Cerebral hemodynamic changes during plateau waves in brain-tumor patients

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The plateau wave, one of the wave forms observed in patients with increased intracranial pressure, has previously been extensively investigated, but its pathophysiological aspect is as yet unclear. The authors undertook a study of cerebral hemodynamic changes while the plateau waves were observed in five brain-tumor patients. Although the number of cases studied was small, a remarkable decrease in cerebrovascular resistance was seen in all patients during the plateau waves. It is suggested that the plateau waves are caused by a marked cerebral vasodilatation. The present results support the thesis that cerebral blood volume is increased during the plateau waves. The plateau waves are closely related to the intrinsic vasomotor control of cerebral circulation, and can occur as long as cerebral vasodilating ability is maintained, irrespective of the existence of cerebral autoregulation.

KEY WORDS • intracranial pressure • plateau wave • cerebral hemodynamic change • brain tumor

The relationship between cerebral blood flow (CBF) and intracranial pressure (ICP) has been studied extensively both clinically and experimentally. It is well known that the patients with brain tumors sometimes have paroxysmal symptoms such as severe headaches and vomiting, accompanied by an acute temporary increase in ICP. This intermittent marked increase in ICP was named "plateau wave" by Lundberg. Plateau waves have been reported in various neurosurgical cases including brain tumor, head injury, benign intracranial hypertension, hydrocephalus, and subarachnoid hemorrhage. They are observed mostly in brain-tumor patients with a fairly advanced degree of intracranial hypertension. These patients are usually alert during the plateau waves in spite of the severity of their intracranial condition with a marked reduction of cerebral perfusion pressure. The plateau waves seen clinically have no counterpart in experimental observations.

We have recorded both CBF and ICP simultaneously during the plateau waves in five brain-tumor patients and have attempted to analyze the accompanying cerebral hemodynamic changes with a review of the literature.

Clinical Materials and Methods

Five patients, three males and two females, with supratentorial tumors were studied. Histology was either glioblastoma multiforme or astrocytoma. Their ages ranged from 29 to 52 years. The ICP was measured as epidural pressure (EDP) with the use of the semiconductor film strain transducer (SFT), which was attached to the dural surface through a burr hole made at the coronal suture 3 to 4 cm from the midline on the side opposite to the tumor. The ICP was recorded continuously, and the regional cerebral blood flow (rCBF) was measured by the \( ^{133} \text{Xe} \) clearance method. The scinticamera with a 4000-hole collimator was placed over the hemisphere on the other side of the tumor. The validity of the use of the scinticamera for rCBF study was reported in the

*SFT transducer manufactured by Matsushita Electric Industrial Co., Ltd., Central Research Laboratory, Kadoma, Osaka 571, Japan.
†Type 3047 Recorder manufactured by Yokogawa Electric Works, Ltd., Chuo Ku, Tokyo 104, Japan.
M. Matsuda, S. Yoneda, H. Handa and H. Gotoh

Fig. 1. Case 3. Simultaneous recording of epidural pressure (EDP) and blood pressure (BP) in a patient with glioblastoma. Arrow indicates intracarotid injection of $^{133}\text{Xe}$.

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Approximately 5 mCi of $^{133}\text{Xe}$ dissolved in 2 ml of saline was injected into the internal carotid artery through a polyethylene catheter. The rCBF was measured in eight regions and calculated by a computer§ connected to the scinticamera. The initial slope index was used for measuring CBF because of the short duration of the plateau waves. The brain-blood partition coefficient of gray matter was corrected according to the hemoglobin content. Blood pressure was monitored with the use of the SFT transducer which was connected to a polyethylene catheter in the internal carotid artery or radial artery, and recorded simultaneously with ICP. Mean arterial blood pressure (MABP) was calculated by adding one-third of the pulse pressure to the diastolic pressure. The ICP was calculated in the same way and expressed as mean pressure. Cerebral perfusion pressure (CPP) and cerebrovascular resistance (CVR) were derived from the following formulas: $\text{CPP} = \text{MABP} - \text{ICP}$, $\text{CVR} = \text{CPP}/\text{CBF}$. Arterial blood gas was analyzed by a blood gas analyzer. All procedures were performed under local anesthesia. Atropin sulfate, 0.5 mg, was given intramuscularly before the procedure.

