J. Neurol. Neurosurg. Psychiat., 1963, 26, 1

Treatment of hydrocephalus: an historical and critical review of methods and results

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ANATOMICAL, PHYSIOLOGICAL, AND PATHOLOGICAL CONSIDERATIONS OF THE BASIC PRINCIPLES OF THERAPY

Hydrocephalus has been recognized as a clinical and pathological entity since the days of Hippocrates; but it is fair to say that as late as the beginning of the present century the pathology of this condition was obscure, no rational methods of therapy had been developed, and, so far as I can determine, no successful surgical treatment of hydrocephalus had ever been achieved. Then between 1913 and 1929, Walter Dandy, almost single-handed, established the true pathology of hydrocephalus and developed sound physiological and surgical principles for its treatment. Dandy and Blackfan (1913, 1914; Dandy, 1919, 1929) first proved that the cerebrospinal fluid is formed within the ventricles, principally if not entirely by the choroid plexuses; that approximately 800 to 1,000 ml. of cerebrospinal fluid is formed each 24 hours within the ventricles; that the only escape of the cerebrospinal fluid from the lateral and third ventricles is by way of the aqueduct of Sylvius, the fourth ventricle, into the cisterna magna, and thence into the other subarachnoid spaces; that the circulation of cerebrospinal fluid from the lateral ventricles to the subarachnoid spaces normally requires only two to three minutes; that the absorption of the cerebrospinal fluid back into the blood stream is from the subarachnoid spaces directly into the rich capillary beds within the subarachnoid spaces.

Dandy and Blackfan (1913, 1914) then proved the existence of two distinct types of hydrocephalus: 1, the obstructive (or non-communicating) type, and 2, the non-obstructive (or communicating) type. They established that the cause of non-communicating (obstructive) hydrocephalus is the inability of the cerebrospinal fluid to escape from the obstructed ventricles to the subarachnoid system where it can be absorbed by natural processes; and that the cause of communicating (non-obstructive) hydrocephalus is impaired absorption of the cerebrospinal fluid after it has reached the subarachnoid system because of congenital mal-development of the subarachnoid spaces or their obliteration by post-inflammatory adhesions.

To distinguish, clinically, between the communicating and the non-communicating types of hydrocephalus, Dandy and Blackfan (1913, 1914; Dandy, 1919) devised an extremely simple (dye) test which successfully serves this purpose.

SIMPLE PHYSIOLOGICAL OPERATIONS NOT REQUIRING MECHANICAL TUBES OR VALVES

For the treatment of obstructive (non-communicating) hydrocephalus Dandy (1922) devised third ventriculostomy, an operation by which a surgical opening is made through the thinned-out floor of the third ventricle, thus establishing communication between the hypothalamic portion of the third ventricle and the interpeduncular subarachnoid cistern. Third ventriculostomy fulfils all of the principal requirements for the successful treatment of obstructive hydrocephalus; namely, 1, the intraventricular fluid from both lateral and third ventricles is drained directly into a large subarachnoid space, the cisterna interpeduncularis; 2, the floor of the third ventricle through which the opening is made is almost paper thin, which minimizes chances of closure; 3, the interpeduncular cistern is prevented from collapsing by the cerebral peduncles on each side of it; and 4, from the interpeduncular cistern the cerebrospinal fluid is distributed directly out over the surface of the cerebral hemispheres whence it is absorbed by natural physiological processes.

For the treatment of non-obstructive (communicating) hydrocephalus Dandy (1918) proposed destruction of the choroid plexuses within the lateral ventricles to reduce the formation of cerebro-

spinal fluid to an amount which could be absorbed by the partially obliterated subarachnoid spaces.

The principles for treating hydrocephalus proposed by Dandy, it should be noted, were based on simple, fundamental, physiological and surgical principles, and in particular they avoided the use and permanent implantation within the central nervous system and other body cavities and tissues of any rubber, plastic, or metallic tubes or valves.

CEREBROSPINAL FLUID SHUNTS REQUIRING MECHANICAL TUBES AND VALVES

Since 1939 there has taken place a great resurgence of interest in hydrocephalus and many new operations have been developed for its treatment. None of these new operations have utilized the simple surgical principles propounded by Dandy. Instead, all of them employ tubes of rubber, plastics, or metal to drain cerebrospinal fluid from one part of the cerebrospinal fluid system to another part of it, or to other body cavities or tissue spaces outside of, and often remote from, the central nervous system. In addition to the simple conducting tubing many of these techniques require the introduction of mechanical valves of plastic or metal interposed along the course of the conductive tubing to permit the flow of cerebrospinal fluid in one direction but to prevent the flow of blood or other body fluids in the opposite direction towards the cerebrospinal fluid cavities or spaces. These operations are the so-called cerebrospinal fluid 'shunts'. They have been used to drain the cerebrospinal fluid into practically every body cavity, organ system, and tissue space within the body.

PRINCIPLES OF THERAPY AT ISSUE

The present study is an effort to determine which types of operation give the best results and offer the best promise in the treatment of hydrocephalus: 1, the simple 'physiological' operations, following the principles laid down by Dandy 20 odd years ago, which do not require mechanical tubes or valves, that is, third ventriculostomy for obstructive hydrocephalus and destruction of the choroid plexuses for non-obstructive hydrocephalus; or 2, the more recently developed and currently popular cerebrospinal fluid shunts, which do require the use, and permanent retention within the body, of mechanical tubes and valves.

The clinical experiences of a large number of representative neurosurgeons with these two basically different types of operation have been collected from the literature and are submitted for comparative evaluation.

CLINICAL EXPERIENCES WITH OPERATIONS NOT REQUIRING MECHANICAL TUBES OR VALVES

THIRD VENTRICULOSTOMY FOR THE TREATMENT OF OBSTRUCTIVE HYDROCEPHALUS

TRANS-TEMPORAL OPERATION (DANDY) Dandy described third ventriculostomy in 1922, and at that time reported that he had performed the operation upon six children; but he made no claims for the success of the operation. Although sound in principle, Dandy's original technique had one serious fault, namely, that it required deliberate section of one healthy optic nerve. In 1933 he described a modified technique for third ventriculostomy using a lateral or trans-temporal approach to the third ventricle (Fig. 1). But it was not until 23 years after his 1922 communication that he reported any results obtained by him from third ventriculostomy. In 1945, however, he reported 92 cases operated upon by him through the lateral or temporal route with a 12% mortality and arrest of hydrocephalus in 50% of the cases for periods ranging from six months to 23 years, the average survival time being between seven and eight years (Table I).

