The Turkish
Journal of Pediatrics

A Quarterly Publication

VOLUME : 7 APRIL 1965 NUMBER : 2

PRINCIPLES AND PRACTICES IN THE TREATMENT OF HYDROCEPHALUS

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Introduction

Hydrocephalus has been recognized as a clinical entity for over 3,000 years, but it is fair to say that as recently as 50 years ago the pathology of hydrocephalus was entirely unknown, no rational principles for its treatment had ever been proposed, and not a single authenticated case of a surgical cure of hydrocephalus had ever been reported.

Then in a brief period of 10 years, from 1912 to 1922, Walter Dandy, while still a resident trainee in general surgery, single-handedly, established the true pathology of hydrocephalus and devised rational methods for its treatment, based upon sound physiological and surgical principles (Figure 1).

A review of Dandy's early brilliant laboratory and clinical studies of hydrocephalus - which are little known to most neurosurgeons today - gives not only a fascinating profile of Dandy's mind and character, but also provides a valuable historical and scientific background for our present-day study of this problem.

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When Dandy set himself the task of finding a rational treatment for hydrocephalus, he immediately faced obstacles which would have stopped most men. For at that time nothing was known of the basic pathology of hydrocephalus; indeed, almost nothing was known of the normal physiology of cerebrospinal fluid. The site and manner of its formation, the very question of its circulation, and the site and manner of its resorption, were all highly controversial subjects upon which there was the widest disagreement.

It stands as an everlasting testimony to the quality of Dandy's mind and character that he recognized that he could never establish rational methods for treating hydrocephalus until he knew the basic facts of the normal physiology of cerebrospinal fluid and, after that, the nature of the pathological disturbances in the cerebrospinal fluid physiology which resulted in hydrocephalus.

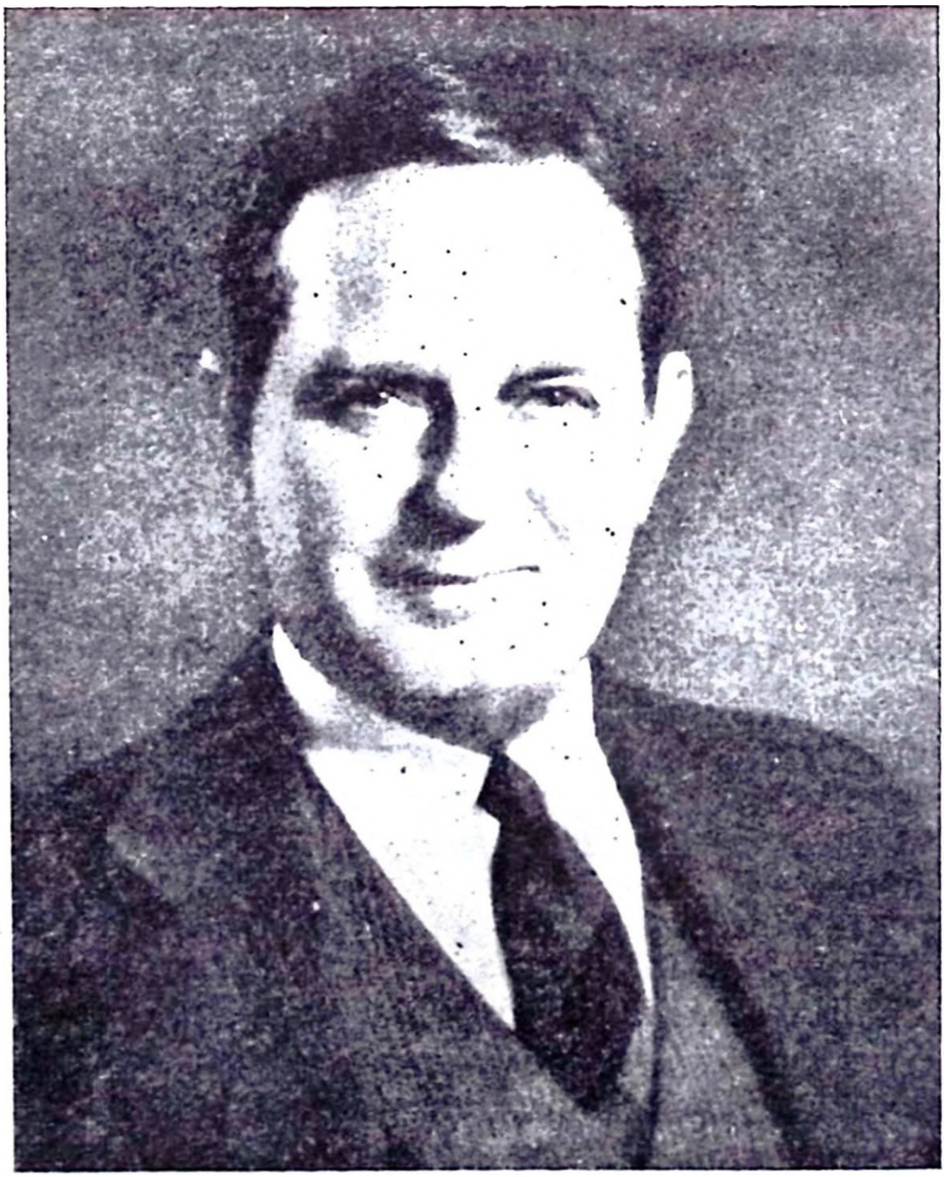

Figure 1. Walter E. Dandy, 1886 - 1946. Dandy was the first to establish the essential pathology of hydrocephalus and to propose rational principles for its treatment.

Contributions of Dandy to the Physiology of Cerebrospinal Fluid Circulation ond the Pathology of Hydrocephalus

Dandy began his tremendous task by first investigating the site and manner of the formation of cerebrospinal fluid. He started by producing, experimentally, in dogs obstructions of the aqueduct of Sylvius which resulted in marked distention of the lateral and third ventricles in these animals. [14, 15]

When he produced an obstruction of one foramen of Monro, that one ventricle became distended; but if he first removed the choroid plexus from that ventricle and then obstructed the foramen of Monro, distention of the ventricle did not occur; in fact, the ventricle shrank in size and remained permanently collapsed. [14 - 16] He thus established that the cerebrospinal fluid was formed within the ventricles, principally if not entirely, by the choroid plexuses.