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§Scintipac 200 computer manufactured by Shimadzu Seisakusho, Ltd., Nakagyo Ku, Kyoto 604, Japan.

||ABL 1 blood gas analyzer manufactured by Radiometer A/S, 72 Emdrupvej, DK 2400, Copenhagen, Denmark.

**Results**

The data for the five patients are shown in Table 1. The simultaneous recordings of ICP and blood pressure in Cases 3, 4, and 5 are illustrated in Figs. 1-3. All the patients but Case 5 were alert and cooperative throughout the study. They all complained of headache while the plateau waves were being observed, but the fifth patient was somnolent. His control ICP and MABP were 84 mm Hg and 118.3 mm Hg, respectively, which brought CPP down to 34.3 mm Hg. During the plateau wave, ICP rose to 123.3 mm Hg, and CPP further decreased to 16.7 mm Hg. The CBF of this patient was accordingly very low, but did not show any significant difference between control values and values during the plateau wave, 19.5 and 21.5 ml/100 gm/min, respectively. The CVR showed a marked decrease by 55.7% from 1.76 to 0.78 mm Hg/(ml/100 gm/min).

In the other four patients (Cases 1, 2, 3, and 4), control ICP ranged from 16.0 to 30.7 mm Hg, with CPP of 62.3 to 94.4 mm Hg. During the plateau waves, the ICP increased to between 50.0 and 80.0 mm Hg, and CPP decreased to between 26.6 and 66.0 mm Hg. The remarkable decrease in CPP caused CBF to decrease by 19.3% in Case 2 and 27.5% in Case 3. The accompanying decrease in PaCO$_2$, particularly in Case 3, might have had some effect on the decrease in CBF. The CBF in Case 1 was decreased by 15.1% and that in Case 4 did not change. The CVR decreased in all cases by 14.4% to 49.1%.
Plateau waves and cerebral hemodynamic changes

Discussion

The EDP as recorded here might not be equivalent to ICP in the strict sense, since EDP, or surface brain pressure, is reported to be higher than cerebrospinal fluid (CSF) pressure or ventricular fluid pressure (VFP). However, in our experimental study on monkeys, EDP was found to be the same as VFP. Also, we prefer the epidural device to ventricular cannulation because it reduces the risk of infection. The plateau waves are characterized by a height of 50 to 100 mm Hg and a duration of 5 to 20 minutes. In this

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Fig. 2. Case 4. Simultaneous recordings of epidural pressure (EDP) and blood pressure (BP) in a patient with astrocytoma. Arrow indicates intracarotid injection of $^{133}$Xe.

Fig. 3. Case 5. Simultaneous recording of epidural pressure (EDP) and blood pressure (BP) in a patient with glioblastoma. Arrow indicates intracarotid injection of $^{133}$Xe.
TABLE 1

Parameters measured in five patients*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>CBF (ml/100 gm/min)</th>
<th>MABP (mm Hg)</th>
<th>ICP (mm Hg)</th>
<th>CPP (mm Hg)</th>
<th>CVR†</th>
<th>PaCO2 (mm Hg)</th>
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<td>88.3</td>
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<td>19.5</td>
<td>21.5</td>
<td>118.3</td>
<td>140.0</td>
<td>84.0</td>
<td>123.3</td>
</tr>
</tbody>
</table>

*CBF = cerebral blood flow; MABP = mean arterial blood pressure; ICP = intracranial pressure; CPP = cerebral perfusion pressure; CVR = cerebrovascular resistance; PaCO2 = partial pressure of CO2 in arterial blood; C = control values; and PW = values during plateau waves.