Late complications Re-operation was performed in seven cases (7%) of the total series of 92 cases reported by Dandy.

TRANS-FRONTAL OPERATION OR PUNCTURE OF LAMINA TERMINALIS AND FLOOR OF THIRD VENTRICLE Stookey and myself in August of 1936, in the middle

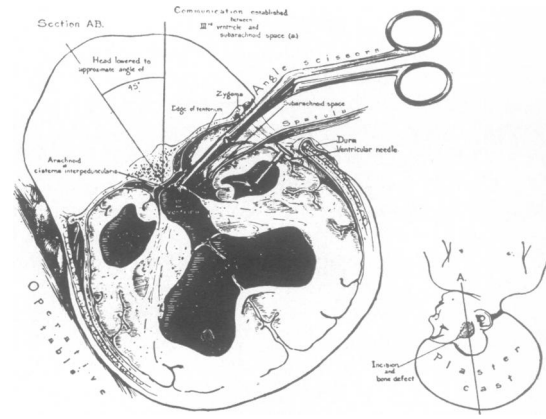


FIG. 1. *Third ventriculostomy by the temporal route. Technique of Dandy.* (*Reproduced from Lewis'* System of Surgery, *vol. 12, 1933, with permission of the publisher.*)

TABLE I

DANDY'S CASES OF THIRD VENTRICULOSTOMY (1945)

	Patients Under 1 Year of Age	*Patients Over 1 Year of Age*
92 cases (99 operations)	63	29 (36 operations)
Arrested hydrocephalus	21 (32%)	24 (80%)
Survival periods (yr.)	<1.....2 1 - 5.....5 5 - 10.....8 Over 10.....6	½ - 1..... 2 5 - 10.....11 10 - 20..... 3 23..... 1
Average survival periods (yr.)	7+	8+

of Dandy's protracted silence regarding third ventriculostomy, described a new and simpler technique for third ventriculostomy by a transfrontal approach, namely, puncture of the lamina terminalis and floor of the third ventricle (Figs. 2 and 3). At that time we reported six patients on whom we had performed this operation with one operative death, one failure to arrest hydrocephalus, and four patients living and well at the time of the report, with hydrocephalus arrested for six months, seven months, two years, and three years, respectively, after operation. In 1951 I reported 34 patients operated upon by Stookey or myself, with an operative mortality of 12% and arrest of hydrocephalus in 54% of the patients, who, at the time the report was published, were still living, with hydrocephalus arrested, two months to 15 years after operation (Table II).

On 5 November 1936, at a meeting of the Société de Neurologie de Paris, Lhermitte, de Martel, and Guillaume reported a single case in which de Martel on 13 October 1936 had successfully punctured the lamina terminalis ('*section de la lame sus-optique*') in an adult male, with relief of the patient's obstructive hydrocephalus. In 1950 Guillaume and Mazars reported this patient to be still alive and working with hydrocephalus still arrested.

In 1938 Wertheimer and Mansuy, after reviewing the six cases of Stookey and Scarff, and the one subsequent case of de Martel and Guillaume, reported three new cases of puncture of the lamina terminalis ('*section de la lame sus-optique*') operated upon by them. At the time of their report two of the patients were still living, hydrocephalus arrested, four months and two years respectively, after operation.

Late complications None of these 29 initially successful cases above reported required reoperation.

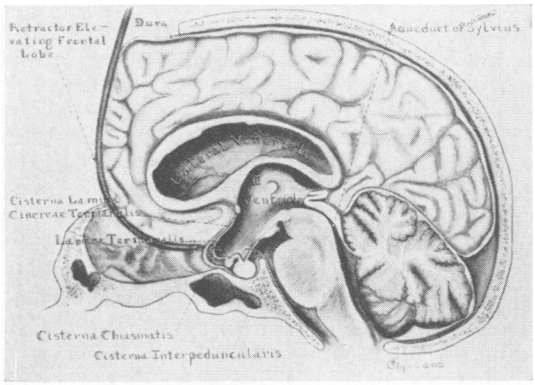


FIG. 2

FIG. 2. *Third ventriculostomy by the frontal route. Puncture of the lamina terminalis and floor of the third ventricle. Anatomical structures involved (Stookey and Scarff, 1936).* (*Reproduced from the* Bulletin of the Neurological Institute of New York.)

FIG. 3. *Third ventriculostomy by the frontal route. Puncture of the lamina terminalis and floor of the third ventricle (Scarff, 1951).* (*With permission of the editor of the* Journal of Neurosurgery.)

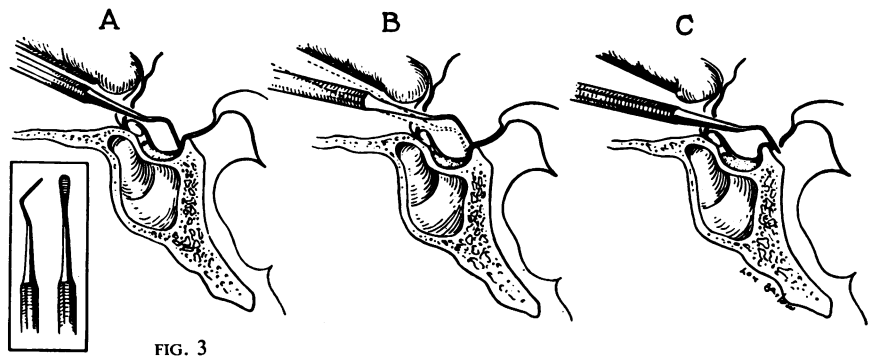


FIG. 3

TABLE II

RESULTS WITH THIRD VENTRICULOSTOMY (SCARFF, 1951)

