Agenesis of arachnoid granulations and its relationship to communicating hydrocephalus

Yezid Gutierrez, M.D., Ph.D., Reinhard L. Friede, M.D., and William J. Kaliney, M.D.

Institute of Pathology, Case Western Reserve University, Cleveland, Ohio

The authors discuss reabsorption of cerebrospinal fluid in relation to the post-mortem findings in two children, one with total agenesis of the Pacchionian system accompanied by hydrocephalus, and the other with a subtotal agenesis and no hydrocephalus. Case 1 is the only known documented case of total agenesis of the Pacchionian system and gives credence to the idea that an impaired reabsorption of cerebrospinal fluid at the level of the Pacchionian system is a cause of hydrocephalus. The patient in Case 2 showed only two small areas of arachnoid granulations containing a few flattened, microscopic villi of normal cellularity.

KEY WORDS arachnoid agenesis hydrocephalus cerebrospinal fluid absorption superior sagittal sinus

Several mechanisms involving overproduction, obstruction of flow, or decreased reabsorption of cerebrospinal fluid (CSF) have been implicated, practically and theoretically, as causes of hydrocephalus in man. Obstruction of flow, or interference with the circulation, of CSF in the ventricles or subarachnoid spaces is the most common cause, occurring in 99% of the cases, and is by far the best documented one. Overproduction of spinal fluid by non-neoplastic choroid plexuses has been poorly documented. Ford has reported a case with marked hypertrophy of the choroid plexus with absence of obstruction and an apparent normal reabsorption of CSF.

Hydrocephalus due to an impaired reabsorption of CSF by the Pacchionian system (the microscopic villi and the grossly discernible arachnoid granulations) has been considered mainly on theoretical grounds; clinical or pathological documentation is scant. Cushing reported that some of his cases of hydrocephalus were due to an absence of granulations or villi, but he did not report detailed pathological observations. Winkelman and Fay studied the Pacchionian system in 200 cases of central nervous system disease and found 14 that had "no fully matured granulations," three with hydrocephalus, but gave no precise assessment of the decrease in the number of granulations. Potter reported two siblings with external hydrocephalus and an unusual form of chondrodystrophy, thought to be associated with absent or nonfunctioning granulations. Gilles and Davidson reported two cases of communicating hydrocephalus.
with a marked diminution of arachnoid granulations.

The present report concerns two patients studied post mortem. One, a 5-year-old mentally retarded boy, had multiple congenital anomalies and a communicating hydrocephalus; there was no obstructive lesion, but there was total absence of granulations and villi. The other was a 7-year-old boy with congenital ventricular septal defect, who had no hydrocephalus but almost complete absence of the Pacchionian system.

Case Reports

Case 1

This 5-year-old boy had been confined to a nursing home all his life because of multiple congenital abnormalities. Neurological examinations had shown that he was deaf, blind, and mentally retarded; chromosomal studies were negative.

General autopsy findings revealed a poorly developed, emaciated child and multiple congenital anomalies. The head circumference was 45 cm (normal 51.5 cm ± 3 cm, 2 standard deviations (SD)²). Internal examination disclosed a large pelvic periproctodeal abscess, purulent pericarditis, and broncho pneumonia caused by Coli aerogenes group.

The brain weight was 1000 gm unfixed, compared to a normal of 1216 gm (± 293 gm, 2 SD) for a 5-year-old child. On section there was evidence of a moderate to marked communicating hydrocephalus (Fig. 1). Gross and microscopic examination did not show congenital or acquired obstruction. The ventricular surfaces were smooth with no signs of ependymitis. The aqueduct and cerebellar foramina were patent. The subarachnoid spaces did not have discernible anomalies or fibrosis. The sagittal and straight sinuses were patent with no bone abnormalities. Choroid plexuses were normal, with no changes suggesting overproduction of CSF. The inner surface of the dura mater covering the superior sagittal sinus was smooth except for scattered trabeculae of connective tissue. There were no traces of arachnoid granulations in the dura mater or in the leptomeninges near the interhemispheric fissure (Fig. 2).