Dandy next demonstrated the existence of an active cerebrospinal fluid circulation. He introduced phenolsulfonphthalein into the lateral ventricles of healthy dogs and found that the dye appeared in the subarachnoid system within 1 to 3 minutes. [14, 15] He thus proved the existence of a very rapid circulation of cerebrospinal fluid from the ventricular system into the subarachnoid system, a fact which until then had been vigorously denied by many anatomists and physiologists. But he also found that if the dye was introduced into the lateral ventricle of an animal in which the aqueduct of Sylvius had first been obstructed, the dye never appeared in the subarachnoid system. [14, 15] He thus established the fact that the only communication between the ventricular system and the subarachnoid system was by way of the aqueduct of Sylvius and the fourth ventricle, and thence into the cisterna magna and the subarachnoid system.

Dandy then investigated the site and manner of resorption of cerebrospinal fluid from the subarachnoid system back into the general blood stream. He found that phenolsulfonphthalein introduced into the subarachnoid system of dogs appeared in the blood stream within 1 to 3 minutes and in the urine within 6 to 8 minutes; and that within 2 hours up to 60 % of it could be recovered from the urine. [14, 15]

Dandy next sought to determine by what mechanism this rapid resorption of cerebrospinal fluid from the subarachnoid system back into the circulating blood was effected. *Did resorption take place through intermediate lymphatic channels lying within the subarachnoid spaces?* To answer this question Dandy exposed and cannulized the thoracic ducts in a series of dogs so that he could examine the lymph, drop by drop, as it came from the open ends of the cannulae. [14, 15] When phenolsulfonphthalein was introduced into the cisternae magnae of these animals, the dye appeared in the blood stream within 1 to 3 minutes; but it did not appear in the lymph, dripping from the open ends of the divided lymphatic ducts until nearly 60 minutes had elapsed, by which time 20 to 25 % of the dye had already been excreted in the urine. [11, 15] He thus proved that lymphatic channels, if present at all within the subarachnoid spaces, played no significant role in the return of cerebrospinal fluid from the subarachnoid system back into the blood stream.

Dandy then investigated the role played by the Pacchionian granulations in the return of cerebrospinal fluid from the subarachnoid spaces to the general blood stream.[14, 10] He attacked that problem in characteristic fashion by dividing all Pacchionian granulations bilaterally, in a series of dogs, [10] and then showing that phenolsulfonphathalein introduced into the subarachnoid spaces of those dogs appeared in the blood stream after exactly the same time interval as in dogs with all Pacchionian granulations intact; and that it was subsequently recovered from the urine after exactly the same time interval and in exactly the same amounts as in animals with all Pacchionian granulations intact. [10] He thus proved that Pacchionian granulations played no essential role in the return of cerebrospinal fluid from the subarachnoid system back to the general blood stream.

By thus excluding any role played by lymphatics or by Pacchionian granulations, *Dandy proved that resorption of cerebrospinal fluid from the arachnoid system back into the general blood stream must take place directly through the rich capillary beds lining the subarachnoid spaces-a* mechanism which he had already proven to be true for the absorption of fluids from the pleural and abdominal cavities. [14, 10]

Having established the essential features of the cerebrospinal fluid circulation in laboratory animals, *Dandy next transferred his*

studies to human subjects. Fortunately, in the children's wards of the Johns Hopkins Hospital he almost immediately had the exceptional opportunity of studying 11 hydrocephalic infants.

He introduced phenolsulfonphthalein into the lateral ventricles of these 11 children, and he found that in 4 of them the dye appeared in the lumbar subarachnoid sac within 1 to 20 minutes, but in the other 7 children the dye did not appear in the lumbar sac until 1 to 4 hours had elapsed.[14, 15]

This was a critical observation, unlike anything which Dandy had encountered in his laboratory animals, the profound significance of which might have been missed by a mind less keen than his. But Dandy recognized immediately that in these two groups of children there must exist two quite different pathologic mechanisms for the production of hydrocephalus. In one group, the hydrocephalus was obviously due to interference with the free passage of cerebrospinal fluid from the ventricular into the subarachnoid system where it could be readily absorbed by natural physiological processes; [8] but in the other, the hydrocephalus must be due to poor absorption of cerebrospinal fluid from the subarachnoid system back into the blood stream. [7] *Here originated the pathological concepts of obstructive as differentiated from non-obstructive (communicating) hydrocephalus.*[14, 15, 6, 7, 8]

Dandy studied the absorption of cerebrospinal fluid from the subarachnoid systems in these two groups of children. He found that when phenolsulfonphthalein was introduced into the lumbar subarachnoid sac of the infants with obstructive hydrocephalus, 30 % of the dye was excreted in the urine during a 2 hour period; but when the dye was introduced into the lumbar subarachnoid sac of the children with nonobstructive hydrocephalus, only 10% of the dye was excreted in the urine during an equal period of time. [15, 6, 7] He thus demonstrated that nonobstructive (or communicating) hydrocephalus was due to reduced rate of resorption of cerebrospinal fluid from the subarachnoid system, and he expressed the opinion that this was probably due to structural abnormalities of the subarachnoid spaces of these infants, either congenital mal-development or partial obliteration by some form of adhesive arachnoiditis.[6]

Dandy returned once more to his laboratory, and there, in dogs, produced adhesions in the basilar subarachnoid cisterns which re-

sulted in the development of true communicating hydrocephalus in those animals. [7]

Dandy now sought actual pathological confirmation in humans of his postulates. Eventually he obtained autopsies upon 5 of the children whom he had diagnosed on clinical grounds as having obstructive hydrocephalus; and in each of these was able to demonstrate obstructive lesions within the ventricles.[15, 8] Unfortunately, he was unable to obtain postmortem examination of a single one of the infants which he had studied and diagnosed, clinically, as having communicating hydrocephalus. However, he was eventually able to study the brain of an infant which had died elsewhere of advanced hydrocephalus; and in that brain he did find that the two lateral ventricles, the third ventricle, the aqueduct of Sylvius, the fourth ventricle and the cisterna magna were all widely dilated, without any obstruction whatever of the ventricles, per se, but with almost complete obliteration of the basal subarachnoid cisterns by dense adhesive arachnoiditis.[6]

The correctness of Dandy's original theses regarding the pathology of obstructive and nonobstructive hydrocephalus was fully corroborated 30 years later by Dorothy Russell in her classic pathological studies of human hydrocephalic brains.[64]

Principles For Treatment Of Hydrocephalus Proposed By Dandy

Having established the pathology of hydrocephalus, Dandy at last undertook to develop sound surgical principles for its treatment.

