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On the flow dynamics of cerebrospinal fluid☆

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ABSTRACT

Despite a not insignificant number of anatomical and experimental studies describing the distribution and movement of the cerebrospinal fluid several questions were answered controversially, leaving room for objections and doubts. Some of these controversies I have tried to address by new experiments. Before going on to describe these studies, some short anatomical notes on the membranes that cover the central nervous system may be appropriate.

Bichat described the anatomical membranes as follows: in between the fibrous lining of the brain-vertebral cavity, the dura mater and the vascularized coat of the spinal cord (the pia mater) a space covered by a serous skin is interposed, the parietal part of which is integrated with the inner side of the dura mater; and the visceral part in contrast is detachable from the underlying pia mater. The watery fluid of the brain-spinal-cord cavity discovered by Cotugno received more attention by Magendie, who initially placed it [*the fluid*] within the serous space described by Bichat, convincing himself [Magendie] however later, that it [*the fluid*] is present in between the visceral sheet of the arachnoid and the pia mater.

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Magendie, who initially placed it [*the fluid*] within the serous space described by Bichat, convincing himself [Magendie] however later, that it [*the fluid*] is present in between the visceral sheet of the arachnoid and the pia mater. Later on, researchers agreed with this assumption and only recently did Henle[1] present this point-of-view in his handbook of anatomy, by describing the subarachnoid connective tissue with its mesh-like spaces as a physiological water-filled connective tissue (Virchow) of unusually loose quality; towards the inside it faces the vascular skin (the pia mater), and towards the outside the so-called arachnoidea visceralis. The latter is adhering – typically tightly – to the inner side of the dura mater. Given that the majority of anatomists now agree that the cerebrospinal fluid is located mainly subarachnoidally, there are nevertheless different views about the presence of fluid in the actual arachnoidal sac (in between dura and arachnoidea visceralis). While Luschka [and] Reichert assume an admittedly very small volume of fluid in that very place, Ecker totally refutes that notion in the live animal. This contradiction arises, I assume, from the fact that some [anatomists] preferentially focus on the scenario at the level of the spinal cord, while others focus on the skull. At least in live animals (dogs, cats, rabbits) I found that in the spinal cord the arachoid[2] always closely adheres to the dura mater, because during incision of the latter the arachnoid in most cases will be concomitantly injured and the subarachnoid fluid will flow out. One would only rarely exclusively incise the fibrous skin [dura mater]; in this case, the arachnoid protrudes like a hernia due to the fluid content within its meshed spaces; the basis of the wound however is staying dry, because in between arachnoid and dura no fluid is present. Also in dead animals, the view into the spinal canal through the foramen magnum reveals that free connective tissue strings are spawning from the pia to the arachnoid; the latter, however adheres to the dura and can only after overcoming a certain resistance be separated from it. When trying via a puncture to make an injection, I never once accessed the interstice in between the arachnoid and dura, but always ended up in the subarachnoid space.

The situation is different at the level of the skull. Here the connective tissue strings between pia and arachnoid are shorter and more robust, the meshed filled spaces (with the exception of the points assigned by Magendie as ``confluents''), narrower; the arachnoid does not stick to the dura, but is separated from it by a capillary fluid layer, therefore in the skull, opening of the dura itself without injuring the [underlying] arachnoid is with some caution relatively easy. [Even] with the dura intact, the distance between both membranes is wide enough to insert a rounded rectangular bent cannula and administer an injection into the actual serous sac in between arachnoid and dura, without injuring the arachnoid. Hence, in the brain, the arachnoid is disconnected from the dura by a capillary fluid layer, whereas at the level of the spinal cord this serous space is non-existent, and instead [in the spinal cord] the arachnoid is tightly adherent to the dura mater. [In the spinal cord], the numerous connective tissue bands (denticulate ligament, nerve roots sheets) running from the pia to the dura may have induced this closer relationship. The transition from one anatomical scenario to the other starts at the back rim of the cerebellum and at the medulla oblongata.

Experiments reported below will show whether a communication between the subarachnoidal and the arachnoidal mesh spaces, exists.

I now continue with the description of experiments where an emulsion of cinnabar was injected at various places into the cavity of the spinal cord of live animals. [For these experiments] I used, as do painters, the finest pulverized cinnabar granulated with sugar water, diluted with five- to ten-fold the volume of water. In a series of animal experiments (exclusively dogs, – cats, rabbits are too small) the cinnabar emulsion was injected into the subarachnoid spaces of the spinal cord cavity via a cannula. Usually this was done by incising the skin above the upper lumbar vertebra and by dissecting the musculature from one side of one or two spinal processes; and when arriving at the vertebral arches, a cannula was passed through the [ligamentum flavum] close to the midline, 1 cm deep, and the cinnabar emulsion was injected. When not considering completely unsuccessful trials, in which case the needle [altogether] missed the spinal canal, successful placement of the tip of the cannula (at the intended spot) depended on pure chance and training. An injury of the spinal cord was usually not an issue, because from such a needle stick the cinnabar may have nevertheless reached the subarachnoidal spaces. Not rarely did it leak through the small, local incision associated with the penetration of the dura mater or – in the case of minute misplacement of the cannula during the injection – directly into the fat-rich loose tissue between the dura and the periost [epidural space]; sometimes it accumulated exclusively in this space; and never advanced further into the space between the dura mater and the arachnoid. After surgery, the skin wound was closed and the animal was left to recover. The behaviour of the animals now was completely different (not considering the after effects of narcosis, which the dogs received in some cases), usually a weakness of one or both lower extremities was observed, presumably due to an injury of the spinal cord. In some dogs this weakness dissipated completely or incompletely over the ensuing days or weeks. The seemingly healthy animals were euthanized after a period of one week to three months (after the injection).

In other experiments, if the animals exhibited strong restlessness the spinal cord was more severely injured by the needle stick, [myelitis developed leading to complete paraplegia]; under these circumstances, the animals were usually euthanized after 2–4 days.

In other cases although the animals appeared to be feeling well after the injection, they would die during the next 12–24 h.

Examination of the brain and spinal cord always revealed dispersion of cinnabar within the subarachnoid connective tissue and in the tissue of the pia mater. In ten out of twelve cases it had travelled to the skull where it preferentially accumulated at the base of the brain, specifically at the site where pia and arachnoid are separated from one another by larger meshed spaces. Beyond, it was observed on [the surface of] the entire brain and spinal nerves if their roots, were

[1] Band III. 2. S. 312.

[2] For the sake of brevity I assign herewith the (anatomically exclusively isolated) arachnoidea visceralis.