CEREBROSPINAL FLUID CHANNELS OF THE PIA MATER

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DISCOVERY OF THE CEREBROSPINAL FLUID CHANNELS
BY THE METHOD OF TRACHYSCOPY

In ordinary microtome sections through the pia mater of the human brain, against the background of the polygonal alveoli filling the subarachnoid space, certain large translucent areas differing in the shape of their outline are constantly found. Sometimes they are so large that they occupy the whole space between the arachnoid and pia mater. Like the alveoli, these spaces are bounded by membranes of arachnoid endothelium. It is impossible by the ordinary techniques to distinguish certain details which would allow their nature to be determined. At a cursory glance they give the impression of an artefact caused by tearing of some of the membranes with the joining of several small alveoli into one large alveolus. However, the careful study of the region of translucency clearly shows the complete absence of any tear of the membranes in this place. Another suggestion is that the large translucencies are the same alveoli but pathologically enlarged in volume as a result of stasis or other disturbances of the CSF circulation. This is how these spaces are seen by some pathologists, who regard them as the initial stage of formation of subarachnoid cysts. Whatever the case, the large translucencies among the alveoli have not attracted attention and have not been studied.

In this investigation the pia mater of the cerebral hemispheres from clinically healthy persons dying from acute trauma was studied. The brain with the pia mater was fixed in 10% neutral formalin, Zenker-formol, by the methods of Navashin—Krylov and Orth, and with osmium fixatives. The fixative was injected by the intravascular route and the brain, after removal, was also immersed in the fixative. Pieces cut from different parts of the brain were embedded in gelatin, celloidin, and paraffin wax, with careful observance of the stages involving the corresponding reagents. Absolute alcohol and xylol were not used but were replaced by methyl benzoate and oil of bergamot. Transverse, two-dimensional, and tangential sections of the pia mater, 10-80 μ thick, were stained with Hansen's iron trioxyhematein and counterstained with aniline blue, with Heidenhain's iron hematoxylin, and by Van Gieson's method and impregnated by the methods of Bielschowsky-Maresch, Zhukhin, and Gomori. The sections were mounted in Canada balsam. Regardless of the method of fixation, embedding, and staining, in all cases without exception large spaces surrounded by alveoli were present in the pia mater. It thus followed that these spaces were not artefacts and were not pathologically changed alveoli. They were cross sections through certain special types of space, possessing a normal membrane and distinct from the comparatively small spaces of alveoli (Fig. 1).

What are these spaces, what is their actual shape and topography in the pia mater, how is the wall of the spaces constructed, and what are their relationships with the alveoli? To answer these questions microtome sections, although irreplaceable for the study of individual structural elements, are completely unsuitable. They break up the single architecture of the pia into disconnected fragments, from which it is impossible to represent either the shape of the spaces or their relations with other formations of the pia. In the present investigation the decisive role was played by the trachyscopic method, by means of which three-dimensional microcopy of the whole thickness of the pia can be undertaken (Baron, 1949, 1963).

Disks 3 to 6 mm in thickness were cut from the fixed brain transversely, parallel with, and tangentially to the surface of the cerebral hemisphere. The disks included different parts of the cortex with the pia mater covering it. The side of the disk for microscopic examination was stained with Hansen's trioxyhematein, while the other side remained unstained. The whole disk was then counterstained with Scharlach by Herxheimer's method. The unstained side was stuck with gelatin to a piece of celluloid film and fixed in that position with formalin. The preparation thus mounted was cleared in a solution of glycerol and potassium acetate, the concentrations of which were gradually raised in the course of 4 to 6 days to 34% glycerol and 20% potassium acetate. The trachyscopic preparations were studied in a stereoscopic microscope, with facilities for visual observation and micromanipulation with fine instruments.


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Fig. 1. Cerebrospinal fluid canal in transverse section through pia mater. 1) Arachnoid mater; 2) subarachnoid alveoli; 3) CSF canal; 4) artery inside CSF canal; 5) brain. Hansen's iron trioxidememanin. Objective: Neupolar 30 mm.

Fig. 2. CSF canal of human pia mater. Trachyscopic brain preparation in tangential section. 1) CSF canal in pia mater; 2) artery inside CSF canal; 3) subarachnoid alveoli of pia mater; 4) vein among subarachnoid alveoli; 5) brain. Hansen's iron trioxidememanin. Objective: Neupolar 60 mm.

On first inspection of such preparations one is struck by the unexpected picture of a well developed network of canals, running at different levels of the pia mater among the surrounding masses of alveoli. Iron trioxidememanin stained the walls of the canals and clearly demonstrated the outlines of the network formed by them (Fig. 2). Contrary to the widespread belief, the subarachnoid space of the pia mater is not uniform everywhere, but can be subdivided into two completely different types of spaces: a system of canals and a system of alveoli. In the three-dimensional trachyscopic preparations it can be seen that the canals constitute a well formed network of tubes, whereas the alveoli are comparatively small spaces, surprisingly reminiscent in shape of honeycombs. In microtome sections the equivalents of the canals are large polymorphic spaces, whereas the cross sections of the alveoli consist of small and, usually, polygonal spaces (Fig. 1) (Baron and Maiorova, 1958a, b). The system of canals was studied experimentally and also examined in autopsy material from neurosurgical patients. These investigations, which are outside the scope of this paper, demonstrated conclusively the great importance of the canals both for the normal CSF circulation and in the pathogenesis of some diseases of the CNS. The almost total absence of any comprehensible references to the existence of a system of canals in the current literature (morphological, morbid anatomical, and clinical) is therefore extremely surprising.

HISTORY OF THE DISCOVERY OF THE CSF CANALS

There is no mention of them in the well-known monographs of Snesarev (1950), Smirnov (1935), Fridman (1957), and Shamburov (1954), in the general articles by Cushing (1914), Dandy (1919), and Weed (1938) or in textbooks specially devoted to the meninges and, in particular, the textbooks by Schaltenbrand and Dorn (1955), Millen and Woollam (1962), Davson (1967), etc. The suggestion made by some workers that they are lymphatics of the pia mater (Iwanow and Romodaowski, 1927; Galkin, 1930; Golman, 1931; Magnus and Jacobi, 1925a, b) has not been confirmed. The present authors in this matter share the critical views of Zhdanov (1948) on the works cited above. The laconic statements of some authors on "perivascular" (Weed, 1938), "periadventitial" (Magnus and Jacobi, 1925), and "extra-adventitial" spaces of the pial vessels contradict one another and are too general in character. The view of Kiss (1950) that there are special vessels which drain the CSF and empty directly into the pial veins, and so on, is definitely erroneous.

It is, however, unlikely that earlier investigators could have seen this regularly constructed system of canals without having doubts about their nature, and it was therefore necessary to turn to the literature of the