First, determine the type of hydrocephalus, obstructive or nonobstructive (communicating), by means of the simple dye test described by Dandy.[15, 6, 7, 8]

For the treatment of obstructive hydrocephalus he laid down the basic principle that the cerebrospinal fluid from the obstructed ventricles must be drained into the subarachnoid system, whence it could be absorbed and returned to the general blood stream by natural physiological processes. [9] To accomplish this he devised third ventriculostomy, an operation by which a surgical opening was made through the thinned-out floor of the third ventricle, thereby establishing free communication between the third ventricle and the large interpeduncular subarachnoid cistern. Third ventriculostomy fulfilled in a nearly ideal manner Dandy's theoretical re-

quirement for the rational treatment of obstructive hydrocephalus in that (1) the intraventricular fluid from both lateral and third ventricles was drained directly into a large subarachnoid space, the cisterna interpeduncularis; (2) the floor of the third ventricle through which the opening was made was paper thin, which minimized chances of closure; (3) the interpeduncular cistern was prevented from collapsing by the cerebral peduncles on each side of it; and (4) from the interpeduncular cistern, the cerebrospinal fluid was immediately distributed out over the surfaces of the cerebral hemisphere whence it could be absorbed by natural physiologic processes.

For the treatment of communicating hydrocephalus, Dandy proposed destruction of the choroid plexuses within the lateral ventricles [6] on the principle of reducing the amount of cerebrospinal fluid formed to an amount which the malfunctioning subarachnoid system could absorb.

These two operations, it will be noted, were based on the simplest physiological and surgical principles, and in particular they avoided the use of any rubber, plastic or metallic tubes or valves.

Operations not Requiring Mechanical Tubes or Valves

A. *Clinical experiences with third ventriculostomy in the treatment of obstructive hydrocephalus.* Dandy first described third ventriculostomy in 1922, and at that time reported that he had performed the operation upon 6 children; but, to use his own words, he «made no claim for its success.» Although sound in principle, Dandy's original operation was for several reasons technically unsatisfactory, and he eventually abandoned it. In 1933,[11] however, he described a new technique for third ventriculostomy performed through a lateral, or subtemporal, route, the general features of which are shown in Figure 2. Dandy cited no case reports and gave no statistical results at that time, and for the next 12 years maintained a curious silence on this entire subject. In 1945,[13] however, he did report 92 cases of third ventriculostomy operated upon by him through the lateral, or subtemporal, route, with a 12 % mortality and with arrest of hydrocephalus in 50 % of the cases, the average survival time being 7 years. Subsequently Voris [53] reported 10 cases which he had operated upon using Dandy's lateral technique, with no operative deaths and with arrest of hydrocephalus in all 10 cases followed for an average of 2 years.

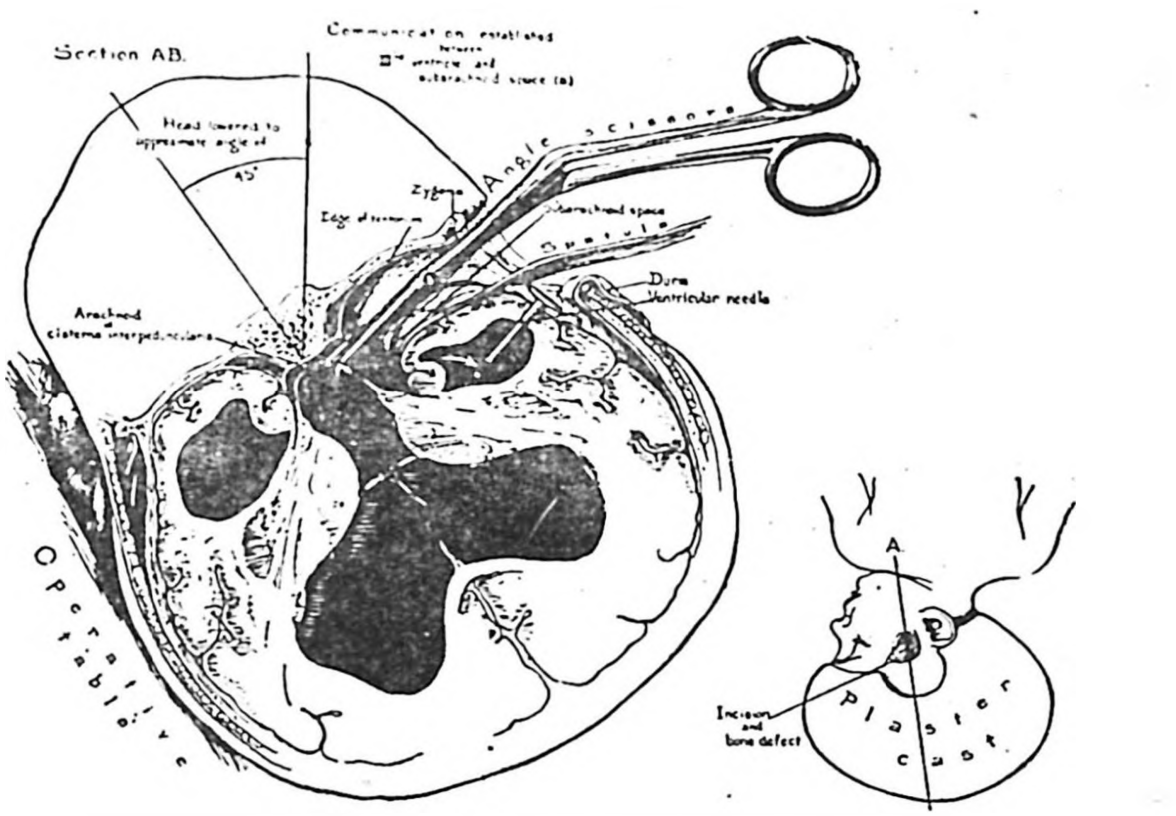

Figure 2. Third ventriculostomy by the temporal route. Technique of Dandy. (Reproduced from Lewis 'System of Surgery' vol. 12, 1933, with permission of the publisher.)

