The Vertebral Venous Plexus as a Major Cerebral Venous Outflow Tract

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Cerebral venous outflow in rhesus monkeys anesthetized with halothane has been studied by angiographic techniques. The effects of body position and pressure within the airway have been studied. With the monkey supine, injection of radiopaque contrast medium into the superior sagittal sinus permitted visualization of the vertebral plexus and internal jugular veins bilaterally. Pressure on the airway decreased the amount of contrast medium appearing in the vertebral plexus and the superior vena cava and caused engorgement of the internal jugular veins. With the animal erect, almost all contrast medium flowed through the vertebral plexus, with the jugular veins barely visible. With pressure applied to the airway, there appeared to be retrograde flow from the vertebral veins into the internal jugular, subclavian and axillary veins. The vertebral plexus was well outlined as far down as the seventh thoracic vertebra and the density of the upper cervical vertebrae increased. These studies demonstrate that the vertebral venous plexus is an important cerebral venous outflow tract in the supine position, and in the erect position it appears to be the major pathway of exit of cerebral blood. (Key words: Vertebral venous plexus; Jugular veins; Cerebral venous blood flow.)

In 1965 one of us suggested that the jugular veins are not always the principal avenue for escape of blood from the brain and that the vertebral venous plexus might be a drainage route of significant proportion, particularly in erect man.[1] It was further theorized that the vertebral venous plexus might provide the means for cerebral circulatory compensation with the sudden assumption of the upright position.

The experiments reported here have been conducted in an attempt to examine this hypothesis.

Methods

Rhesus monkeys varying in weight from 6 to 10 kg were anesthetized with 0.5 mg/kg of phencyclidine hydrochloride (Sernylan), their tracheas intubated, and anesthesia maintained with 0.5–1.0 per cent halothane in 4 to 5 l oxygen/min, using a nonrebreathing system. Under aseptic conditions a catheter was introduced into the sagittal sinus through a burr hole in the skull or into a jugular vein occluded below the point of insertion. Preliminary studies were directed toward finding suitable radiologic conditions for visualization of the vertebral plexus. The use of an image amplifier with magnetic-tape recording and portable still x-ray films did not provide optimal contrast and definition. Other technical difficulties encountered which prevented clear visualization of the vertebral venous plexus included catheters too small to allow rapid injection and contrast media too dilute to be seen clearly. Finally, insertion of a 17-gauge plastic catheter into the superior sagittal sinus and injection of 5 to 10 ml of a radiopaque contrast medium, 60 per cent diatrizoate methylglucamine solution (Renografin-60, Squibb) enabled us to visualize the vertebral plexus clearly. Still films taken in the radiology department, using the equipment ordinarily used for head and skull x-rays, gave the desired quality of picture. Twenty-three experiments in nine monkeys have been completed. Our last seven experiments have consisted solely of injection of diatrizoate methylglucamine into

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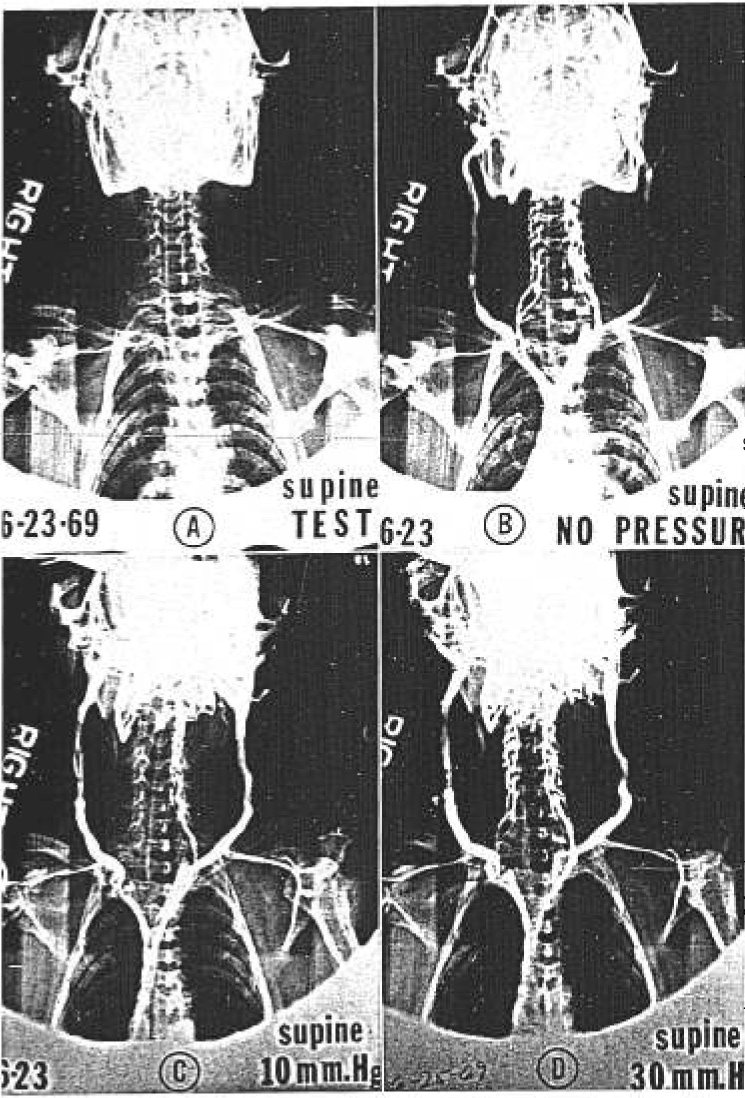


