Reaction of Pial Arteries and Veins to Sympathetic Stimulation in the Cat

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SUMMARY  The diameters of pial arteries and veins were continuously monitored by a multichannel video-angiometer through a closed cranial window in 13 cats. Seventy-two arterial portions (diameter 30–283 μm) and 103 venous segments (diameter 32–486 μm) were studied under resting conditions and during stimulation of the cervical sympathetic chain. Arteries with a diameter of ≤ 150 μm constricted 7.3 ± 0.8%; those > 150 μm 13.1 ± 1.4% (p < 0.0005 for both groups). Veins constricted significantly more than arteries of corresponding size (p < 0.005). Veins ≤ 150 μm constricted 11.5 ± 0.9% and those ≥ 150 μm constricted 19.9 ± 1.9% (p < 0.0005 for both groups compared to resting levels). Since the venous compartment contains about 70% of the regional blood volume the tone of the veins is of importance for intracranial pressure. Further studies on the role of sympathetic nervous activity in the regulation of cerebral venous tone under physiological and pathological conditions seem essential.

Since the early studies on the functional importance of the adrenergic innervation of cerebral vessels initiated by Forbes & Wolff the role of the sympathetic nervous system in regulation of cerebral vessel tone has been debated. Many in vivo investigations on the reaction of pial vessels have been performed with an open cranial window technique. Investigations have generally concentrated on pial arteries and, surprisingly, pial veins have been neglected. Since sympathetic activity is a main regulator of the tone in veins in other vascular beds and since the filling of the veins regulates blood volume, the present study was performed to compare the reaction of pial arteries and veins during sympathetic stimulation. A multichannel videoangiometer for continuous monitoring of vessel diameter variations through a closed cranial window was used. A preliminary report on the venous reaction has been published elsewhere.

Material and Methods

Thirteen cats with a body weight of 1.5–3.0 kg were anesthetized with 30 mg·kg⁻¹ pentobarbital sodium, immobilized with 0.006 mg·kg⁻¹ pancuroniumbromide, intubated endotracheally and respirated with a 3:1 mixture of N₂O:O₂. Body temperature was continuously controlled with a Philips rectal-thermosensor unit and maintained at 37°C–38°C with a heating pad. Mean arterial pressure (MAP) was continuously monitored via a PVC-catheter into the descending aorta through the left femoral artery. The right femoral artery was cannulated for administration of bicarbonate solution if required to maintain acid-base balance. The right cervical sympathetic chain was isolated and sectioned below the superior sympathetic ganglion and the cranial end mounted on bipolar silver electrodes fixed in a plastic tube. The animals were then placed in a prone position, and the head was fixed into a stereotaxic head-holder. A parietal cranial window with a diameter of 10 mm ipsilateral to the side of the sympathetic preparation was made, closed with a glass shield, and sealed with acrylic. Pial arterial and veins were investigated through a Leitz intravital microscope, evaluating data by the aid of a multichannel video-angiometer. Single experiments were monitored with a TV system and stored on video tape. Measuring lines — freely movable on the TV screen — could then be placed on any wanted vessel portion to get continuous data on the variation of vessel diameter expressed in micrometers (μm). Multiple replay of experiments on tape thus allowed analysis of a large number of vessel segments.

The sympathetic chain was stimulated for 90 seconds with square wave pulses of 10 ms duration at 15 Hz to produce maximal pupil dilatation and retraction of the nictitating membrane (1–10 v). Student's t-test was used for statistical evaluation.

Results

The resting mean arterial pressure (MAP) was 124 ± 5 mm Hg (SEM). No significant change was noticed during sympathetic stimulation. PaCO₂ was kept at 29.0 ± 0.7 mm Hg and Paco₂ at 105.7 ± 2.7 mm Hg throughout the experiments.

Arteries

Seventy-two arterial portions were observed. Thirty-seven had a resting diameter of > 150 μm, ranging from 153–283 μm (mean value ± SEM: 205 ± 8.08 μm) and 35 arteries had a resting diameter between 30 μm and 150 μm (70 ± 4.62 μm). During sympathetic stimulation, vessels started to constrict after an overall mean latency period of 10.7 ± 1.23 seconds (9.4 ± 1.7 seconds in arteries above 150 μm, 12.5 ± 1.7 seconds in arteries up to 150 μm). This time difference was not statistically signifi-
sympathetic stimulation of cat pial arteries, Veiks/Auer et al.

Figure 1. High speed paper record of 3 arteries between 120 μm and 320 μm resting diameter: the largest artery is the first to start constricting, the smallest artery has the longest latency period.

cant, although multichannel recordings on high speed paper gave the impression that large arteries reacted earlier than smaller arteries (fig. 1). Maximal constriction was achieved after widely varying periods of time from 30 seconds to 4.5 minutes with a mean period of 102.2 ± 12.7 seconds.