†Measured as mm Hg/ml/100 gm/min.

study, all the plateau waves lasted less than 10 minutes, but they were long enough for CBF measurement (183Xe injection) by the initial-slope index method. 23

Kety, et al., 18 found that CBF was significantly reduced in the brain-tumor patients with CSF pressures greater than 33 mm Hg. Greenfield and Tindall 24 reported a significant reduction of internal carotid blood flow at a CSF pressure of 28 mm Hg or above, and their patients remained asymptomatic until CSF pressure reached 68 mm Hg. Heilbrun, et al., 9 reported a remarkable decrease in CBF when ICP (EDP) reached 65 to 90 mm Hg and CPP decreased to 15 mm Hg. Lundberg, et al., 27 and Pálvölgyi 29 observed a reduction in rCBF in brain-tumor patients with increased ICP.

The effect of increased ICP on CBF has been extensively investigated in animal experiments. The critical level of ICP that causes a reduction of CBF varies from 35 to 100 mm Hg, depending on the method of raising ICP. 8,14,15,20,29,30 As ICP affects CBF secondarily to changes in CPP, the effect of increased ICP on CBF should be investigated from the standpoint of CPP. 8,30 The CPP is generally defined as the difference between MABP and ICP. 8,13,20

The mechanism that maintains CBF during intracranial hypertension is equivalent to the process of CBF autoregulation that occurs during alterations in arterial pressure. 8 The lower limit of CPP that causes a reduction of CBF varies from 30 to 60 mm Hg in experimental animals. 7,8,15,20,30 When a decrease in CPP is associated with an increase in ICP, maintenance of CBF becomes dependent on dilatation of the resistance vessels, that is, the decrease in CVR. Experimental reports have indicated a progressive fall in CVR and cerebrovascular dilatation in response to an increase in ICP. 14,15,21 Reports of cortical vasodilatation observed through a cranial window 41 and vasodilatation seen on angiograms 27 support the concept of CVR decrease during intracranial hypertension. The present results also showed that CVR decreased in every case during the plateau waves. The increased ICP created experimentally and the one observed during the plateau waves might be substantially different. The former is passive and the latter active and spontaneous; however, in either case, the CVR decreased. On the other hand, Kety, et al., 18 concluded that CVR increased when ICP increased. This contradictory result might be explained by their calculations of CVR as MABP divided by CBF and the fact that ICP was not taken into account.

Human studies showed a decrease in CBF 27 and an increase in CBV 26 during the plateau waves. This discrepancy between CBF and CBV was explained by a shift of main CVR from the arterial to the venous side. 28 In their experiments, Langfitt, et al., 22 and Grubb, et al., 7 reported an increase in CBV during increased ICP, while Lowell and Bloor 29 reported a decrease. This decrease in CBV was attributed to loss of cerebral autoregulation. 7 The present study shows definitely that the plateau waves are accompanied or caused by a marked cerebral vasodilatation, and gives support to the report of CBV increase during the plateau waves. 29

However, what causes a marked cerebral vasodilatation is not yet known. Although it is one of the most potent cerebral vasodilators, CO2 is not likely to cause the plateau waves that appear and disappear abruptly in a matter of seconds, and, in this study, in the initial phase of the plateau waves PaCO2 was not increased at all. An increase in MABP observed during the plateau waves with CBF measurement in Cases 4 and 5 actually had occurred 15 to 20 minutes before the onset of the plateau waves. This MABP increase did not always accompany every plateau wave even in the same case, and this finding confirms the observation that the plateau waves occurred irrespective of variations of systemic blood pressure. 29 It is reported that the plateau waves are closely related to the intrinsic vasomotor control of
Plateau waves and cerebral hemodynamic changes

cerebral circulation. The mechanism that can bring about a remarkable cerebral vasodilatation in a matter of seconds could be neurogenic.

The plateau waves are observed in patients who are in an advanced stage of persistent intracranial hypertension with marked impairment of intracranial spatial compensation. Many of the patients with brain tumor have disturbed autoregulation. The vasodilating ability is maintained, irrespective of the vasodilatation and could occur as long as cerebral vasodilatation ability is maintained, irrespective of the existence of cerebral autoregulation.

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References


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