Preserved autoregulation in the rhesus spinal cord after high cervical cord section

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The authors studied the effect of high cervical cord section on the phenomenon of autoregulation in the rhesus monkey with the hydrogen clearance method to measure focal spinal cord blood flow (SCBF). Laminectomies were performed at T7-11 and C1-2. The spinal cord was completely severed at C1-2. Under normocapnic conditions, SCBF was then measured in the thoracic spinal cord over a wide range of blood pressures (MAP). The MAP was either lowered by bleeding or raised by the intravenous infusion of angiotensin. Autoregulation was found to be intact between 50 and 125 mm Hg, following a pattern similar to the one observed in the intact animal.

KEY WORDS spinal cord • autoregulation • blood flow • sympathetic nervous system • hydrogen clearance method

That autoregulation exists in the brain is a well-established fact.\textsuperscript{1-2,4,5} The mechanisms responsible for this control, however, are not fully understood. In previous reports, we have demonstrated the presence of autoregulation in the spinal cord, which follows a pattern similar to that observed in the brain.\textsuperscript{8,9,11} The present series of experiments was undertaken to learn more about the mechanism of autoregulation in the spinal cord, and hopefully, therefore, about similar mechanisms in the brain.

Methods and Materials

Six rhesus monkeys weighing from 2.5 to 3.5 kg were initially anesthetized with 0.5 ml phencyclidine HCl and 1.0 ml sodium pentobarbital. Catheters were inserted into the femoral artery for continuous blood pressure monitoring and periodic blood gas determinations, and into the femoral vein for continuous fluid replacement and the administration of drugs. The animals were then intubated and placed on a volume respirator, receiving N\textsubscript{2}O and O\textsubscript{2} in a 2:1 mixture for the remainder of the experiment. Temperature, continuously monitored by a rectal probe, was kept at 37° to 39° C, using a heating pad when necessary. The inspired gas mixture was adjusted so as to maintain the PaO\textsubscript{2} and the PaCO\textsubscript{2} in the normal range. The animal was then placed in a headholder in a sphinx-like position, and a standard dorsal laminectomy was performed exposing the dura mater from T7-11. At this time a second laminectomy was performed at C1-2. The dura mater was opened at this level, and the spinal cord parenchyma was completely divided. Care
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FIG. 1. Measurements made in a monkey with the spinal cord severed at C1–2. A best-fitting line is drawn through the means (± SD) of spinal cord blood flow as it varied with changes in mean arterial blood pressure. The left ordinate is in units of blood flow (ml/min/100 gm). The right ordinate is in units of vascular resistance (mm Hg/ml/min/100 gm).

was exercised to avoid injury to the anterior and posterior spinal arteries. One to three platinum electrodes, each 250 μ in diameter, were then inserted into the lateral funiculus of the thoracic cord through the intact dura, in a fashion similar to previous reports.12

After stabilization of the animals, multiple blood flow determinations were then made at varying levels of systemic arterial blood pressures (MAP). The MAP was either raised by an infusion of angiotensin, or lowered by bleeding. In each animal, the MAP was either raised or lowered; flow recordings were not obtained in an animal at an abnormally low MAP subsequent to determinations at an abnormally high MAP, and vice versa.

Using the hydrogen clearance method, blood flow was calculated from the monoeponential tissue desaturation curve of inhaled hydrogen gas. The specific details of this method are available in earlier publications.10,12 This technique is used to measure focal blood flow in a discrete volume of tissue surrounding the electrode tip, less than 0.5 cu mm.12

Results

In all animals a transient rise in MAP, often to 180 to 200 mm Hg, accompanied the high cervical cord section, and lasted from 1 to 2 minutes before returning to the normal range. In four animals this was followed by a persistent decrease in the MAP to 50 to 60 mm Hg.

