16\) Previous investigations have been concerned mainly with two aspects: the response of vasomotor reserve to chemical stimulation (hypocapnia, hypercapnia, perfusion of acetazolamide)\(^17-19\) and the variations in CBF velocity induced by orthostatic hypotension, reactive hyperemia, and sodium nitroprusside administration.\(^20-22\) Our study was designed to assess cerebral autoregulation in patients with primary orthostatic hypotension versus a population of healthy subjects. We used the reactive hyperemia test proposed by Aaslid et al,\(^21\) monitoring the TCD parameters that correlate best with CBF (ie, mean blood flow velocity \([mV]\)^7\(^8\)) and that are the most strongly influenced by blood flow resistance (ie, diastolic velocity \([dV]\) and pulsatility index \([PI]\)^9\(^-16\) and evaluating their time course in relation to arterial blood pressure variations, irrespective of the latency time for cerebral autoregulation.

Subjects and Methods
We studied 24 men after excluding subjects with cerebrovascular disease, occlusive disease of the supraortic trunks revealed by duplex scanner, cardiac arrhythmias, cardiac decompensation, arterial hypertension, arterial or venous disorders of the lower limbs, vasomotor reserve less than 25% evaluated by TCD with the breath-holding test,\(^18\) mVs on TCD below the reference standards,\(^23-24\) inadequate temporal window, and onset of fainting or presyncope symptoms during the test. The subjects were allocated to two groups: group A, composed of 12 healthy volunteers (mean age, 48.8 years [range, 27 to 71 years]) and group B, composed of 12 patients (mean age, 48.9 years [range, 26 to 72 years]) with autonomic nervous dysfunction (pure autonomic failure and multiple system atrophy) ascertained by accepted criteria\(^25\) and with at least two syncopal episodes in the preceding 6 months. The diagnosis of autonomic dysfunction was ascertained for orthostatic systolic arterial blood pressure (SABP) decreases of more than 50 mm Hg in the normotensive patients and for SABP decreases of more than 20 mm Hg in the hypotensive patients (basal SABP values, <120 mm Hg). All patients underwent measurements of plasma catecholamines,\(^26\) and the diagnosis was based on plasma catecholamine values in the lying and standing positions. All subjects gave their informed consent to the investigation, and the study was approved by the hospital's ethics committee.
The TCD scanner (Trans-scan 3D, EME) was equipped with a 2-MHz probe with elastic fastening device (TC-track, EME) to hold it in the same position throughout the examination. The CBF velocity was recorded in the middle cerebral artery (MCA) through the temporal window by the technique already described27,28 at a depth of between 53 and 62 mm, depending on the position that ensured maximum signal intensity. The horizontal sweep speed was 10 seconds. Before the test every subject underwent a full TCD investigation (to exclude circulatory insufficiency, perfusion asymmetry, and presence of active collateral circulations) and a vasomotor reserve test with breath-holding as stimulus.29 The TCD parameters, calculated as the mean of three consecutive cycles, were mV, dV, and PI,29 recorded at the following times: 5 seconds before the induction of the hypotension (basal values), at maximum hypotension (T0), and 30 seconds (T1), 60 seconds (T2), 90 seconds (T3), and 120 seconds (T4) after T0. SABP in the third finger of the dominant hand and heart rate (HR) were monitored concurrently by blood pressure monitor (Finapres 2300, Ohmeda), and the mean of the values for three consecutive cycles was recorded at the same times as the TCD recordings. The subjects were tested lying down. A sphygmomanometer cuff of suitable size was wrapped around the root of each lower limb, and the cuffs were inflated to suprasystolic pressure for 2 minutes to ensure a reactive hyperemia sufficient to act as hypotensive stimulus when deflating these cuffs.21 For each parameter the values recorded during the test were normalized with reference to the baseline, and the difference between the normalized values from the recording time to the next was calculated. The normalized absolute values and the differences between the times were compared by statistical analysis; furthermore, within each group the normalized absolute values and the differences (D) between the times for the various parameters (mV, dV, PI, DmV, DdV, DPI) were compared with the SABP. Because the PI values present a trend opposite that of the other parameters (ie, PI values increase with reduced CBF and decrease with vasodilatation), they have been expressed for convenience with the opposite sign (—DPI). The significance level was evaluated by ANOVA, rating P<.05 as significant and P<.01 as highly significant.

Results

There were no significant differences between the groups with respect to the baseline values of the SABP (141.3±16.0 mm Hg in group A versus 143.8±17.2 mm Hg in group B), HR (66.7±10.2 beats per minute in group A versus 68.1±8.9 beats per minute in group B), dV (51.3±13.8 cm/s in group A versus 52.4±12.6 cm/s in group B), or PI (0.82±0.16 in group A versus 0.80±0.18 in group B).

Fig 1 provides the means of the normalized values, and Fig 2 provides the means of the variations at times T0 through T4. Comparison of the two groups by means of ANOVA yielded the results shown in Fig 3 for the normalized values and in Fig 4 for the variations. There was no significant difference between the groups in maximum fall of SABP (T0), but there was a significant difference (P<.05) in the recovery values (times T1 through T4); it is remarkable that at the end of the test, when there was nearly complete recovery of the baseline in group A, the values were significantly lower in group B (P<.05). The reflex increase in HR was greater in group A at maximum hypotension (T0), P<.05, and 30 seconds later (T1, P<.01). The mV values remained significantly higher (P<.05 at times T0 and T4, P<.01 at times T1 through T3) in group A at every stage in the test, although the differences (DmV) between successive recordings were not significantly greater in group A. The dV values were significantly higher in group A at every stage in the test (P<.05 at T0, T2, and T3; P<.01 at T1) except at the last (T4). The differences (DdV) after 30 seconds (T1, P<.05) and 60 seconds (T2, P<.01) were significantly greater in group A. The PI likewise differed at times T1 and T2, and to a highly significant degree (P<.01). The graphs in Figs 5 and 6 compare SABP and the various TCD parameters. At the time T0 the maximum SABP fall was greater than the mV decrease in both groups, but only in group A were the mV values...
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VARIATIONS OF NORMALIZED VALUES

