The Comparison between the Cerebral Blood Flow Directly Measures and Cerebral Blood Flow Velocity in the Middle and Basilar Cerebral Arteries Measured by Transcranial Doppler Ultrasonography

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ABSTRACT. Transcranial Doppler ultrasonography (TCD) may be useful for determining alterations in cerebral blood flow (CBF) during excessive hemodynamic changes by non-invasive measurement of the CBF velocity. The purpose of this study was to measure the correlation between CBF and the middle cerebral artery (MCA) and basilar artery (BA) flow velocities, as measured by TCD during excessive hemodynamic changes produced by hypertension and hypotension in adult dogs. The peak, diastolic, and mean flow velocities were measured by TCD. Arterial hypertension was induced by administration of dopamine at 5 and 15 µg/kg/min, and hypotension was induced by hemorrhage. During the hemodynamic changes, the BA velocity correlated more closely with the alteration in the CBF than the MCA velocity. In terms of percentages of the values during anesthesia, there was good correlation between CBF and the MCA and BA velocities. In conclusion, our findings indicate that MCA and BA velocity measurements, as a percentage of the values during anesthesia, both give an equally accurate indication of alterations in CBF during excessive hemodynamic changes.—KEY WORDS: canine, cerebral blood flow, cerebral blood flow velocity, transcranial Doppler ultrasonography.

Cerebral blood flow (CBF) is kept constant over a wide range of cerebral perfusion pressure by cerebral autoregulation. However, intravenous and volatile anesthetics, cerebrovascular disorders, and trauma of the central nervous system may lead to impairment or a shift in the cerebral autoregulatory response. Therefore, there are a number of ways to monitor changes in cerebral hemodynamics. These include 133Xe inhalation or injection, and the venous outflow technique [6, 11]. However, these invasive methods have limited uses in veterinary medicine.

Transcranial Doppler ultrasonography (TCD) is a method that was introduced by Aaslid et al. [1]. It is a non-invasive technique that can be used repeatedly, allowing real-time measurement of blood flow velocity in the major cerebral arteries in humans [1, 10, 12]. Usually, blood flow is described as the product of blood vessel cross-sectional area and mean blood flow velocity. However, CBF velocity does not always reflect alterations in blood vessel cross-sectional area. Major changes in cerebral arteries are produced at the microcirculatory level, as there is little change in the diameter of the main trunk [4, 13]. Therefore, an increase of CBF appears to correlate more closely with an increase in CBF velocity. TCD may be useful for determining alterations in CBF during excessive hemodynamic changes by non-invasive measurement of the CBF velocity. The purpose of this study was to determine the correlation between CBF and the blood flow velocities in the middle cerebral artery (MCA) and basilar artery (BA), as measured by TCD during excessive hemodynamic changes produced by hypertension and hypotension in adult dogs.

MATERIALS AND METHODS

We used eight adult mongrel dogs (weight 7–11 kg) which had been declared healthy after routine physical examination and hematological testing. Anesthesia was induced with intravenous thiopental sodium (25 mg/kg) and maintained with isoflurane (1.6–1.9% end-tidal) in 100% oxygen after tracheal incubation. Paralysis was achieved by intravenous administration of pancuronium bromide (0.25 mg/kg). The end-tidal CO₂ (EtCO₂) was maintained at approximately 45 mmHg [3, 5, 9]. Body temperature was measured using a rectal thermistor probe, and maintained at approximately 38°C using a servo-controlled heating pad. A 7F cannula was surgically inserted into the right femoral artery to determine cardiac output (CO) using an electromagnetic flow meter (F1-120; NIHON KODEN, Japan) was attached to the ascending aorta to determine cardiac output (CO) using an electromagnetic flow meter (MFV-3200; NIHON KODEN, Japan). The heart rate was recorded with a standard electrocardiograph.