Figure 1 illustrates the changes observed in spinal cord blood flow (SCBF) that accompanied induced changes in the MAP. The ordinate on the left represents SCBF; the right ordinate represents the calculated vascular resistance (RU). The SCBF remained relatively constant and in the normal range between an MAP of 50 to 125 mm Hg. Above 125 mm Hg, SCBF increased with further increases in MAP. Reductions in the MAP below 50 mm Hg were accompanied by similar decreases in SCBF. Vascular resistance was calculated for each MAP from the equation:9

$$RU_{100} = \frac{\text{perfusion pressure}}{\text{flow}} = \frac{\text{MAP (mm Hg)}}{\text{flow (ml/min/100 gm)}}$$

and is plotted in Fig. 1.
Discussion

In a previous series of experiments, we have demonstrated the presence of autoregulation in the spinal cord of the intact rhesus monkey within a range of 50 to 135 mm Hg (MAP).\(^8,9,11\) We have also shown that as the MAP is raised above 135 mm Hg in the intact animal, vasodilation occurs with a subsequent rise in SCBF.\(^8\) The mechanisms responsible for this phenomenon, however, are not well understood. Studies involving cerebral autoregulation have suggested that the sympathetic nervous system (SNS) may play an important role.\(^1,2,4,5\) Anatomic studies have demonstrated adrenergic nerve endings in the walls of blood vessels at the base of the brain.\(^9,12\) Physiological studies have also tended to implicate the SNS in control of the cerebral circulation.\(^1,2\) Harper, \textit{et al.},\(^6\) have suggested a dual mechanism for cerebral autoregulation involving the SNS in control of the extraparenchymal vessels, and local tissue pH changes in control of the small intraparenchymal vessels. Yet, the role of the SNS in control of the spinal cord circulation remains moot. The presence of adrenergic receptors in the blood vessels of the spinal cord parenchyma has not been established.\(^14\) The data from the present experiment tend to negate a major role of the SNS in the mechanism of autoregulation in the spinal cord, since in this preparation autoregulation has remained intact after separation of the spinal cord from the cerebral control of the SNS.

An alternative, however, is a spinal-cord-mediated reflex sympathetic involvement. The cell body for the preganglionic nerve fiber is in the intermediolateral gray matter of the thoracic spinal cord. This neuron is influenced by the descending fibers that arise primarily in the hypothalamus. We should, however, consider the possibility that information from the peripheral end organs is brought to the neuron and influences its output by way of the afferents returning to the spinal cord, modulated through the internuncial pool. Hence, a spinal reflex may exist that allows the SNS to exert control over the end organ in situations in which the cerebral control of the SNS is removed. Further studies employing pharmacological blocking agents of the SNS are in progress in an attempt to define more clearly the role of the SNS in this phenomenon.

At an MAP greater than 125 mm Hg, we have demonstrated a breakthrough of autoregulation, with further increases in MAP effecting a marked rise in SCBF. This breakthrough occurs at approximately the same level as in the intact animal.\(^8\) It can be seen from Fig. 1 that, as the MAP is increased above 125 mm Hg, the vascular resistance decreases and vascular dilatation occurs. The vascular dilatation appears to reach the same maximum value at very high MAP levels (180 to 200 mm Hg) as it does at extremely low MAP levels (20 to 30 mm Hg). This phenomenon appears essentially unchanged when compared to the intact animal.\(^8\) Again, the similarity of this phenomenon in intact and spinal-injured animals tends to question the role of the SNS in this phenomenon, or to suggest that the SNS exerts its influence through a spinal reflex.

The data from the present experiment are in general agreement with those of Kindt,\(^6,7\) who has shown a similar response of SCBF to changes in MAP in intact and spinal-injured animals with a surface flow-measuring device that records qualitative blood flow changes.

Summary

Spinal cord blood flow was measured in the lateral white matter of the rhesus monkey over a wide range of artificially varied MAP's after complete high cervical cord section. The SCBF remained constant and in the normal range with the MAP at 50 to 125 mm Hg, demonstrating intact autoregulation. Below 50 mm Hg, SCBF fell as the MAP was further reduced. Above 125 mm Hg, vascular dilatation occurred and was accompanied by marked increases in SCBF. These findings were essentially unchanged from observations of similar phenomena in the intact animal and therefore provide evidence against the importance of either the sympathetic nervous system or its cerebral control in these situations.

References


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