In August 1936, Stookey and Scarff described a new technique for third ventriculostomy which was performed through an anterior, or subfrontal, approach, namely, puncture of the lamina terminalis and floor of the third ventricle.[77] The essential features of that operation are indicated in Figure 3, reproduced from their original 1936 publication. In that report were cited 6 patients upon whom the operation had been performed, with one operative death, one failure to arrest hydrocephalus, and 4 patients living and well with hydrocephalus arrested for from 6 months to 3 years after operation. Subsequently, in 1951, Scarff described in further detail the operative technique of the punctures (Figure 4)* and reported 34 cases with a 15 % operative mortality and with arrest of hydrocephalus in 56 % of cases.[70]

Three *months* after Stookey and Scarff had published their description of puncture of the lamina terminalis and floor of the third ventricle, and 3 *years* after they had performed their first successful operation by this technique, Lhermitte, de Martel and Guillaume,[37] reported a single case of a man with obstructive

* An even more fully illustrated description of the operative technique is currently in press.[74]

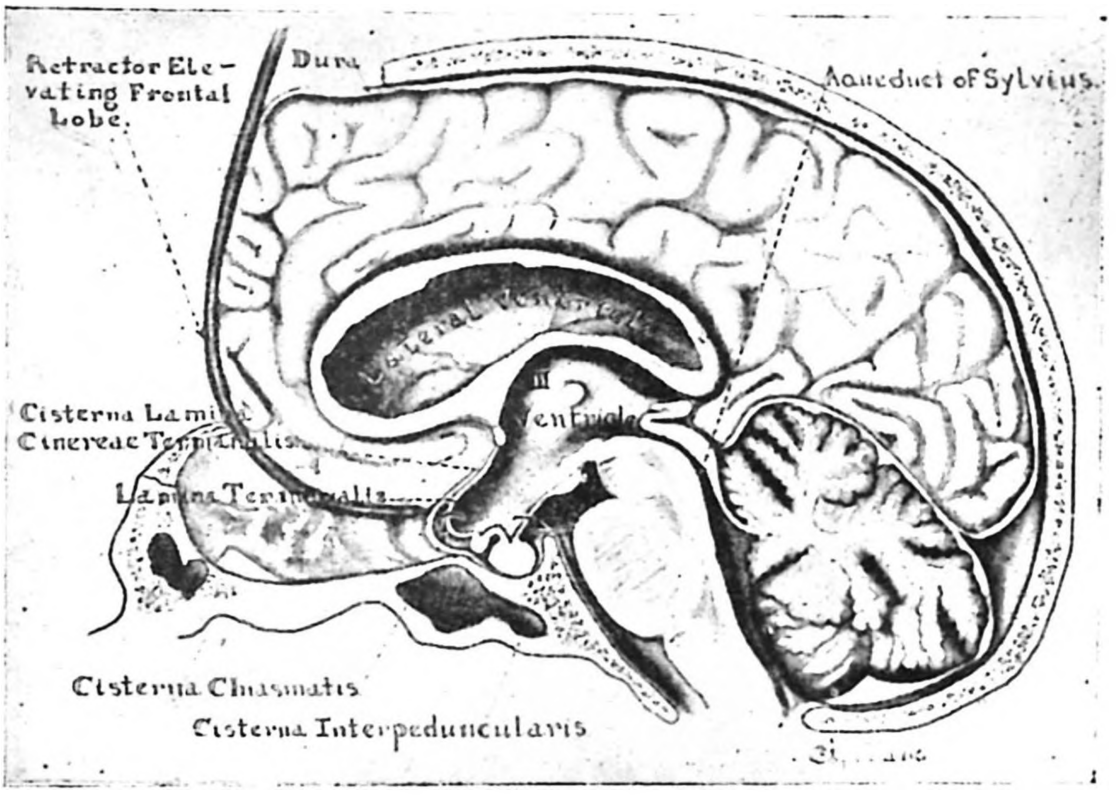

Figure 3. Third ventriculostomy by the frontal route. Puncture of the lamina terminalis and floor of the third ventricle. Technique of Stookey and Scarff. Anatomical structures involved. (Reproduced from the **Bulletin of the Neurological Institute of New York, 1936.),**

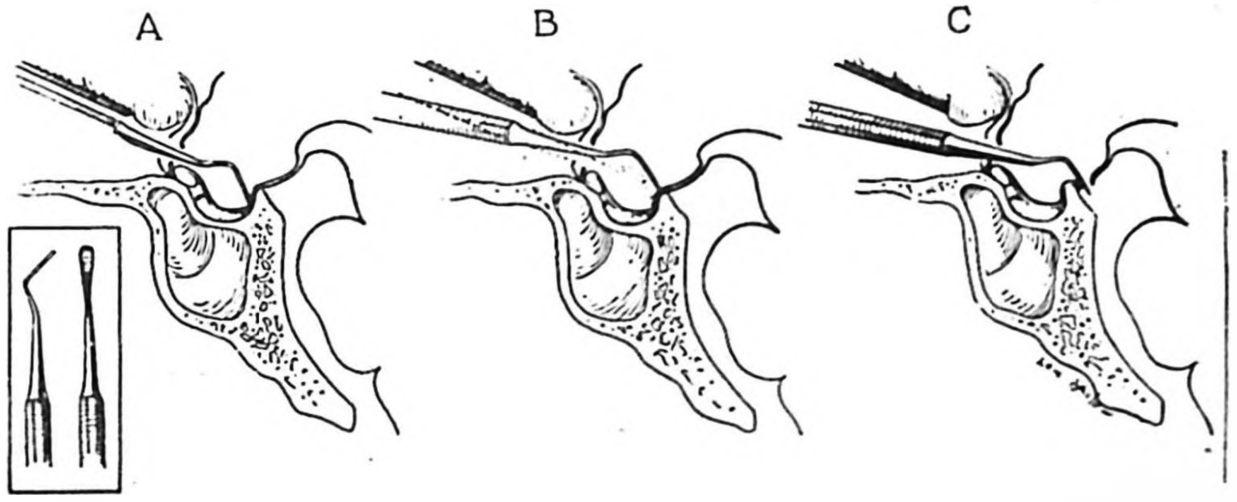

Figure 4. Third ventriculostomy by the frontal route. Puncture of the lamina terminalis and floor of the third ventricle. Technique of Stookey and Scarff. Technical detail of puncture. (Reproduced from an article by Scarff in the **Journal of Neurosurgery,** 1951 with permission of the editor.)

hydrocephalus, in which de Martel, just a month before, had successfully punctured the lamina terminalis — to which operation he gave the name «section de la lame sus-optique.»