	Total	*Benign Aqueductal Stenosis*	*Para-aqueductal Tumours*	*Miscellaneous*[2]
Total no. of cases	34	16	13	5
Operative mortality	5 (15%)	2 (13%)	1 (8%)	2 (40%)
Cases of arrested hydrocephalus	19 (56%)	10 (62%)	9 (69%)	0 (100%)
Survival periods of arrested cases		Patients living (with hydrocephalus arrested at time of 1951 report): 6 wk., 8 mth., 14 mth., 14 mth., 2 yr., 2½ yr., 3 yr., 4 yr., 5 yr., 15 yr.[1] after operation	Hydrocephalus arrested until extension of tumour into brain-stem caused death: 6 wk., 6 mth., 7 mth., 20 mth., 2 yr., 2 yr., 2 yr., 3 yr., 9 yr., after operation	
Average survival period (yr.)		3 (approx.)	2 (approx.)	

[1]This patient ('M' 1936 series, case 4) was alive and working, with hydrocephalus arrested, in April 1962.

[2]These consisted of two cases of obstructive hydrocephalus plus severe arachnoiditis caused by communicating hydrocephalus, the Arnold-Chiari syndrome, cerebellar tumour (not recognized at operation), and one case in which no cause of death was found at necropsy.

In 1939 White published a short report of three cases of obstructive hydrocephalus treated by puncture of the lamina terminalis, in which report he states that he followed the technique of Stookey and Scarff. In 1942 White and Michelsen reported an enlarged series of 11 cases of obstructive hydrocephalus operated upon by them, again employing the Stookey-Scarff technique. In only one of these cases was hydrocephalus due to aqueduct stenosis; in each of the other 10 cases hydrocephalus was due to midline tumour. There were two hospital deaths (18%); four patients (36%) died within a few weeks or a month from extension of the tumours but five (46%) were alive and free from signs of generalized intracranial hypertension during a follow-up period of two months, three months, nine months, one and a half years, and two and a half years after operation, at the time the report was made. The patient surviving two and a half years was their single case of aqueductal stenosis. In a necropsy performed in one patient who died six weeks after operation, due to extension of the tumour, the third ventriculostomy was found to be widely open, with margins well epithelialized (see Fig. 30).

Late complications In none of these cases was re-operation performed.

In 1940 Pennybacker reported results of third ventriculostomy in five children suffering from benign aqueduct stenosis. One child, in whom he performed both the puncture of the lamina terminalis and the floor of the third ventricle, died 24 hours after operation with hyperthermia (20% operative mortality). In the four children in whom he performed only puncture of the lamina terminalis there was no operative mortality, although one child died three weeks after operation from meningitis. The others (60%) were alive, with hydrocephalus apparently arrested, at the time the report was made, two months, four months, and two years respectively after operation.

Late complications None were reported.

In 1941, Guillaume, who had assisted at the operation on de Martel's case in 1936, reported 24 cases of puncture of the lamina terminalis with seven operative deaths (approximately 30%), and one death several months after operation due to extension of tumour into one of the cerebral peduncles; but 16 of the patients (66%) had survived 'for a number of years, the results continuing to be excellent, the patients having no more trouble'.

Guillaume and Mazars, in 1950, reported that between 1946 and 1950 they had performed puncture of the lamina terminalis (*'ventriculostomie susoptique'*) for relief of obstructive hydrocephalus in 230 patients, all of whom were adults. Their results are summarized in Table III.

Late complications Guillaume and Mazars (1950) state: 'The opening in the lamina terminalis constitutes a permanent "by-pass" which practically never closes. I have had the opportunity to observe patent, healed ventriculostomies in three patients, who had died of causes other than hydrocephalus,

TABLE III

RESULTS OF PUNCTURE OF LAMINA TERMINALIS (GUILLAUME AND MAZARS, 1950)

	Totals	*Tuberculomas*	*Tumour*	*Aqueduct Stenosis*
No. of cases	230	18	70	142
Operative mortality	8 (3+%)	—	—	—
Permanently relieved	125	—	—	125 (90%) ('most of these are alive and working 7 to 8 years after operation; many 10 years after operation; one 14 years after operation')

TABLE IV

SURVIVAL PERIODS OF TOLOSA'S 13 SUCCESSFUL CASES OF PUNCTURE OF LAMINA TERMINALIS

Type of Case	*No. of Cases*	*Follow-up Periods*	*Status of Patients at Time of Report*
Benign aqueduct stenosis in infants	3	4 yr.-5 mth., 3 yr.- 4 mth., 3 yr.	All living, hydrocephalus arrested
Benign obstructive lesions in adults	5	2 yr.-10 mth., 2 year-2 mth., 2 yr., 1 yr., 0 yr.-3 mth.	All living, hydrocephalus arrested
Tuberculoma of posterior fossa	1	3 yr.	Living, hydrocephalus arrested
Pinealoma	1	2 yr.-6 mth.	Living, hydrocephalus arrested
Tumours of brain-stem	3	11 mth., 6 mth., 3 mth.	Living, hydrocephalus arrested

4 years and 5 months (maximum); 2 years and 3 months (average

three months, six months, and two years after puncture of the lamina terminalis had been performed. . . . In only two cases (1·3% of the 142 patients operated upon for benign aqueduct stenosis), three months and six months, respectively, after the initial operation, did a new opening have to be established.'

In 1949 (Table IV) Tolosa reported 26 cases of lamina terminalis puncture (*'perforacion de la laminilla supra-optica de Stookey-Scarff'*). He had an operative mortality of 25% and failure in an additional 25%; but he reported 'good results' in 50% of his cases (13 patients), all of whom were living at the time Tolosa's report was published.

Late complications There were no re-operations.

In 1951 Voris reported results of third ventriculostomy performed by the lateral (temporal) technique of Dandy (1933, 1945) in 10 children with obstructive hydrocephalus all associated with Arnold-Chiari malformations. His results were as set out in Table V.