Arteries with a diameter ≥ 150 μm constricted 7.3 ± 0.8%, those > 150 μm constricted 13.1 ± 1.4% (p < 0.0005 for both groups). The different degree of constriction between small and larger arteries was also statistically significant (p < 0.0005). The stronger effect of sympathetic stimulation on larger arteries becomes visible on figures 2 and 3.

On single instances, a shortlasting episode of faint dilatation preceded the period of constriction (fig. 3). Vascular reactions in one and the same animal were uniform whereas the reaction to sympathetic stimulation varied considerably among different animals (see table).

Veins

Continuous recordings of venous caliber changes were performed from 103 vessel segments with resting diameters between 32 and 486 μm, mean vessel caliber 141 ± 9.4 μm.

The mean overall latency period after onset of stimulation was 9.1 ± 1.2 seconds. Comparison of veins with diameter < 150 μm (mean value 101.8 ± 4.2 μm) and > 150 μm (mean 279 ± 22 μm) resting diameter revealed no significant difference in the speed of reaction although the mean interval for veins ≤ 150 μm was 10.8 ± 1.6 seconds, for veins > 150 μm 7.2 ± 0.8 seconds. Veins with a resting

Figure 2. Resting arterial diameters in μm plotted against percent diameter changes (ΔφA). Large arteries constrict more than small arteries.

Figure 3. Five-channel recording of arterial reaction to stimulation. The resting diameters are between 190 μm and 25 μm. On several vessel portions, the phase of constriction is preceded by a short episode of dilatation.

Table

Pial arterial (φA) and Venous (φV) Constriction in % of Resting Diameters (%) for Each Experiment Animal.
N = Number of Vessel Portions.

<table>
<thead>
<tr>
<th>Animal-Nr.</th>
<th>N</th>
<th>%φA</th>
<th>N</th>
<th>%φV</th>
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<tr>
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</tr>
<tr>
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<tr>
<td>10</td>
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</table>
FIGURE 4. Venous resting diameters ($\phi V$) plotted against the degree of constriction during stimulation in $\Delta\%$ of $\phi V$.

FIGURE 5. Example of venous reactions to stimulation in a single experiment: Maximal constriction is reached at the end of stimulation. The return to the initial diameters is much slower than the change from normal to maximal constriction. The time interval from resting diameter to maximal constriction is markedly shorter than the period between the end of stimulation and return to initial diameters.

Discussion

The influence of the sympathetic nervous system on cerebral blood flow and on pial vessel reactivity under resting conditions is still a controversial subject which recently has been extensively reviewed. Earlier reports on the reaction of pial arteries to sympathetic stimulation have dealt with small numbers of arteries.

The presently used method to study pial vessel diameter has the important advantage that a great number of vessels can be analyzed simultaneously. Our data show that both arteries and veins respond to sympathetic stimulation and that larger vessels (> 150 $\mu m$ in diameter) generally respond more than smaller ones. Moreover, veins constricted significantly more than arteries of corresponding size. Our finding that larger arteries react more than smaller ones is in agreement with some earlier reports. All sizes of pial arteries constricted (see fig. 2) and we could thus not confirm the suggestion by Wei et al. of a threshold resting diameter below which there is a complete unresponsiveness to sympathetic stimulation.

Little attention has so far been given to the regulation of cerebral veins. To our knowledge there has been no systematic study on the innervation of cerebral or pial veins but it has been briefly reported that pial veins have a more scarce adrenergic innervation than pial arteries. The only earlier information about the reaction of pial veins to sympathetic stimulation is a figure legend from Forbes and Wolf stating that "the vein did not show any measurable change." Our results indicate that sympathetic activity can modify the diameter of pial veins which is in agreement with the role of sympathetic nerves in other vascular beds. The significantly higher degree of constriction in veins than in arteries suggests that the changes in the veins are not only passive responses to arterial diameter variations. The present observations allow us to postulate an active regulation of the veins and consequent decrease of blood volume in the brain during sympathetic stimulation. Considering the importance of blood volume for intracranial pressure and the fact that the venous compartment contains about 70% of regional blood volume, further studies on the regulation of the veins seem essential. It has been shown that sympathetic nerve stimulation can reduce the cerebral blood volume in mice. It is known that intracranial pressure can be modified by sympathetic stimulation; this could be a dual effect on blood volume and alteration of the secretion of cerebrospinal fluid.

While the present technique with a closed cranial window eliminates some of the risks for unphysiological reactions of pial vessels, the question of the relevance of data from electrical sympathetic stimulation as compared to physiological stimulation by reflex activation of neuronal pathways remains to be elucidated.

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References

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