FIG. 1. Anteroposterior x-rays of the head and upper thorax of the monkey in the supine position.

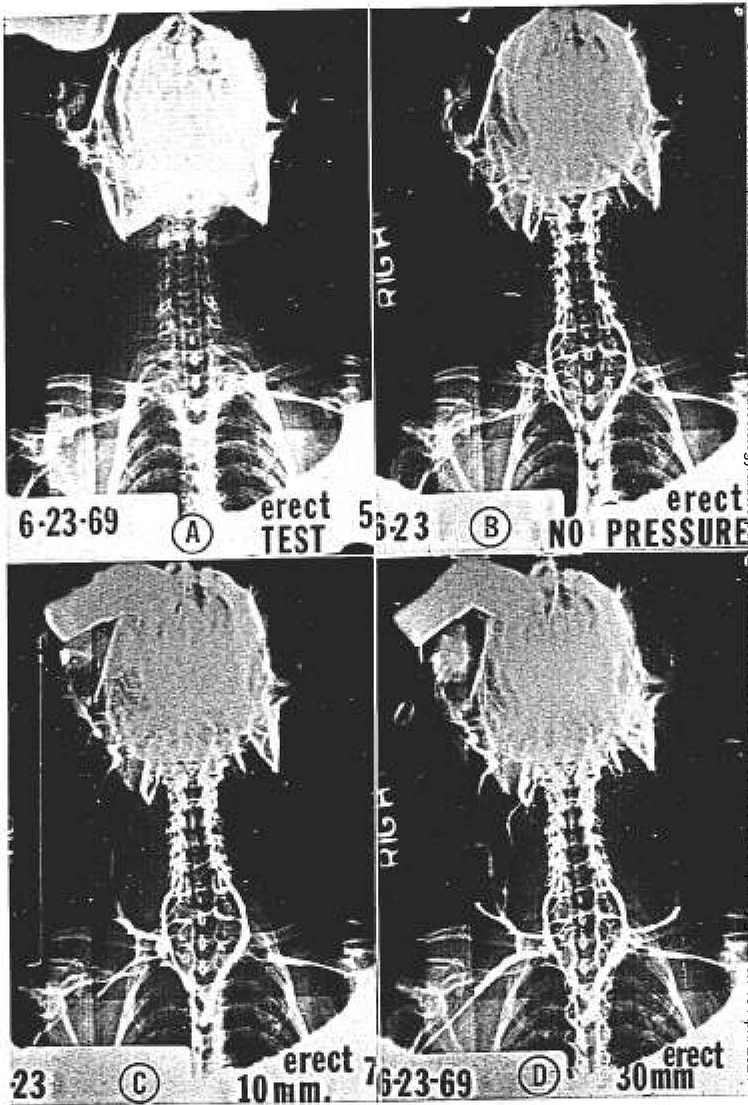
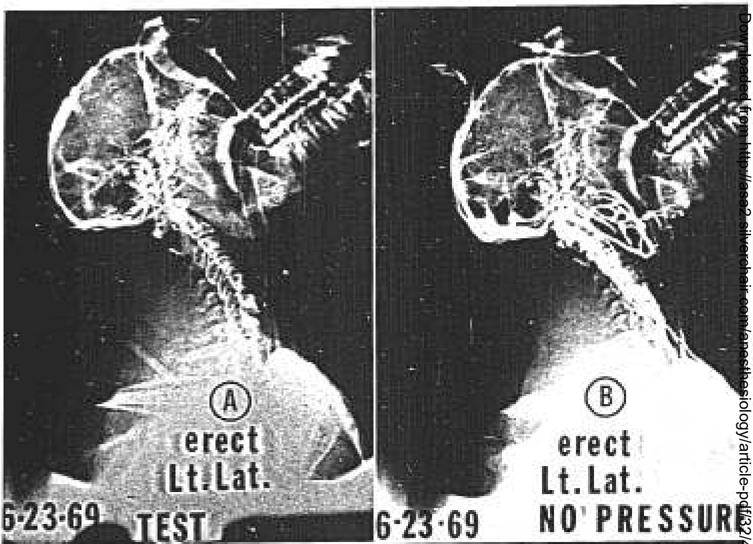