TABLE V

RESULTS OF THIRD VENTRICULOSTOMY BY THE LATERAL TECHNIQUE (VORIS, 1951)

Number of cases	10
Operative mortality	0
Successful arrest of hydrocephalus	10 (100%)
Post-operative survival periods	All 10 children were alive and well, with hydrocephalus arrested, at time of the report, 6 mth. to 4 yr. after operation

In 1950 Krayenbuhl, Werner, and Martin published a report of 17 cases of obstructive hydrocephalus due to a variety of pathological lesions treated by puncture of the lamina terminalis, which is especially valuable because of the authors' detailed case reports and their long follow-up observations (Table VI).

Late complications No re-operations were performed.

In 1951 Fasiani reported 72 cases of obstructive hydrocephalus which he had personally treated between 1941 and 1950 by *'ventriculo-cisternostomie*, following the technique of Stookey and Scarff', with an operative mortality in 14 cases (19% approximately), failure to relieve hydrocephalus in eight cases (10% approximately), and arrest of hydrocephalus in 50 cases (70% approximately), with follow-up studies carried out in 30 of these cases for periods ranging from one to eight years after operation (Table VII).

Late complications Fasiani reported no re-operations.

In 1959, Morello and Migliavacca published a remarkable and valuable series of 28 consecutive cases of obstructive hydrocephalus all due to benign aqueductal stenosis, treated by puncture of the lamina terminalis and floor of the third ventricle, 'following the technique of Stookey and Scarff' (Table VIII). There was one operative death (3%), six failures (21·5%), and 21 successful cases (75%), followed for a minimum of two years and a maximum of 11 years.

Late complications None of the 21 cases (75%) of this series reported by the authors as 'satisfactory' was re-operated upon.

Table IX is a summary of the experience of various authors who used third ventriculostomy.

TABLE VI

THIRD VENTRICULOSTOMIES REPORTED BY KRAYENBUHL, WERNER, AND MARTIN (1950)

Site of Obstruction	*Totals*	*Posterior part of Third Ventricle*	*Aqueduct of Sylvius*	*Posterior Fossa*
No. of cases	17 (100%)	7	6	4
Deaths	3 (17%)	1 (post-operative)	1 (20th post-operative day)	1 (after 4 mth.)
Temporarily improved	4 (23%)	—	3 (2 to 5 yr.)	1 (4 yr.)
Permanently cured with social rehabilitation	10 (60%)	6 (2 to 4 yr.)	2 (3 and 10 yr.)	2 (4 and 10 yr.)

Maximum follow-up 10 years; average 5 years

TABLE VII

LATE RESULTS AFTER PUNCTURE OF LAMINA TERMINALIS AND FLOOR OF THIRD VENTRICLE (FASIANI, 1951)

Type of Case	*No. of Cases Operated*	*Operative Mortality*	*No. of Cases Followed Up*	*Number of Patients Still Living After*							
				Eight Years	*Seven Years*	*Six Years*	*Four Years*	*Three Years*	*Two Years*	*One Year (+)*	*One Year (−)*
Stenosis of aqueduct	29	6	21	2	2	2	2	2	4	3	4
Obstruction of foramina of Magendie and Luschka	6	0	2						1	1	4
Tumour of pineal	12	1									
Tumour of cerebral pedicles	9	2									
			27			1	3	3	3	4	14
Tumour of posterior part of third ventricle	8	2									
Tumour of clivus	1	0									
Totals	71	14 (20%)	50	Maximum follow-up 8 yr.; average 2 yr.							

TABLE VIII

RESULTS OF PUNCTURE OF LAMINA TERMINALIS AND FLOOR OF THIRD VENTRICLE (MORELLO AND MIGLIAVACCA, 1959)

Type of Lesion	*No. of Cases*	*Results*
Benign aqueduct stenosis	28	
Operative deaths	1 (3·5%)	Patient died 1 mth. post-operatively of sudden intraventricular haemorrhage. No necropsy
'Poor' results	6 (21·5%)	Case 10: Hydrocephalus not arrested
		Case 28: Hydrocephalus not arrested Case 2: Hydrocephalus not arrested; subsequent plexectomy with complete relief; alive, hydrocephalus arrested 4 yr. post-operatively Case 20: Hydrocephalus very advanced and patient blind pre-operatively. Hydrocephalus completely arrested by operation. Patient alive 2 yr. post-operatively but blind and a total invalid Case 11: Hydrocephalus completely arrested 7 yr. post-operatively but patient can't walk Case 17: Hydrocephalus completely arrested 9 yr. post-operatively but patient invalid
'Satisfactory' results	21 (75%)	All patients promptly relieved of all symptoms and signs of increased intracranial pressure by operation All patients in good health and functioning normally at time report was published with follow-up periods of 2 to 11 years

TABLE IX

SUMMARY OF EXPERIENCES WITH THIRD VENTRICULOSTOMY

Author	*Type*	*No. of Cases*	*Operative Mortality (%)*	*Initial Successes (%)*	*Follow-up Periods*	
					Maximum	*Average*
Dandy (1922; 1945)[1]	Puncture lateral wall of hypothalamus	92	12	50	8+ yr.	7½ yr.
Stookey and Scarff (1936); Scarff (1951)	Puncture lamina terminalis and floor of third ventricle	34	15	54	25 yr.	2½ yr.
Lhermitte, de Martel, and Guillaume (1936)[2]	Puncture lamina terminalis (lame sus-optique)	1	0	100	15 yr.[3]	
Wertheimer and Mansuy (1938)	Puncture lamina terminalis	3	33	66	5 mth.	
Pennybacker (1940)	Puncture lamina terminalis and puncture lateral wall	5	20	80	2 yr.	14 mth.
Guillaume *et al.* (1941; 1950)	Puncture lamina terminalis	230	2	90	14 yr.	7 yr.
White and Michelsen (1942)	Puncture lamina terminalis	11	18	46	2½ yr.	12 mth.
Tolosa (1949)	Puncture lamina terminalis	26	25	50	4 yr.	2 yr. 3 mth.
Krayenbuhl *et al.* (1950)	Puncture lamina terminalis	17	17	60	10 yr.	5 yr.
Voris (1951)	Puncture lateral wall of hypothalamus	10	0	100	4 yr.	2 yr.
Fasiani (1951)	Puncture lamina terminalis and floor of third ventricle	72	20	70	8 yr.	2 yr.
Morello and Migliavacca (1959)	Puncture lamina terminalis and floor of third ventricle	28	3	75	11 yr.	5 yr.
Summary		527	15 (approx.)	70 (approx.)	25 yr.	5 yr.