Since 1936, 425 cases of puncture of the lamina terminalis, with or without the additional puncture of the floor of the third ventricle, have been reported by 11 neurosurgeons [13 - 20, 73] (Table I), with an operative mortality of approximately

TABLE I

SUMMARY OF ALL REPORTED CASES OF THIRD VENTRICULOSTOMY

Surgeon	Number of Cases	Operative Mortality	Initial Success	Follow-up (Average)
Dandy	92	12%	50%	7½ yrs.
Stookey and Scarff	34	15%	54%	2½ yrs.
Lhermitte et al.	1	0	100%	15 yrs.
Wertheimer and Mansuy	3	33%	66%	5 mos.
Pennybacker	5	20%	80%	14 mos.
Guillaume et al.	230	2%	90%	7 yrs.
White and Michelsen	11	18%	46%	1 yr.
Tolosa	26	25%	50%	2 yrs.
Krayenbuhl	17	17%	60%	5 yrs.
Voris	10	0	100%	2 yrs.
Fasiani	72	20%	70%	2 yrs.
Morello and Migliavacca	28	3%	75%	5 yrs.
TOTALS	529 cases	15%	70%	5 yrs.

15 % and with arrest of hydrocephalus in approximately 70 % of cases, followed for an average period of 5 years. The most recent and the best series of cases is that reported in 1959 by Morello and Migliavacca,[16] who reported 28 consecutive cases of benign aqueduct stenosis, with a mortality of only 3 % and with arrest of hydrocephalus in 75 % of the cases followed for an average of 5 years.

A detailed review and analysis of all of these published cases of third ventriculostomy was prepared and published by this writer in 1963.[73]

B. *Clinical experience with choroid plexectomy in the treatment of nonobstructive hydrocephalus.* The first surgical extirpation of choroid plexuses from the lateral ventricles was performed by Dandy in 1918;[6] but despite the fact that the rationale of his operation was sound, his technique was a poor one (Figure 5). The basic defect in it lay in the fact that in order to surgically avulse the choroid plexuses Dandy had to empty the ventricles of cerebrospinal fluid. This allowed the thinned-out wall of the ventricles to col-

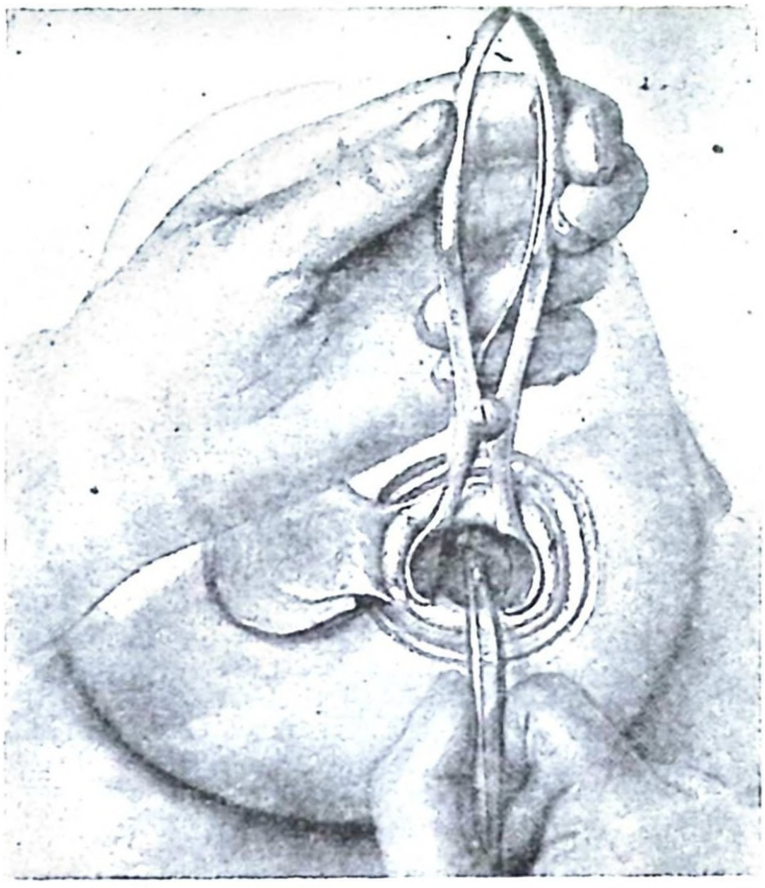

Figure 5. Extirpation of the choroid plexuses by the open surgical technique of Dandy (1918). The ventricles were first emptied of cerebrospinal fluid, after which the plexuses were grasped by forceps and avulsed. Although this operation was sound in principle, in practice it was technically a poor one. The evacuation of the fluid from the ventricles was followed by collapse of the thinned-out cerebral cortices and by severe shock, and resulted in an operative mortality of 75 % in Dandy's original series. (Reproduced with permission of the editors of the Annals of Surgery.)

lapse, which in turn caused profound shock to the patients. Of the 4 infants operated upon by him in 1918, 3 died immediately after operation although one lived for many years therafter.