FIG. 2. Anteroposterior x-rays of the head and upper thorax of the monkey in the upright position.



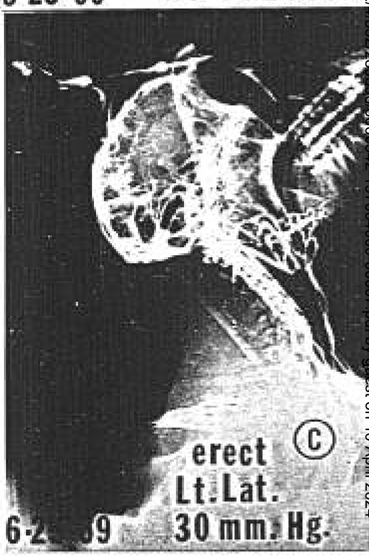


Fig. 3 (above and right). Left lateral x-rays of the head and thorax of the monkey in the erect position.

the superior sagittal sinus through a large-bore catheter, with both jugular veins untouched.

During each experiment studies were carried out with the monkey in two positions, supine and erect, with lateral and/or anteroposterior films being taken. A control film was obtained of each position, after which contrast medium was injected with ambient airway pressure and with positive airway pressure maintained at 10 and at 30 mm Hg.

Results

The experiments demonstrated two major cerebral outflow tracts: the jugular veins and the vertebral venous plexus. Although the emissary veins are reputed to play some part in cerebral venous drainage, we saw little evidence of this.

Once the technique was perfected, results were consistent. In order best to demonstrate these, we have selected a series of x-rays from one animal (figs. 1, 2, and 3).

Figure 1*A* shows the control x-ray of the upper thoracic and cervical regions and skull of a 10-kg monkey. The animal lay quietly in the supine position with the head in the anteroposterior position. Outlines of the endotracheal tube are visible. The x-ray in figure 1*B* was taken immediately at the conclusion of injecting 10 ml of contrast medium into the sagittal sinus, at a rate of 1 ml/sec. The animal was breathing quietly and there was no pressure on the airway. The internal jugular veins are clearly visible bilaterally, as is the upper portion of the vertebral venous plexus draining into the vertebral veins which empty into the internal jugular veins. Some anastomoses are visible between the two sides of the vertebral plexus at the three uppermost vertebrae.

Figure 1*C* was obtained about ten minutes later, following injection of 10 ml of diatrizoate methylglucamine and during the maintenance of 10 mm Hg pressure on the airway via the breathing bag. In comparison with figure 1*B*, both jugulars are more prominent, and the external jugular veins are faintly visible. The vertebral plexus is less well outlined, not visible on the right. There is less contrast medium in the superior vena cava.

Figure 1*D* represents the effect of 30-mm Hg positive airway pressure recorded about ten minutes after figure 1*C*, following injection of 10 ml of contrast medium. Both internal jugular veins appear more distended and the right vertebral plexus is again visible. The anastomoses between the two sides of the vertebral plexus are quite dense at the level of the upper two cervical vertebrae.