[1]First patient operated upon 9 March 1933; reported August 1936
[2]Operation performed 13 October 1936; reported 5 November 1936
[3]Guillaume and Mazars (1950) reported this patient still living

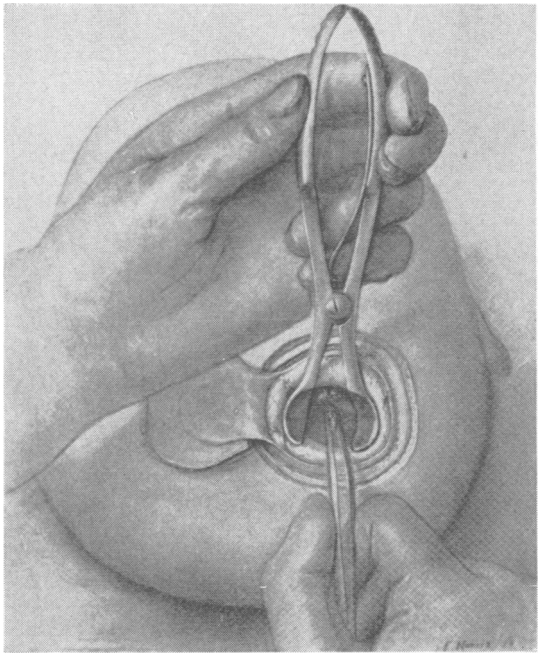


FIG. 4. *Extirpation of the choroid plexuses by the open surgical technique (Dandy, 1918).*

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 severe shock, and resulted in an operative mortality of 75% in Dandy's original series. (With permission of the editors of the Annals of Surgery.)

DESTRUCTION OF THE CHOROID PLEXUSES FOR TREATMENT OF NON-OBSTRUCTIVE HYDROCEPHALUS

OPEN SURGICAL EXTIRPATION OF CHOROID PLEXUSES (DANDY) In 1918 Dandy performed the first open surgical extirpation of the choroid plexuses from the lateral ventricles of infants with non-obstructive or communicating hydrocephalus; but despite the fact that the rationale of the operation was sound, the actual operation which he employed to destroy the choroid plexuses was technically a very poor one (Fig. 4). The basic defect in his technique lay in the fact that in order to avulse the choroid plexuses surgically he had to empty the ventricles of cerebrospinal fluid; this allowed the thinned-out walls of the ventricles to collapse, which in turn resulted in profound shock to the patients. Of the four infants operated upon by him in 1918, three died immediately after operation, although one lived for many years thereafter.

In 1938 Dandy reported two more operative cases, with one hospital death and one arrested hydrocephalus a year after operation.

The high operative mortality and low percentage of success attendant upon open surgical extirpation of the choroid plexuses was subsequently confirmed by the experiences of Sachs (1942) and of Davidoff (1948). A brief summary of their results is given in Table X.

Late complications None were reported. However, the high operative mortality attending open surgical excision of the plexus as reported by Dandy (75%), Sachs (46%), and Davidoff (43%) makes this 'open' operation surgically unacceptable.

ENDOSCOPIC CAUTERIZATION OF THE CHOROID PLEXUSES (PUTNAM AND SCARFF) Endoscopic cauterization of the choroid plexuses was first proposed by Dandy in 1922, but discarded by him after a single unsuccessful attempt. The value of the endoscopic technique, however, was clearly demonstrated by Putnam (1934; 1935; 1943) and by Scarff (1935; 1936; 1942; 1952; 1959). The ventriculoscopes developed by these two workers differed considerably in their construction but the surgical principle behind them was the same, namely, destruction of the choroid plexuses without allowing escape of the cerebrospinal fluid from the ventricles and collapse of the thinned-out cortex, thus decreasing the operative shock and the patient mortality (Fig. 5). Putnam's results are set out in Table XI.

Late complications None: once the hydrocephalus had been arrested by adequate cauterization of the choroid plexuses, no re-operations were

TABLE X

SURGICAL EXTIRPATION OF CHOROID PLEXUSES

Reported by Sachs (1942)		*Reported by Davidoff (1948)*	
Number of cases	90 (76 under 1 yr.)	Number of cases	32 (all infants)
Operative deaths	42 (46%)	Operative deaths	14 (43%)
Operative recoveries	48 (54%)	Failure to arrest hydrocephalus	2 (6+%)
Follow-up periods	7 yr. 1 case	Successful arrest of hydrocephalus	16 (50%)
	4 yr. 1 case	Follow-up periods	2 mth.-11 mth. (5 cases)
	1½ yr. 1 case		1 yr.-4 yr. (11 cases)
	<1 yr. 45 cases		

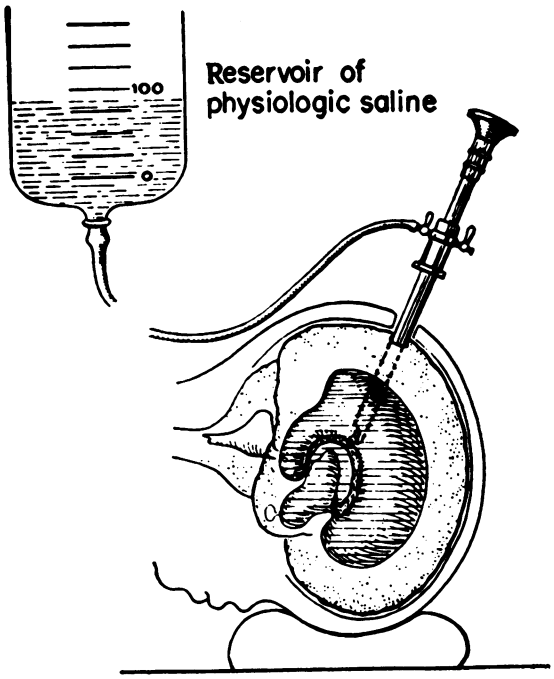


FIG. 5. *Endoscopic cauterization of the choroid plexuses Scarff's second series was reduced to 5%. (With permission pressure is continuously maintained throughout the operation, which prevents collapse of the thinned-out cortex and minimizes shock. As a result the operative mortality in Scarff's second series was reduced to 5%. (With permission of the editor of the* Journal of Neurosurgery.)