We measured heart rate (HR), mean arterial pressure (MAP), cardiac output (CO), systemic vascular resistance (SVR), CBF, and CBF velocity. Arterial hypertension was induced by intravenous drip infusion of dopamine (Dopa-5, Dopa-15: 5 and 15 µg/kg/min). Hypotension (Hemo) was induced by bleeding the dogs at approximately 20 ml/kg to maintain a MAP of 45-55 mmHg [17]. The above values were measured when the arterial blood pressure was stable. To allow the hypertension to stabilize, dopamine administration was stopped for intervals of approximately

30 min for stabilizing the blood pressure. The CBF velocities in the MCA and the BA were measured using a 5 MHz phased array sector scanning probe (EUP-C324T; HITACHI Medical Corporation, Japan) and device (EUB-565; HITACHI Medical Corporation, Japan) through the trans-temporal foramen magnum. For Doppler examination the output power level was 100% with a 100 Hz wall filter and variable sample size between 1.0 and 1.5 mm. The pulse repetition rate (PRF) was 2.5 KHz. Following an initial B-mode examination, color flow Doppler was performed to identify the vessels (MCA and BA) of interest. Once identified, pulse wave Doppler was initiated and a spectral tracing with at least 3 sequential similar spectral waveforms was collected. Collection of blood flow angle was done in the calculation of blood flow velocities and the angle was maintained at less than 40 degrees. Measurements were made on a representative spectral waveform to determine systolic peak velocity (Vp), end-diastolic peak velocity (Vd), mean velocity (Vm), and resistance index (RI). Data for CBF and CBF velocities were estimated using both absolute values and taking into account anesthetic-induced changes. The resistance index (RI) was calculated according to the formula: RI=(Vp–Vd)/Vp.

The CBF was measured using an electromagnetic flow meter and a transit-time ultrasonic flow meter (T101; Transonic Systems, U.S.A.). The electromagnetic flow probe (FB-040; NIHON KODEN, Japan) was attached to the proximal vertebral artery near the bifurcation of the left subclavian artery. The vertebral artery flow was measured after ligation of the distal artery (Fig. 1). The transit-time ultrasonic flow probe (RB2-190; Transonic Systems, U.S.A.) was attached to the common carotid artery, and the internal carotid arterial flow was measured after ligation of the external carotid artery (Fig. 1). Therefore, the presumptive CBF value was determined as (vertebral arterial flow + internal carotid arterial flow)×2 [8]. All data are given as mean ± standard deviation (SD). The correlation of the CBF and CBF velocity data is expressed as a percentage of the value during anesthesia (baseline = 100%).

Values were analyzed using Pearson’s correlation coefficients and the student’s t-test. Differences at P<0.05 were considered significant.

### RESULTS

The hemodynamic data are presented in Table 1. The CBF and CBF velocity data for both the MCA and BA are presented in Table 2. The MAP and CO increased, with Dopa-15 causing a greater increase than Dopa-5. The SVR did not change with Dopa-5, but increased with Dopa-15 and with Hemo. With Hemo, all measurement values apart from the SVR and RI decreased. After Dopa-5 administration, Vp increased significantly and Vm increased slightly in both the MCA and BA groups. The CBF increased with both Dopa-5 and Dopa-15 administration, but the increase with Dopa-15 was slightly greater. The absolute values correlation between MCA velocity and CBF during the hemodynamic changes was Vp: r=0.32, Vd: r=0.22 and Vm: r=0.33 (Fig. 2). The absolute values correlation between BA velocity and CBF during hemodynamic changes was Vp: r=0.81, Vd: r=0.53 and Vm: r=0.7 (Fig. 2). The CBF and the CBF velocity data expressed as a percentage of the values during anesthesia (baseline=100%) and related to both the MCA and BA velocities are presented in Fig. 3. The correlation between changes in MCA velocity and CBF during the hemodynamic changes was Vp: r=0.91, Vd: r=0.80 and Vm: r=0.88. The