The high operative mortality and low percentage of success attending open surgical excision of the choroid plexuses was subsequently confirmed by the experiences of Sachs in 1942 [65] and of Davidoff in 1948. [16]

The value, however, of choroid plexectomy by endoscopic cauterization was clearly demonstrated by Putnam [59] in 1934 and by Scarff in 1935 - 6. [67, 68] The ventriculoscope designed by Putnam and that designed by Scarff (Figure 6) differed considerably in construction, but the surgical principle behind them was the same, namely, destruction of the choroid plexuses without allowing escape of cerebrospinal fluid from the ventricles and the subsequent collap-

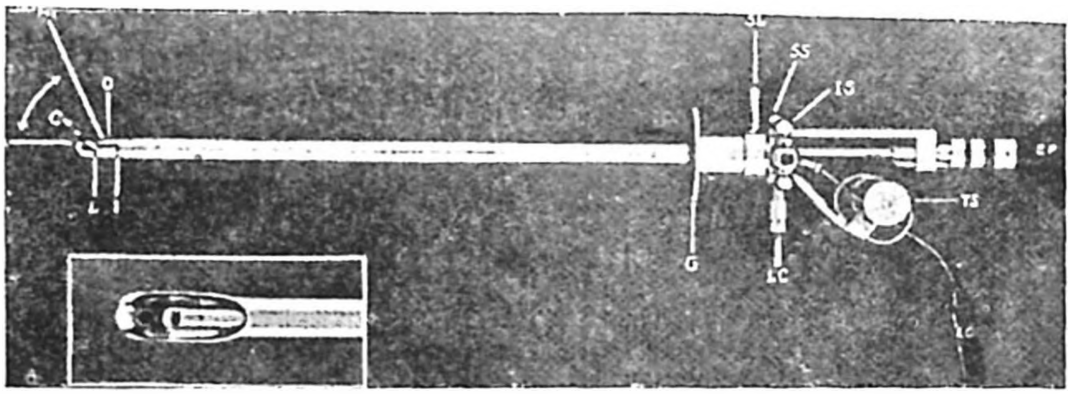

Figure 6. Ventriculoscope developed by Scarff in 1936. The lens system permits both forward and oblique vision as indicated by the lines OA and OA-1. The cautery tip (C) can be advanced or retracted as desired by means of the thumbscrews (TS). Irrigation of the operative field is controlled by a stopcock (IS). LC is a lighting connection leading to a battery box. EC is a connection between the cautery and the endothermy machine. A new model just developed (1964) has a powerful light source, separate from the ventriculoscope, the light being conducted from source to the ventriculoscope by means of a flexible fibreglass light cord. This provides 5 times more light within the ventricles and, in addition, eliminates failure of light during cauterization of the plexuses.

se of the thinned out cortex (Figure 7). This greatly decreased the operative shock and operative mortality which had attended open surgical excision.

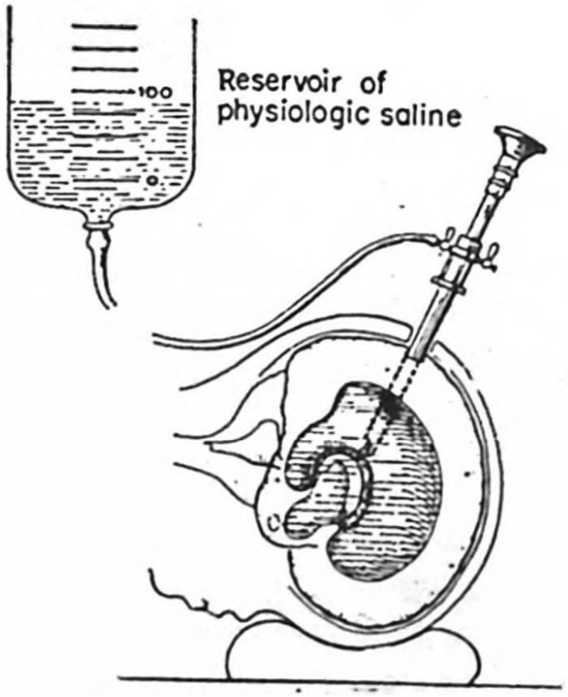

Figure 7. Endoscopic cauterization of the choroid plexuses. Technique of Scarff. Intraventricular pressure is maintained continuously throughout the operation. This prevents collapse of the thinned-out cortex and minimizes operative shock. As a result, the operative mortality in Scarff's second series of cases was only 5%.

In 1943 Putnam [61] published a long-term review of 42 cases treated by him in which there was an operative mortality of 25 % and arrest of hydrocephalus in 40% of cases which he had followed for an average of 3 years.

In 1942 Scarff [69] reported a series of 20 consecutive cases in which he had performed cauterization of the choroid plexuses, and in 1952 [71] Scarff reported a second series of 19 children.

In 1959 [72] and 1963 [73] Scarff published long-term follow-up studies of these 39 children with fully documented case histories which are given in condensed form in Table II.

TABLE II

SUMMARY OF ALL REPORTED CASES OF ENDOSCOPIC CAUTERIZATION OF CHOROID PLEXUS

Surgeon	Number of Cases	Operative Mortality	Initial Success	Follow-up (Average)
Putnam	42	25%	40%	3 yrs.
Scarff (1942 series)	20	15%	50%	16 yrs.
Scarff (1952 series)	19	5%	80%	12 yrs.
Feld	10	0	90%	1½ yrs.*
TOTALS	91 cases	15%	65%	8 yrs.

* Follow-up terminated by death of Dr. Feld.

In Scarff's first (1942) series of cases (Table II) there was an operative mortality of 15%, with successful arrest of hydrocephalus in 50% of the children followed for an average of 16 years. In his second (1952) series of 19 cases (Table II) the operative mortality was only 5 %, with successful arrest of hydrocephalus in 80 % of the children, followed for an average of 12 years.

In 1956 Feld [21] described a ventriculoscope of his own design and in 1957 [22] reported 14 cases in which he had performed endoscopic cauterization of the choroid plexuses, with no operative mortality, and with successful arrest of hydrocephalus in 65 % of his cases, all living and well 2 months to 27 months after operation, at the time of Dr. Feld's tragic death.

A total, therefore, of 91 cases of endoscopic cauterization of the choroid plexuses has been reported in the literature, with an overall operative mortality of 15 %, and with arrest of hydrocephalus in 65 % of the cases followed for an average of 8 years (Table II).

A condensed summary of clinical results obtained with operations for the relief of hydrocephalus based on Dandy's simple surgical principles, not requiring the use of mechanical tubes and valves, as reported in the literature between 1918 and 1963, [73] is presented in Table IV. There were 529 third ventriculostomies and 91 endoscopic cauterizations of the choroid plexuses. The combined operative mortality for these 2 groups of 620 cases was approximately 15%, with arrest of hydrocephalus in approximately 65% of cases followed for an average of 7½ years (Table IV).