TABLE XI

RESULTS OF ENDOSCOPIC CAUTERIZATION OF THE CHOROID PLEXUSES REPORTED BY PUTNAM (1943)

Number of cases	42
Hospital deaths	10 (25% approximately)
Failures to arrest hydrocephalus	15 (35% approximately)
Successful arrest of hydrocephalus	17 (40%)

Length of follow-up (yr.)	(15 cases; 2 'lost')
1-3	11 cases
3	1 case
6	2 cases
9	1 case

Follow-up 9 years (maximum), 3 years (average)

needed in the 15 successful cases in which follow-up studies were made.

In 1942 I reported a series of 20 children in whom I had performed cauterization of the choroid plexuses for relief of non-obstructive (communicating) hydrocephalus, and, in 1952, a second series of 19 additional children. In 1959 I published a fully documented follow-up study of these 39 children, which is given, in greatly condensed form, in Table XII.

TABLE XII

SUMMARY OF RESULTS OF ENDOSCOPIC CAUTERIZATION OF CHOROID PLEXUSES REPORTED BY SCARFF (1959)

First Series (1942)	
Number of cases	20
Hospital deaths	3 (15%)
Failures to arrest hydrocephalus	7 (35%)
Successful arrest of hydrocephalus	10 (50%)
Survival periods of arrested cases (Scarff, 1959)	5 yr, 9 yr, 10 yr, 14 yr, 15 yr.; 17 yr*, 18 yr,*, 18 yr.*, 20 yr.*, 20 yr.*
Second Series (1952)	
Number of cases	19
Hospital deaths	1 (5%)
Failure to arrest hydrocephalus	2 (10%)
Successful arrest of hydrocephalus	16 (80+%)
Survival periods of arrested cases (Scarff, 1959)	8 yr., 9 yr., 9 yr., 10 yr., 10 yr., 10 yr., 10 yr., 10 yr.*, 10 yr.*, 11 yr.*, 11 yr.*, 11 yr.*, 11 yr.*, 11 yr.*, 11 yr.*

In the cases marked by asterisks in Table XII the patients are still living (1962), with their respective survival periods increased to 20 yr., 21 yr., 21 yr., 23 yr., and 23 yr., respectively. The average survival period of the entire group of 10 arrested cases becomes 16 years. The first of the five living patients is a severe epileptic and is mentally retarded; the second and third both finished the eighth grade of school and now live at home with their parents; the fourth is now attending his first year of college; the fifth successfully completed the first year of college, and is now employed as a secretary. In the second series of marked cases, the patients are still living (1962) with hydrocephalus arrested, thus increasing their survival periods after operation to 13, 13, 14, 14, 14, 14, 14, and 14 years respectively. The average survival period for the entire group of 16 arrested cases is thus increased to 12 years. The first five of the arrested patients listed above remained severe mental defectives and had been living in institutions for five to 10 years when last seen (Scarff, 1959). Two children, with hydrocephalus completely arrested, and each with normal mental development, died 10 years after operation of causes unrelated to hydrocephalus.

Eight children are still living and well in 1962. Three of them have moderately severe intellectual impairment, and stopped school after the third grade. Five children (25%) are now (1962) attending school and are in appropriate grades for their respective ages.

Late complications None: once hydrocephalus in these cases was arrested it never recurred.

In 1957 Feld described a ventriculoscope of original design, and reported 14 cases in which he had performed endoscopic cauterization of the choroid plexuses. His experiences with these cases are given in Table XIII.

TABLE XIII

RESULTS OF ENDOSCOPIC CAUTERIZATION OF CHOROID PLEXUSES REPORTED BY FELD (1957)

		Comments
Number of cases	14	Five of these were premature infants
Operative mortality	0	
Failures to arrest hydrocephalus	5	Death 3 to 5 months after operation. Five cases had post-mortem examinations. Three showed multiple developmental anomalies of the brain; two showed extensive meningitis secondary to infected meningoceles
Successful arrest of hydrocephalus	9 (65%)	At the time of report all nine patients were living and well with hydrocephalus arrested two months to 27 months after operation

TABLE XIV

SUMMARY OF ALL REPORTED CASES OF ENDOSCOPIC CAUTERIZATION OF CHOROID PLEXUSES

	No. of Cases	*Operative Mortality*	*Successes*	*Follow-up Successes (yr.)*	
				Maximum	*Average*[1]
Putnam	42	10 (25%)	17 (40%)	9	3
Scarff (1942 series)	20	3 (15%)	10 (50%)	23	16
Scarff (1952 series)	19	1 (5%)	16 (80%)	14	12
Feld	10	0 (0%)	9 (90%)	2½	1½
Totals	91	14 (15%)	52 (65%)	23	8

[1]Estimated

CLINICAL EXPERIENCES WITH CEREBROSPINAL FLUID SHUNTS EMPLOYING MECHANICAL TUBES AND VALVES

Since the end of World War II there has been a great revival of interest in hydrocephalus and many new operations have been devised for its treatment. None of these has employed the simple physiological and surgical principles outlined by Dandy. Instead they employ rubber, plastic, or metal tubes, inserted, and permanently retained, within the body, to carry cerebrospinal fluid from one part of the cerebrospinal fluid system to another, or to other body cavities and tissue spaces, where it is hoped that absorption will take place. These are the so-called cerebrospinal fluid 'shunts'; they have been used to deliver cerebrospinal fluid into practically every cavity and tissue space within the body. Following are descriptions of the various types of cerebrospinal fluid shunts which have been developed and a review of the clinical experience with the various types of shunts as reported in the literature.