significantly higher than SABP values after 30 (T1, P<.01) and 60 (T2, P<.05) seconds; the mV increases (DmV) were never greater than the SABP rises (DSABP) in group B, whereas in group A the DmV was significantly higher (P<.01) than DSABP after 60 (T2) and 90 (T3) seconds. In group B neither the absolute values nor the variations in dV differed significantly from those of SABP; in group A the dV values were significantly higher than those of SABP at the first stages after acute hypotension (T1 and T2, P<.01); furthermore, at the same stages, DdV values were significantly greater than DSABP (P<.01). The PI presented a different course from SABP in both groups, but while in group A the opposite variations of PI (−DPI) were significantly greater than DSABP after 30, 60, and 90 seconds (T1 through T3, P<.01), they did not differ significantly from DSABP in group B.

Discussion

The hypotensive stimulus induced maximum SABP decreases of more than 22% below the baseline without significant differences between the two groups; the incomplete recovery of SABP in group B is attributable to the disease from which these subjects suffered.

The mV value during the test was higher in group A than in group B because of the presence in the former of autoregulation, which depends on a more effective local vascular mechanism for maintaining a normal CBF. This can be assumed on the basis of previous validation studies that reported high correlation between CBF variations and mV variations. Monitoring of mV and SABP showed that in group B the two parameters moved in parallel fashion, with SABP the determining factor; this trend clearly suggests the lack of cerebral autoregulation in these subjects. In the control group, in contrast, mV rose significantly (P<.01) more than did SABP after 60 seconds and 90 seconds,
confirming the existence of a regional regulation mechanism. It is clear from these data that, while mV scanning alone can reveal the existence of a regional autoregulation mechanism, it cannot show clearly the quick intervention of the mechanism, because in the first stage of the test (T1: 30 seconds after maximum hypotension) the mV increase (DmV) was not significantly greater than SABP increase (DSABP). For this purpose the course of dV is relevant because this parameter, while not correlating with CBF, is strongly influenced by the resistance of the microcirculation.\(^\text{9,10,13,14,16}\) In the early stages of the test, after maximum hypotension, dV increased significantly more in group A than in group B, showing greater increases at 30 seconds (P<.01) and 60 seconds (P<.05). Furthermore, in group A the dV increased significantly more than did SABP in the early stages (T1 and T2, P<.01), suggesting the prompt onset of an active vasodilation in the cerebral microcirculation independent of SABP. In group B there were no dV increases significantly greater than those of the SABP, presumably because there was no mechanism for cerebral autoregulation efficient enough to release the CBF velocity from the perfusion pressure. The same reasoning applies to the course of PI, for the value of this parameter is strongly influenced, although in the opposite direction, by the resistance of the cerebral microcirculation.\(^\text{11-13}\) Indeed, the variations of the PI outstripped those of SABP from the first measurements after maximum hypotension.

Our results justify the following inferences: (1) In the patients with orthostatic hypotension the cerebral hemodynamics show a "passive" behavior, with the mean CBF velocity falling and recovering in parallel with the variations in perfusion pressure and in subject to them. In normal subjects, on the other hand, recovery after acute hypotension is significantly greater. (2) The Dv and PI values 30 seconds after maximum hypotension suggest that in normal subjects cerebral hemodynamics are relatively independent of the pressure values.

Appendix

The procedure used in this study of cerebral autoregulation exploits the fact that TCD supplies real functional information on the variations in cerebral hemodynamics. The hypotensive stimulus applied is based on the works of Aaslid.\(^\text{5,21}\) Certain methodological limitations and differences in approach from Aaslid's procedure are worth comment.

(1) The mV/CBF correlation fails when there are large variations in the diameter of the insolated artery.\(^\text{30}\) However, previous studies\(^\text{5,21}\) showed that the variations in MCA diameter during the test are negligible for the purpose of the interpretation.

(2) The recordings were taken in one MCA only, eliciting only indirect information on the dynamic variations in the microcirculation. Aaslid et al.\(^\text{21}\) took recordings in the straight sinus, which affords a less indirect approach to the problem. While agreeing that this is so, we did not extend our study to the venous side because the appropriate window is less easy to find,\(^\text{21}\) because the fixing of the probe is more complex, and because the software and instrumentations are not available at the majority of neurological ultrasound units. Another point worth noting is that a comprehensive assessment of the cerebral circulation would require a study of the basilar artery, which was not undertaken for similar technical reasons. This does not detract from the interest of our study, because studies on the vasomotor reserve in the basilar artery under the stimulus of hypercapnia\(^\text{21,32}\) have shown practically the same behavior as in the MCA.

(3) Activation of cardiovascular reflexes might condition the results; we therefore from the start ignored systolic velocity, the parameter most affected by reflex increase in cardiac inotropism. Tachycardia might likewise cause a decrease in mV,\(^\text{19,24}\) but this possibility does not seem to be relevant, because the HR increases were greater in the group with higher mV values.

(4) Although TCD recording allows even a beat-by-beat recording, we opted for the mean value of three consecutive cycles at intervals to minimize errors of interpretation that have arisen from the physiological variability from one cardiac cycle to the next.

References


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