INTRAVITAL OBSERVATIONS OF CEREBROSPINAL FLUID MOVEMENT IN THE SUBARACHNOID SPACE

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The topography of the system of pial canals and compartments of the dog's brain was demonstrated by intravital staining with trypan blue. Movement of the cerebrospinal fluid in each of three systems was studied by injecting an emulsion of mineral oil, prepared by sonication, into the cerebrospinal fluid (CSF). In the canals the CSF performs three types of visually observable oscillatory movements, differing in their amplitude. Progressive oscillating currents of CSF produced by muscular forces or by changes in the position of the animal's body have the greatest amplitude. Under physiological conditions they mix the CSF of the basal cisterns of the brain with the CSF in the canals. In the labryinths of the compartments these oscillatory movements disappear completely, and the CSF here moves very slowly in variable directions. As the CSF moves through the compartments, the droplets of emulsion mixed in the CSF are trapped in them and immobilized.

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Many writers have described the subarachnoid space as a continuous gap between the arachnoid and pia, and have represented the circulation of cerebrospinal fluid (CSF) as a one-way flow of liquid.

However, steromorphological studies of the pia covering the cerebral hemispheres using the method of tachyscopy have shown that the subarchnoid space in fact is complex in its configuration and is differentiated into two morphologically and functionally distinct systems: the CSF-carrying canals and the subarachnoid compartments [2]. The question has thus arisen of the pathways of CSF circulation within the subarachnoid space itself.

The object of this investigation was, ignoring the initial and final stages of CSF circulation, to study the principles governing its movement along the system of canals and in the system of compartments.

EXPERIMENTAL METHOD

Experiments were carried out on dogs weighing 10-20 kg anesthetized with morphine and thiopental. A burr hole 14 mm in diameter was made in the skull in the temporoparietal region with a special drill. The dura was removed beneath the burr hole, carefully securing hemostasis and ensuring integrity of the arachnoid. In the experiments with a hermetically closed skull, a transparent window was fixed in the burr hole, while in the experiments with an open skull the brain in the burr hole was irrigated with warm physiological saline. A needle was introduced into the cisterna magna, and through it, after withdrawal of 2-3 ml of CSF, the same volume of 0.2% trypan blue in physiological saline was injected into the cisterna. Later, also by substitution, 1-2 ml of sonicized emulsion of mineral oil† was introduced into the cisterna. The emulsion remained stable throughout the experiment. It consisted of droplets about 1) μ in diameter, strongly refracting light and readily distinguishable in the microscope. A valuable property of the emulsion was its inertness relative to the minengeal tissues. The pia was observed in a stereoscopic microscope in incident light from a powerful lamp fitted with a heat filter.

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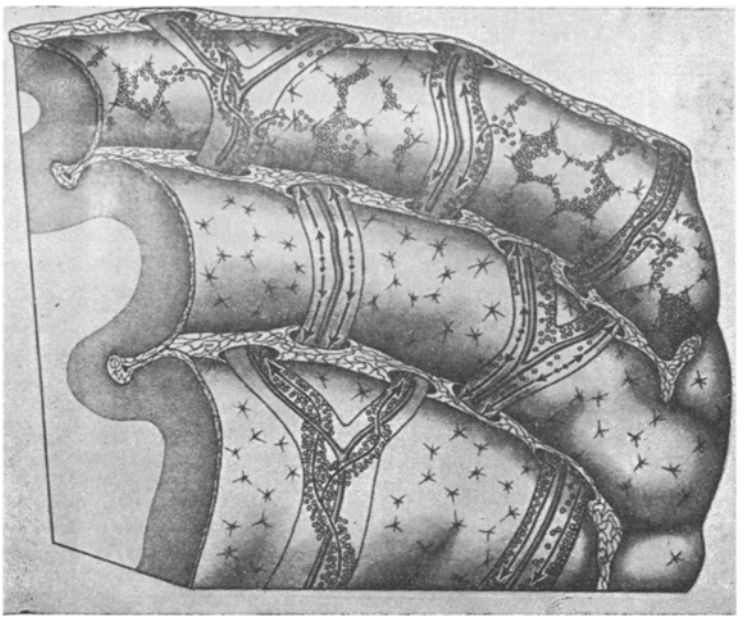