INTRACRANIAL SHUNTS

VENTRICULO-CISTERNOSTOMY (TORKILDSEN'S OPERATION) The first and best known of the cerebrospinal fluid shunts which have been developed since World War II is the ventriculo-cisternostomy of Torkildsen. In this operation a plastic tube is led

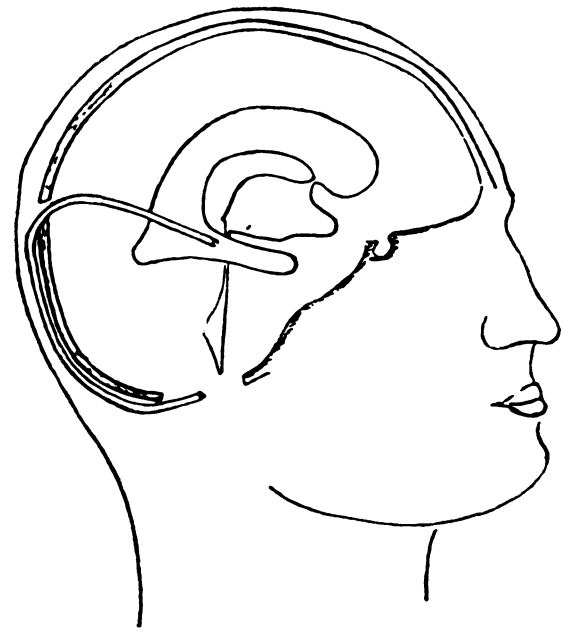


FIG. 6. *Intracranial shunt. The ventriculo-cisternostomy of Torkildsen (1939). A small rubber or plastic tube is led from one of the lateral ventricles, extracranially and subcutaneously, to the cisterna magna. This operation relieves only obstructive (non-communicating) hydrocephalus. (With permission of the author and of the editors of* Acta Chirurgica Scandinavica.)

transcortically from one of the lateral ventricles out through a small opening in the skull, thence beneath the scalp down to the occipital bone, and thence through an opening of the bone into the cisterna magna. The operation bypasses an occluded aqueduct of Sylvius; its use is limited strictly to the treatment of obstructive hydrocephalus (Fig. 6).

Torkildsen's original description of the operation was published in 1939 and was accompanied by case reports of four patients, none of whom had been followed more than nine months. In 1947 and 1948 he published reports of 35 cases with eight operative deaths (24%), hydrocephalus arrested in 22 cases (65%), with follow-up periods ranging from two months to eight years. These cases fell into three categories: 1 benign aqueduct stenosis, 2 pineal body tumours, and 3 infiltrating tumours of the third ventricle. In 1960 Torkildsen published a closely documented and rather remarkable follow-up report on the survival periods of the 35 cases originally reported by him in 1947-48.

The data submitted by Torkildsen in his three publications just cited have been condensed into Table XV.

In addition to Torkildsen's personal series the results of ventriculo-cisternostomy have been reported by Fincher, Strewler, and Swanson (1948), by Herlin (1950), by Fasiani (1951), and by Paine and McKissock (1955). A greatly condensed summary of these reports is given in Table XVI.

Late complications Ventriculo-cisternostomy performed by Torkildsen personally for relief of obstructive hydrocephalus due to benign aqueduct stenosis has been followed by late complications occurring one and a quarter months to four years after operation, leading to death in seven out of the 16 cases (50% approximately) of this group. Curiously, the results are almost identical with the long-term results obtained by him with infiltrating tumours of the third ventricle. The series reported by other surgeons, unfortunately, are either too small in number or too short in follow-up periods to permit really valid long term follow-up evaluations.

INTRACRANIAL SHUNTS OTHER THAN VENTRICULO-CISTERNOSTOMY OF TORKILDSEN Intracranial shunts other than the ventriculo-cisternostomy of Torkildsen, include the following: the ventriculo-(anterior) transcallosal shunt (Fig. 7) of Lazorthes, 1953; Lazorthes, Anduze-Acher, Campan, and

TABLE XV

SUMMARY OF 35 CASES OF VENTRICULO-CISTERNOSTOMY (1947-48 SERIES) REPORTED BY TORKILDSEN (1960)

Type of Case	*No. of Cases*	*Operative Deaths*	*Later Deaths and Survival Periods*	*Patients Alive in 1960*
Benign aqueduct stenosis	16	5 (30%)	8 (50%) 1½, 4, 15 mth.; and 2½ 4, 4, 4, and 10 yr. (with pulmonary tuberculoma), after operation	3 (20%) 13, 15, 19 yr. after operation
Pinealomas	8	1 (12%)	6 (75% 2, 2, 6½ mth.; 4 and 10 yr. after operation	1 (12%) 22 yr. after operation
Infiltrating tumours of third ventricle	11	2 (20%)	7 (60%) 3 and 5 mth.; 2, 2, 4-3/4, 5, 7, and 8 yr. after operation	2 (20%) 19 and 22 yr. after operation
Totals	35	8 (22%)	21 (60%) (Five of these cases lived 5 yr. or longer after operation.)	6 (17%)

Maximum follow-up 22 years, average four years

TABLE XVI

RESULTS OF VENTRICULO-CISTERNOSTOMY (TORKILDSEN'S OPERATION) AS REPORTED BY VARIOUS SURGEONS

Surgeon	*No. of Cases*	*Type of Cases*	*Operative Mortality (%)*	*Initial Arrest of Hydrocephalus*	*Follow-up Periods (yr.)*	
					Maximum	*Average*
Torkildsen (1939; 1960)	35	Mixed, benign obstruction, tumours	22	77	22 (11 cases survived 5 or longer)	4
Fincher, Strewler, and Swanson (1948)	19	Mixed, benign obstruction, tumours	25	58	3	1¼
Herlin (1950)	22	Same	40	60	10 (3 survived 5 or longer)	2-2/3
Fasiani (1951)	35	Same	30	20	3	10 mth.
Paine and McKissock (1955)	25	Same	25	72	4	
Totals	136		30	58	22 (14 patients survived 5 or longer)	2 (average)