Shunting Operations Requiring Mechanical Tubes and Valves

Since World War II there has occurred a vigorous renaissance of interest in hydrocephalus, and many new and ingenious operations have been devised for its treatment. None of these have followed the simple physiological and surgical principles proposed by Dandy. Instead, all of them use mechanical tubes to convey the cerebrospinal fluid from distended ventricles to other ventricles, or subarachnoid spaces, or to remote viscera, body cavities or tissue spaces. These operations are the so-called cerebrospinal fluid «shunts» which are so widely used in the current practice of neurosurgery.

The number and variety of these shunts are great (Table III). There are 7 types of intracranial shunts [2, 8, 20, 24, 32, 35, 36, 80, 81, 82, 73]; 2 types of ventriculo-cardiac shunts [1, 4, 50, 56, 57, 60, 73]; a ventriculopleural shunt [63]; 3 types of ventriculoperitoneal shunts [5, 31, 38, 55, 75, 73]; 2 types of ureteral shunts [39, 40, 42]; as well as shunts to the gall bladder [76, 73], fallopian tube [29, 73], small intestine [53, 73], and epidural tissue spaces [25, 28, 73] - a total of more than 20 different types of shunts.

Unfortunately, space does not here permit illustrations of these various operative techniques nor detailed reviews of the results reported by the various authors for each type of shunting operation. However, all of this information can be found in an exhaustive review of the subject published by Scarff in 1963. [73]

In Table III is given a greatly condensed summary of the number of cases reported for each type of shunt, the overall operative mortality (approximate), the overall percentage (approximate) of initial successes in arresting hydrocephalus, and the overall average (approximate) follow-up period reported.

TABLE III

SUMMARY OF ALL REPORTED CASES OF CEREBROSPINAL FLUID SHUNTS

Surgeon	Number of Cases	Operative Mortality	Initial Success	Follow-up (Average)
Intracranial 7 types	254	25%	60%	2 yrs.
Cardiac 2 types	345	6%	62%	2½ yrs.
Pleural 1 type	108	8%	53%	1½ yrs.
Peritoneal 3 types	230	13%	55%	2 yrs.
Ureteral 2 types	108	1%	65%	3½ yrs.
Miscellaneous to gall bladder to fallopian tube to ileum to thoracic duct to salivary duct to tissue spaces	42	3%	65%	1 yr.
TOTALS	1,087 cases	10%	60%	2 yrs.

TABLE IV

OPERATIVE MORTALITY AND INITIAL SUCCESS

	Number of Cases	Operative Mortality	Initial Success
PHYSIOLOGIC OPERATIONS			
Third ventriculostomy	529	15%	70%
Cauterization choroid plexus	91	15%	60%
TOTALS	620 cases	15%	65%
SHUNTS			
Intracranial	254	25%	60%
Cardiac	345	6%	62%
Pleural	108	8%	53%
Peritoneal	230	13%	55%
Ureteral	108	1%	65%
Miscellaneous	42	3%	65%
TOTALS	1,087 cases	10%	60%

Comparison of Results Operations not Requiring Mechanical Tubes Versus Operations Requiring Mechanical Tubes

In an effort to determine, so far as possible, which methods of treatment yielded the best results, the present writer in 1963 [73] carried out an exhaustive review of 1707 cases of hydrocephalus reported in the world literature which had been treated by various types of operation with a critical analysis of the results of surgery reported for each type of operation by the authors.

Of the cases reviewed, 620 had been operated upon by the so-called «physiological» operations, following the principles proposed by Dandy not requiring the use of mechanical tubes or valves; 530 of these were cases of obstructive hydrocephalus treated by third ventriculostomy; and 90 were cases of non-obstructive (communicating) hydrocephalus treated by endoscopic cauterization of the choroid plexuses. The other 1087 cases reviewed had been operated upon by one or the other of the various «shunting» operations requiring the use of mechanical tubes or valves.

The results of these various operations, as reported by the different authors, can be evaluated in terms of : (1) operative mortality, (2) initial success in arresting hydrocephalus, (3) incidence of late, serious complications, and (4) survival periods.

The *operative mortality* was found to be essentially the same for those operations not requiring mechanical tubes and for the operations requiring mechanical tubes or valves, namely, 10 % - 15 % (Table IV).

The *initial successes* in arresting hydrocephalus were also found to be essentially the same for the two large groups of cases, namely, 60 % - 65 % (Table IV).

The *incidence of late, serious complications* causing death of the patient, requiring re-operation, or otherwise seriously threatening the life of the patient, was found to be 15 to 20 times greater after operations requiring the use of mechanical tubes or valves (57 % approximately) than after operations not requiring the use of mechanical tubes or valves (2.5 % approximately) (Table V).

TABLE V

LATE COMPLICATIONS

	Occlusion Shunts	Sepsis	Miscellaneous	Total (Approx.)
PHYSIOLOGIC OPERATIONS 620 cases				
Third ventriculostomy	0	0	2%	2%
Cauterization choroid plexus	0	0	3%	3%
TOTALS	0	0	2.5%	2.5%
SHUNTS 1,087 cases				
Intracranial	50%	0	0	50%
Cardiac	28%	12% (septicemia)	6% (thrombosis superior vena cava)	46%
Pleural	100%	0	0	100%
Peritoneal	58%	0	0	58%
Ureteral	16%	8% (meningitis)	20% (metabolic crises)	44%
Miscellaneous	50%	0	0	50%
TOTALS	50%	3%	3.5%	57%

The *survival periods,* at least the reported periods of follow-up observations, were on the average considerably longer for the cases treated by operations not requiring the use of mechanical tubes or valves than after operations requiring the use of mechanical tubes or valves. The overall average for the former group was 6 1/2 years and for the latter group only 2 years. Furthermore, five-year survivals (follow-up observations) were reported in 30 % of the former group and in only 2 % of the latter group (Table VI).