Fig. 1. Diagram showing three gyri of the cerebral hemispheres. Star-like structures are present only in the zones of the compartments. Arteries lie within the lumen of the canals (represented disproportionately large). The direction of advance of the emulsion in the canals at the beginning of the experiment is indicated by arrows on the lower gyrus. On the middle gyrus, arrows of different sizes conventionally represent oscillatory movements of the emulsion of different amplitude in the canals: pulsatory movements, respiratory movements, and movements caused by muscular contractions. The large arrows on the upper gyrus also represent the oscillatory movement of the emulsion in the canals, while the small arrows indicate places where emulsion leaves the canals to enter the compartments. Droplets trapped in the compartments are stationary.

EXPERIMENTAL RESULTS

After injection of trypan blue solution into the cisterna magna, microscopic examination of the cerebral hemispheres showed that the dye moved progressively into the canals of the fissures, surrounding the large cerebral arteries lying in them. The next moment the dye moved into the canals of the gyri, surrounding arterial branches of the surface of the gyri readily visible to the eye (Fig. 1). The dye spread along the system of canals for 1-2 min. It literally overflowed along the arterial branches, making the outlines of the arteries ill defined and hiding the crimson color of the blood flowing in them. No changes were observed along the course of the veins, both large and small, because unlike the arteries the veins lie outside the canals.

After filling the system of canals, the dye starts to leave them for the surrounding compartments. The pale blue trypan blue solution, noticeably diluted with CSF, now covers the whole surface of the hemispheres. At that moment, charactistic star-like structures, stained with trypan blue, appear in the field of vision of the microscope. Subsequently the staining of these stars becomes progressively deeper. Conversely, staining of the CSF everywhere becomes weaker, partly because of adsorption of trypan blue on the stars and partly because of its removal with the CSF draining away. Staining of the CSF even in the canals was no longer visible 20-30 min after the beginning of the experiment. The only sign of dye previously injected into the cisterna magna was the bright blue stars. Histological investigation of fixed material (not described in this paper) showed that the stars are places of contact between walls of adjacent compartments, or meeting points of the fibers forming the framework of the compartments. The stars are situated in certain zones which correspond to groups of compartments. Between these zones are bands of

arachnoid free from stars, and arteries can be seen against their background. These bands correspond to the outlines of the canals. Hence, by staining the stars it is possible to detect the position of the canals and compartments during life, a factor of essential significance for subsequent experimental observations.

Next, the emulsion of mineral oil was injected into the cisterna magna. It spread rapidly along the canals, and under the microscope the progressive movement of the strongly refractory droplets could be seen. Often the movement of the emulsion in adjacent canals of the same gyrus took place in opposite directions: from below upward in one canal and from above downward in the other. As the pressure in the CSF pathways became equalized soon after injection of the emuslion, the progressive advance of the droplets in the canals slowed down and at the same time they began to oscillate. After 10-15 min, the progressive movement of the emulsion in all the canals had completely stopped and was replaced by oscillatory movements synchronized with respiration and the pulse. Measurements showed that the larger respiratory oscillations of the droplets, with an amplitude of about 5-8 mm, interfered with small pulsatory movements whose amplitude did not exceed 1-2 mm.

In a state of complete anesthesia, oscillatory movements of this type of the emulsion in the canals could be observed for hours, and no definite flow of CSF toward the place of its departure could be detected. However, a state of anesthesia cannot be regarded as physiological. For that reason, another type of movement of the CSF in the canals, observed as the animal awoke from the anesthetic, and also during changes in the position of its head or trunk, was more interesting.

During the first muscular movements of the animal – movements of its tail or limbs, and also during strong inspiration, this "dance on the spot" of the droplets suspended in the CSF in the canals stopped instantly. The droplets moved on from the surface of the hemispheres along the canals into the cisterns at the base of the brain. After the end of the muscular contraction or during expiration the droplets returned along the same canals in the opposite direction to the surface of the hemispheres, where they resumed their "dance on the spot." Under physiological conditions, because of its considerable amplitude, this oscillatory movement plays the role of a factor mixing the CSF of the cisterns with the CSF of the canals. By comparison,the importance of the respiratory and pulsatory oscillations in mixing the CSF is secondary.