The entire sinus and representative sections from the falk and its insertion at the tentorium were cut into blocks at 0.5-cm intervals. The blocks were processed, cut in sections 6 μ thick, stained with hematoxylin-eosin and studied for evidence of villi. Sections from the brain and spinal cord included representative samples with extensive coverage of ventricular walls and leptomeningeal spaces.

Microscopic examination of the walls of the superior sagittal sinus revealed no evidence of arachnoid villi. The sinus was an anomalous structure consisting of multiple vascular channels of variable sizes separated by sheets of dense fibrous connective tissues covered with endothelium, extending over the entire length of the superior sagittal sinus (Fig. 3). The falk was relatively short; the interior sagittal sinus was replaced by a dense venous plexus, especially evident toward the anterior portion of the falk. A sinus rectus was present. The ventricular walls and subarachnoid spaces revealed no significant anomalies, and there were no parenchymal lesions in the brain. There was no evidence of loss of brain substance or decreased cortical cellularity.

Case 2

This 7-year-old boy with congenital pulmonary hypertension and a ventricular septal defect was admitted for cardiac surgery and soon after surgery became cyanotic and tachypneic; he developed severe bradycardia and died 2 days later.

Postmortem examination revealed a well developed child with no external abnormalities. There was severe right ventricular hypertrophy and pulmonary vascular conges-
Arachnoid granulation agenesis with hydrocephalus

tion with hemorrhage. The middle lobe of the right lung was hypoplastic. Liver, spleen, and intestinal mucosa were hyperemic and congested.

The unfixed brain weight was 1465 gm, compared to a normal of 1269 gm (± 270 gm, 2 SD) for a 7-year-old child. On gross examination the dura mater detached easily from the brain, disclosing a smooth inner surface with a complete lack of visible Pacchionian granulations along the superior sagittal sinus or elsewhere (Fig. 4). Subarachnoid spaces were normal with no signs of fibrosis. The brain surface along the interhemispheric fissure was smooth, except for two patches, 3 × 3 mm in area, of arachnoid granulations located in the frontal and occipital lobes, lateral from the superior sagittal sinus (Fig. 5). Coronal brain sections showed no signs of hydrocephalus or other abnormalities, and the choroid plexuses were normal. The entire superior sagittal sinus, sinus rectus, and right and left sinuses were processed and studied as for Case 1. Multiple brain and spinal cord sections were also taken for histopathological examination. Microscopically, the walls of all sinuses and spinal cord leptomeninges revealed no villi. The two patches of arachnoid granulations on the brain surface were composed of flattened granulation tissue of a normal cellularity. A few small flattened villi were found in one of the samples from the dura mater just above these two areas of granulation.

Discussion

The Pacchionian granulations first become visible at 6 months of age; they are obvious by the age of 18 months and project well into the sagittal sinus. By the age of 3 to 4 years there are more than 50 large granulations. Villi are detected microscopically at birth, and they have been demonstrated in the 80-mm embryo. Both villi and granulations are seen microscopically as highly cellular invaginations of leptomeninges into the walls of the sinuses. Arachnoid granulations in man are principally distributed along the superior sagittal sinus, but they occur also along the transverse, cavernous, superior petrosal, sphenoparietal and straight sinuses and the middle cerebral veins. Hassin reported arachnoid granulations in the meninges of the spinal cord.

The absorption of CSF through the arachnoid granulations was demonstrated by Key and Retzius and confirmed by Weed, who postulated that filtration plays the main role. Some investigators have proposed the existence of channels within the granulations with valves which allow the passage of fluid and particulate matter up to 7.5 μ in diameter. However, electron microscopic studies in animals have not confirmed the existence of such channels.

Blockage of CSF reabsorption at the level of the Pacchionian system has been considered in the production of hydrocephalus in man. An acquired, acute blockage by erythrocytes entrapped in the granulations was reported for six patients with subarachnoid hemorrhage and elevated CSF pressure. Reports of congenital defects of the sagittal sinus responsible for hydrocephalus are few. Emery and Zachary reported two cases with communicating hydrocephalus and a bony ridge covering the sagittal sinus, but no evidence of obstruction; there was no mention of the Pacchionian system.