The above series of radiographs were repeated with the animal maintained in the upright position on a board. Figure 2*A* is the control x-ray and 2*B* the x-ray obtained immediately following injection of 10 ml of contrast medium into the sagittal sinus. Compared with figure 1*B*, the left internal jugular vein is invisible and the right only faintly visible. The vertebral plexus is more clearly outlined bilaterally and there is less contrast medium in the superior vena cava. There is increased density of the bony substance of the uppermost cervical vertebrae.

Figure 2*C* shows the effect of 10-mm Hg airway pressure. The right internal jugular vein is more visible and the right external jugular vein has become apparent, although faintly so. Neither the left external nor the left internal jugular vein is apparent. The vertebral plexus is clearly apparent bilaterally. The density of the bony substance of all the cervical vertebrae is increased. The contrast between figures 2*C* and 1*C* is striking.

Figure 2*D* demonstrates the effect of 30-mm Hg airway pressure. Now both internal jugular veins can be seen, although faintly. There is evidence of retrograde flow from the vertebral veins into both of these vessels. Little contrast medium is apparent in the superior vena cava, but retrograde flow into the right subclavian and axillary veins can be seen. The vertebral plexus is well outlined down to the seventh thoracic vertebra. The density of the vertebral bony substance is increased compared with figure 2*C*.

The final series of x-rays was similar to the second series, but made from the lateral aspect with the animal erect. Figure 3*A* is the control. Close inspection reveals the position of the catheter in the sagittal sinus. Figure 3*B* followed injection of the contrast medium without pressure on the airway. The passage of nearly all the contrast medium down the vertebral plexus is apparent. The retropharyngeal plexus of veins is also clearly visible. Figure 3C was made with 30-mm Hg pressure on the airway. There is some increase in filling of the jugular veins. The density of the vessels within the bony canal has increased. Some of the posterior cervical plexus of veins can be seen faintly.

Discussion

These experiments demonstrate visually that blood flows from the brain by two major routes and that the volume of blood leaving the brain by either route is variable, depending upon body position, intrathoracic pressure, and perhaps other factors as yet undefined. Although it has been generally assumed that the jugular veins are the only significant source of cerebral venous drainage, it is now apparent that the vertebral venous plexus is always functional in accommodating cerebral venous outflow and, furthermore, in the upright position, may be far more important than the jugular vessels.

The existence of the vertebral plexus has been known since the 1820's. Bock, in 1823,[2] and Breschet, in 1828–32,[3] published anatomic atlases which quite accurately describe the anatomy of the plexus. It remained for Batson,[4,5] a century later, to describe one of the pathophysiologic functions of the system and to define the ramifications of the plexus in greater detail. Batson suggested the plexus as an avenue by which pelvic tumor or infection could be transmitted directly to the brain. This plexus is a valveless, thin-walled, distensible system of veins, and blood is free to flow in any direction, influenced only by pressure gradients and perhaps by blood volume. Although Batson observed that radiopaque substances could leave the cerebral venous circulation via the vertebral venous plexus, he did not extend these investigations. So far as we are aware, no one has demonstrated that the vertebral plexus is a major cerebral outflow tract. Our work suggests that the vertebral plexus may act as a siphon, facilitating the flow of blood across the brain when the body is in the upright position.

So far, we have dealt with the monkey, for obvious reasons. Recent extensive anatomic dissections of human cadavers (Cardoso, Whitehouse, and Eckenhoff, unpublished data) have shown a close relationship between the vertebral venous plexus of man and the data obtained from the monkey. There is, therefore, little reason to doubt that what we have seen in the monkey is applicable to man. Should the opportunity to investigate this in a patient present itself, we see no reason why venograms of this system might not be obtained safely.

We have confined our investigation of this venous system to a study of cerebral blood outflow. However, there are many additional physiologic implications of the vertebral venous plexus, some of which are of import to the anesthesiologist.[6] These include: 1) a principal determinant of cerebrospinal fluid volume and pressure; 2) a role in determining doses of spinal anesthetics in the parturient; 3) the basis for an explanation for post-lumbar-puncture headache; 4) a source of excessive bleeding in patients undergoing operations on the spine and suboccipital region; 5) a source of air embolization to heart and brain during operations upon the spine or skull; 6) an explanation for maintenance of adequate cerebral blood flow during deliberate hypotension with head-up tilt. We are investigating these possibilities.

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