Discussion

Every type of shunt reported in the literature developed serious, late complications sufficient to cause the death of the patient, require re-operation, or to otherwise seriously threaten the life of the patient. The incidence of these complications varied with the type of shunt, from a low of 44 % with ureteral shunts, to a high of 100 % with pleural shunts; but the overall incidence of late seri-

TABLE VI

FOLLOW-UP PERIODS
(Approximations)

	Average	Over 5 Years
PHYSIOLOGIC OPERATIONS		
Cauterization choroid plexus	5 yrs.	157 cases
Third ventriculostomy	8 yrs.	26 cases
TOTALS (620 cases)	6½ yrs.	183 cases (30% approx.)
SHUNTS		
Intracranial	2 yrs.	14 cases (Torkildsen)
Cardiac	2½ yrs.	0
Pleural	1½ yrs.	0
Peritoneal	2 yrs.	0
Ureteral	3½ yrs.	11 cases (Matson)
Miscellaneous	1 yr.	0
TOTALS (1,087 cases)	2 yrs.	20 cases (2% approx.)

ous complications for all of the 1087 cases of cerebrospinal fluid shunts reported in the literature up to 1963 was approximately 57 %[73] (Table V).

In striking contrast to this figure, the overall incidence of serious, late complications which followed third ventriculostomy and endoscopic cauterization of the choroid plexuses was only 2.5 % (approximately) [73] (Table V).

The reasons for the high incidence of severe, late complications following the various «shunting» operations are easy to understand. Cerebrospinal fluid is laden with proteins and minerals which gradually are deposited as particulate matter on the inner surfaces of the tubes and valves of the shunts, eventually causing their obstruction or malfunction. Moreover, whenever any foreign body of rubber, plastic, glass or metal, such as is used for shunt tubes or valves, is implanted within the human body, there is immediately set up a local inflammatory reaction by the tissues of the host in contact with the foreign body, resulting in the immediate proliferation of granulation tissue, and ultimately in the formation of fibrous scar tissue about the foreign body, which tends to occlude one end or both ends of the shunt. Obstruction of the shunt tubing was the most frequently reported complication, and it occurred with all types of shunts in approximately 50 % of the cases. [73] The cardiac shunts, in addition to obstruction of the shunt tubes and valves common to all types of shunts, had their own unqiue complications,

namely, thrombosis of the superior vena cava in 6 % of cases, and bacterial endocarditis leading to septicemia in another 12 %. [73, 50] In addition, the natural growth of all children necessitates the elective replacement of the shunt tube leading from cerebral ventricle to heart by a longer tube every year or two, in every case of cardiac shunt performed in a child. [50] The ureteral shunts also had, in addition to obstruction of the shunting tubes, their own peculiar complications in the form of meningitis of urinary tract origin in 8% of cases; and the continuous loss of body electrolytes which produced a unique and serious threat to life in 20 % of all cases. [73, 42, 43] All of these complications, it must be stressed, are inherent in the shunts and cannot be eliminated by technical refinements.

The reasons for the low incidence of late complications following the simple physiological (non-shunting) operations proposed by Dandy, are equally simple. With third ventriculostomy, if the surgical openings made through the greatly thinned-out lamina terminalis and floor of the third ventricle (Figure 8) remain open for as long as 2 weeks, the edges of the openings will, by that time,

Figure 8. The attenuated floor of the third ventricle in a typical case of obstructive hydrocephalus. The hypothalamic nuclei have either been displaced laterally or entirely destroyed by the pressure of the intraventricular fluid, which explains the absence of hypothalamic symptoms following puncture of the floor of the third ventricle. (Scarff, 1951.) (Reproduced with permission of the editor of the **Journal of Neurosurgery.**)

have become completely epithelialized by the meeting of the ependyma from the third ventricle with the pia mater from the subarachnoid cisterns [73, 85, 86] (Figure 9); and once the edges of these openings have been thus epithelialized the ventriculostomy will never close [73, 77, 87] (Figure 10). Similarly, when choroid plex-

uses have once been destroyed, they will never re-form; and if enough of the plexuses have been destroyed initially to reduce the amount of cerebrospinal fluid formed within the ventricles to that which can be absorbed from the subarachnoid spaces, the hydrocephalus will remain permanently arrested.

Figure 9. Lamina terminalis six weeks after puncture. The edges of the stoma are already completely epithelialized by union of the ependyma and pia (White, 1939). (Reproduced with permission of the author and of the editor of the Yale Journal of Biology and Medicine.)

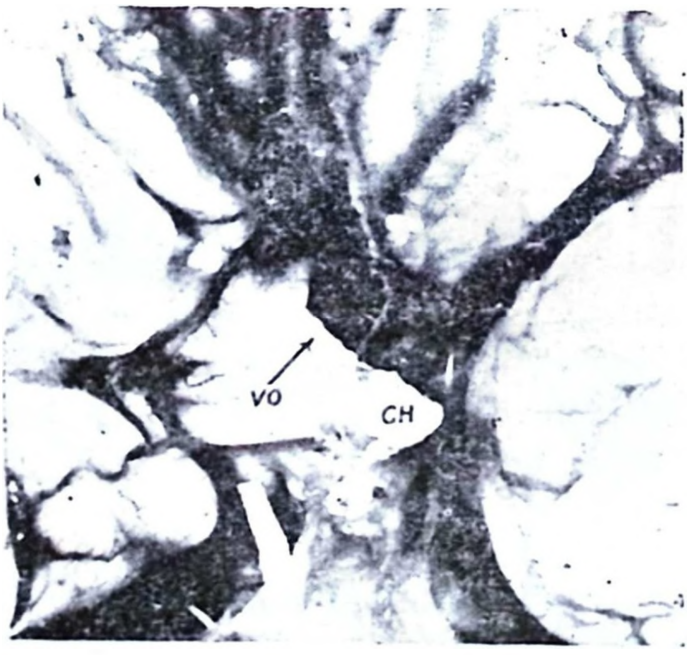

Figure 10. Lamina terminalis nine months after puncture. The epithelialized edges of the stoma still show no tendency to close (Stookey and Scraff, 1936). (Reproduced from the **Bulletin of the Neurological Institute of New York.**)

Summary

The evidence, therefore, indicates that if not only operative mortality and initial success are considered but also, and more important, the incidence of late, serious complications and the duration of survival periods, the results obtained with third ventriculostomy and endoscopic cauterization of the choroid plexuses are considerably better than those obtained with any of the various shunting operations which require the use of mechanical tubes and valves.

This historical and critical review of the surgical treatment of hydrocephalus is presented in the hope that it may re-awaken interest in the physiological and surgical *principles* for the treatment of hydrocephalus proposed by Dandy over 40 years ago, and may result in the wider use of third ventriculostomy and endoscopic cauterization of the choroid plexuses in the future *practice* of neurosurgery.

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