### Table 1. Hemodynamic data

<table>
<thead>
<tr>
<th></th>
<th>HR (beat/min)</th>
<th>MAP (mmHg)</th>
<th>CO (l/min)</th>
<th>SVR (dyne·sec·cm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>119 ± 15</td>
<td>78 ± 13</td>
<td>0.99 ± 0.24</td>
<td>6597 ± 1831</td>
</tr>
<tr>
<td>Dopa-5</td>
<td>130 ± 18</td>
<td>93 ± 17</td>
<td>1.21 ± 0.38</td>
<td>6626 ± 2021</td>
</tr>
<tr>
<td>Dopa-15</td>
<td>171 ± 36</td>
<td>132 ± 37</td>
<td>1.39 ± 0.48</td>
<td>8388 ± 3475</td>
</tr>
<tr>
<td>Hemo</td>
<td>126 ± 12</td>
<td>50 ± 9</td>
<td>0.47 ± 0.2</td>
<td>9428 ± 2760</td>
</tr>
</tbody>
</table>

Value are mean ± SD. HR: heart rate, MAP: mean arterial pressure, CO: cardiac output, SVR: systemic vascular resistance, Baseline: pre experimental data, Dopa-5, -15: administration of dopamine 5, 15 µg/kg/min to achieve hypertension, Hemo: bleed of 20 ml/kg to achieve hypotension. a) p<0.05 compared to Baseline.
correlation between relative changes in BA velocity and CBF during the hemodynamic changes was Vp: r=0.94, Vd: r=0.80 and Vm: r=0.84.

**DISCUSSION**

Radioactive tracers and microspheres are used to determine CBF in animals [6]. However, as there are
problems with measuring CBF in real time using these methods, we used an electromagnetic flow meter to determine the arterial blood flow in this study. Although this procedure cannot measure CBF absolutely, it can be adapted for real-time information [8], as we did here.

Usually, cerebral hemodynamics are kept within a normal range by cerebral autoregulation in the range of 50–150 mmHg of MAP. Therefore, cerebral autoregulation response changes when MAP exceeded this and declined. The intravenous and volatile anesthetics during surgery, cerebrovascular disorders, and hemorrhagic hypotension may lead to impairment or a shift in the cerebral autoregulatory response [2, 7]. It is reported that isoflurane produces a normal autoregulatory response at a level below 1 MAC [14]. However, at 1.5 MAC it inhibits this response [15]. In this study we used dopamine to change the systemic hemodynamics under a 1.6–1.9% end-tidal isoflurane concentration. Dopa-5 increased the CO, MAP, HR, CBF, and CBF velocity. In comparison, Dopa-15 increased the CO, MAP, HR, and SVR, but there was no significant change in the CBF and CBF velocity. This may indicate that the autoregulatory response was not completely inhibited under these conditions. RI and SVR raised in order of Dopa-5, Dopa-15, and Hemo. This shows the strength of the peripheral blood vessel resistance. Especially SVR raised in Hemo in significantly, and the peripheral blood vessel resistance of the whole body was thought to rise most. RI also raised, but the degree was light. This may indicate that the change of the cerebral blood flow resistance was lighter than that of peripheral blood flow resistance of whole body.

Acute hemorrhagic hypotension has been reported to suppress autoregulation at a MAP of less than 49 ± 9 mmHg [16]. Therefore, CBF and CBF velocity are significantly decreased during hemorrhagic hypotension. We have shown that the changes in CBF were correlated poorly with the changes in the absolute value for MCA blood velocity. By contrast, the changes in the CBF correlated well with the changes in both MCA velocity (Vp: r=0.91, Vd: r=0.80, Vm: r=0.88) and BA velocity (Vp: r=0.94, Vd: r=0.80, Vm: r=0.84) (Fig. 3). Giller et al. [4] reported that the diameter of the MCA changed slightly but that there was no significant change in the diameter of the BA, when
high arterial blood pressure varied. Therefore, CBF remained proportional to the BA velocity during variation in the arterial blood pressure because there was no or only minimal change in the diameter of the BA. However, since the MCA diameter does alter slightly during excessive blood pressure changes, the CBF was not proportional to the MCA velocity in terms of the absolute value.

In conclusion, our findings indicate that MCA and BA velocity measurements, especially Vp, give an accurate indication of changes in the CBF during excessive hemodynamic changes. As a percentage of the values during anesthesia, both the measurements give an equally accurate indication of these changes.

REFERENCES