Brief reference to a congenital absence or diminution of granulations in children with communicating hydrocephalus and no evidence of obstruction was made by Cushing, Winkelman and Fay, and Potter. The extensive report of Gilles and Davidson documents two patients, aged 2 years 7 months and 3 years 2 months, with communicating hydrocephalus and diminution in the number of Pacchionian granulations; those granulations that were present were abnormal.

The above data imply a cause-effect relationship between diminution or abnor-
Y. Gutierrez, R. L. Friede and W. J. Kaliney

mality of the Pacchionian system and the production of hydrocephalus. It is commonly accepted that the granulations are the only sites for reabsorption of CSF. However, it has been suggested that the capillaries in the subarachnoid spaces are sites of production and reabsorption of CSF. Normal CSF renewal in man has been estimated to be 0.37% per minute. Johnson described a patient who was drained of a daily average of 200 to 300 ml of CSF for a period of 2 years; this amount was considered to be the excess fluid not being reabsorbed.

Our Case 1 is the only documented instance of complete absence of the Pacchionian system associated with moderate to marked hydrocephalus. The brain weight was within 2 standard deviations of normal, and there was no evidence of loss of brain substance or decreased cortical cellularity. Hydrocephalus ex vacuo cannot be excluded; however, it seems unlikely in view of the findings cited above. During the patient's 5 years of life CSF must have been produced at some unknown rate and reabsorption must have taken place at sites other than the Pacchionian system. Wislocki and Putnam showed that reabsorption in a hydrocephalic animal occurs in small amounts through the ependymal lining of the ventricles. Turner advanced the hypothesis that in newborns and infants CSF reabsorption occurs through routes other than the Pacchionian system. It seems, therefore, that if reabsorption of CSF occurred through an alternative route in Case 1, this route was not sufficient to handle all of the CSF produced, and this led to the development of hydrocephalus. Dandy estimated that one-fourth to one-fifth of the total CSF production is absorbed through the arachnoid granulations and the rest through the capillaries of the brain surface. However, we cannot infer from Case 1 whether reabsorption sites other than the arachnoid granulations operate in the normal individual.

The sagittal sinus in Case 1, though patent, was an anomalous multichanneled structure (Fig. 3) similar to that seen in the 18-mm embryo (40 to 42 days); this anomaly possibly corresponds to an arrest in development. With embryonic development the cribriform pattern becomes pronounced, but it disappears when the adult sagittal sinus morphology is acquired by the time the embryo has reached 80 mm (3 months).
The patient in Case 2 had subtotal agenesis of arachnoid granulations and villi, but CSF reabsorption was apparently sufficient since he did not develop hydrocephalus. The cases of hydrocephalus described by Gilles and Davidson had a diminution of arachnoid granulations and villi, and these were abnormal. Dandy demonstrated that young dogs did not develop hydrocephalus 4 to 6 months after surgical cutting of all brain attachments to the superior sagittal, transverse, and circular sinuses. Our Case 2, with an almost total lack of attachments between brain and meninges, appears to be nature's counterpart in man to the experiments described by Dandy. Although it is presumed that villi were still present in Dandy's animals in spite of the surgically severed attachments between brain and meninges, he did not elaborate on this.

Weed first advanced the concept that the villi in newborns, infants, and laboratory mammals are the equivalent of arachnoid granulations in children and adults. Turner proposed that CSF reabsorption in newborns and infants must occur through these microscopic villi, or through alternative routes, or through both, since gross granulations are not present at this early age. Quantitative studies on the normal development of the Pacchionian system of children and young adults are lacking, but Case 2 indicates that a subtotal agenesis of the system can coexist with a nonhydrocephalic brain. Whether only two areas of apparently normal arachnoid granulations are sufficient for complete CSF reabsorption, or whether alternative sites were operative in Case 2, cannot be ascertained.
References


This work was supported in part by NIH Grant 2TO-1 GUM 1784 from the National Institute of General Medical Sciences. Address reprint requests to: Yezid Gutierrez, M.D., Ph.D., Institute of Pathology, Case Western Reserve University, Cleveland, Ohio 44106.