With a change in the position of the animal's head or body (raising the hind limbs to an angle of 45°, compression of the abdomen), a progressive oscillatory movement of the CSF like that observed during muscular contractions also developed in the canals. Irregular changes in the lumen of the canals were often seen under these circumstances: some became wider, others narrower. Some canals completely collapsed and droplets of emulsion disappeared from them. After stabilization of the position of the head or trunk, the progressive movement of CSF in the canals was slowed and replaced by respiratory and pulsatory oscillations.

During movement of the emulsion in the canal, and especially if it was thick, the boundaries of the canal alongside the artery were clearly outlined. Although the canal wall is indistinguishable during life, it was clearly evident that the droplets of emulsion slid along this boundary without crossing into the territory of the compartments. Clearly, therefore, over a greater part of its extent, the wall of the canals is unbroken and impermeable to droplets suspended in their lumen.

Meanwhile, a different picture was observed at certain points of the canals lying considerable distances apart. At these points many droplets crossed the border of the canals and escaped in stress visible under the microscope into the surrounding compartments. This escape of droplets began soon after injection of the emulsion into the cisterna magna and did not cease in the subsequent stages of the experiment. In the period of progressive movements of the CSP caused by muscular contractions or changes in the animal's position, the escape of droplets was increased, while during periods of slight respiratory or pulsatory movements of the CSF it decreased. However, oscillatory movements of the CSF in the canals continually forced droplets of emulsion into the compartments at these points. Consequently, at these places there are holes in the wall of the canal through which CSF with suspended particles in it can penetrate. These holes are clearly visible in stained histological preparations.

At first the droplets could be seen only in a few compartments lying next to the canal. Later they spread from one compartment to another through numerous holes in their contiguous walls, which also are clearly distinguishable on histological preparations. An important observation was made: after penetration of the droplets into the territory of the compartments, their oscillatory movements rapidly disappeared and eventually the droplets became stationary. In the early stage of the experiment some compart-

ments were densely packed with droplets, while in others they were few in number. Later the emulsion filled most of the compartments. However, throughout the experiment, droplets trapped in the compartments stayed motionless. This was in sharp contrast with the unceasing oscillatory movement of the same droplets simultaneously observed in the lumen of the canals.

This description of the movement of emulsion with the CSF of the canals and the CSF of the compartments was identical whether the skull was hermetically closed or open.

At a time when nothing was known of the existence of canals and compartments, experiments were carried out in the author's laboratory which revealed two types of movement of the CSF; a very slow, steady circulation from the ventricles to the brain surface, from which the CSF was drained through the arachnoid, and a comparatively more vigorous respiratory and pulsatory oscillatory movement, mixing the CSF [1]. These two types of CSF movement were confirmed by electromanometric measurement [5]. However, other workers are of the opinion that only respiratory and pulsatory movements of the CSF in fact exist [6]. Observations have also been made showing that CSF may flow in two opposite directions on the outer surface of the cerebral hemispheres in dogs [8].

The present investigation showed that under physiological conditions, during contractions of muscles or changes in the position of the head, progressive oscillatory movements of CSF arise in the subarachnoid space, the amplitude of which is far greater than the amplitude of its respiratory and pulsatory movements. In the cerebral hemispheres, oscillatory movements of the CSF occur only in the canals. These have no valves and are adapted for movements of the CSF in opposite directions. At the same time, a circulation of CSF takes place along the canal, i.e., it is delivered to the arachnoid and flows away into the subdural space [3]. In groups of compartments resembling a finely porous sponge, the oscillatory movement disappears on the fall in pressure in adjacent canals. In the course of movement of the CSF through the labrinth of compartments, foreign matter suspended in the CSF is held up within them, just as in the case of movement of lymph through the sinuses of the lymph gland. This is a very important factor under pathological conditions, especially during metastasization of tumor cells via the CSF and after subarachnoid hemorrhages, when blood cells enter the CSF [4].

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