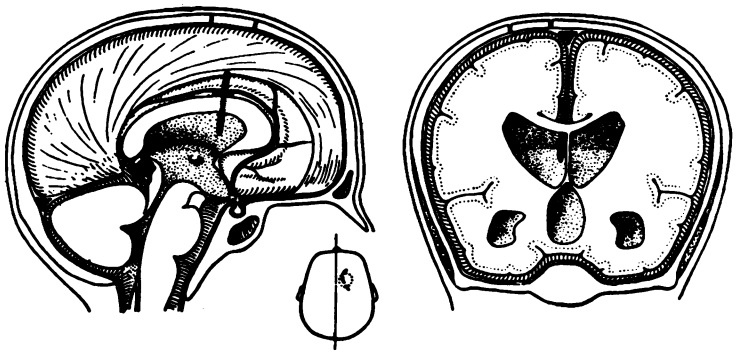


FIG. 7. *Intracranial shunt. The (anterior) ventriculo-transcallosal shunt of Lazorthes (1953). A small rubber or plastic tube is led from one of the lateral ventricles through the corpus callosum to the anterior supracallosal space. (With permission of the author and of the editors of* Presse Medicale.)

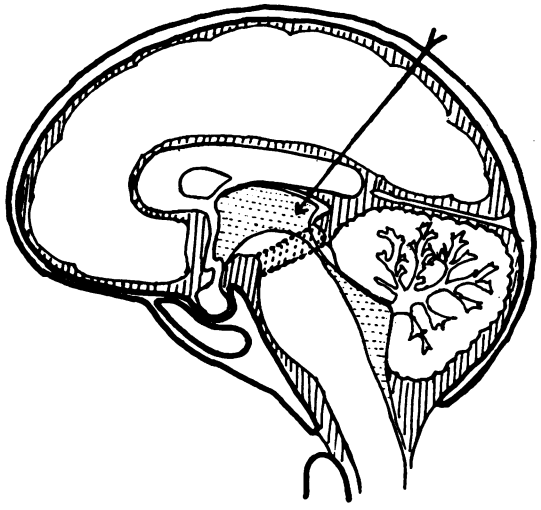


FIG. 8. *Intracranial shunt. The (posterior) ventriculo-trancallosal-cisterna ambiens shunt of Kluzer and Geuna (1955). A small rubber or plastic tube is led from one of the lateral ventricles down through the posterior part of the corpus callosum into the cisterna ambiens. (With permission of the authors and the editors of* Minerva Chirurgie.)

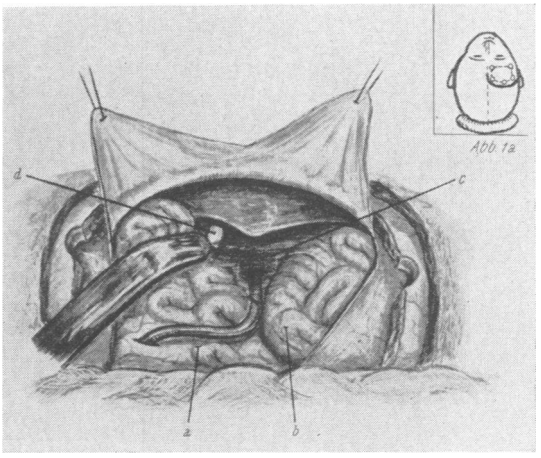


FIG. 9. *Intracranial shunt. The ventriculo-cisterna chiasmatis shunt originally proposed by Feld (1951) but first performed by Burmeister (1959). The illustration is from the latter's case report. (With permission of the author and of the editors of* Acta Neurochirurgica (Wien).)

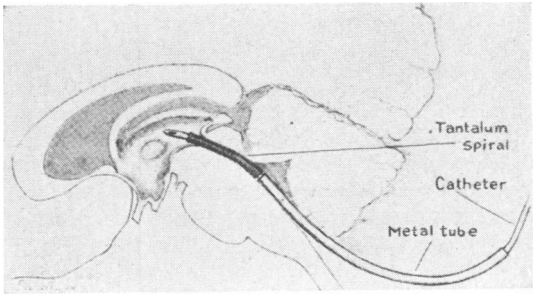


FIG. 10. *Intracranial shunt. The third-to-fourth ventricular shunt (technique of Leksell, 1949). This operation is similar to one which was devised but discarded by Dandy in 1920. (With permission of the author and of the editors of* Acta Psychiatrica et Neurologica.)

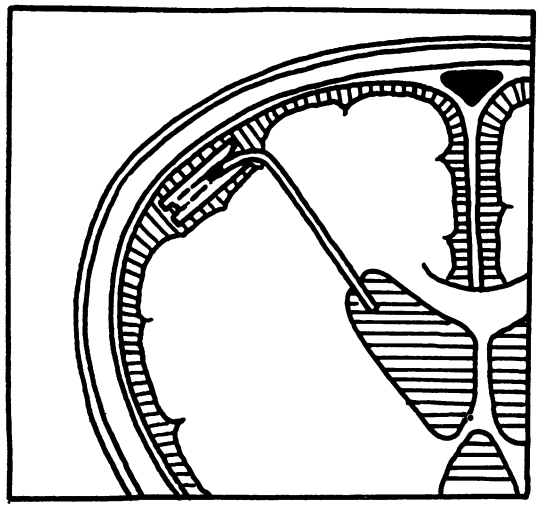


FIG. 11. *Intracranial shunt. The ventriculo-subdural shunt of Forrest, Laurence, and MacNab (1957). One end of a short plastic tube is introduced into one lateral ventricle; the other end of the tube ends in the flanged edge of a plastic button introduced between dura and arachnoid membranes of the cerebral convexity. (The illustration is a schematic composition by the present writer.)*

FIG. 12. *Intracranial shunt. The ventriculo-mastoid shunt of Nosik (1950). A small plastic tube is led from the temporal horn of a ventricle, transcortically and transdurally, and inserted through a small opening in the petrous bone into one of the mastoid air cells, whence the ventricular fluid escapes via the Eustachian tube into the posterior pharynx. (With permission of the editor of the* Journal of Neurosurgery.)

FIG. 11

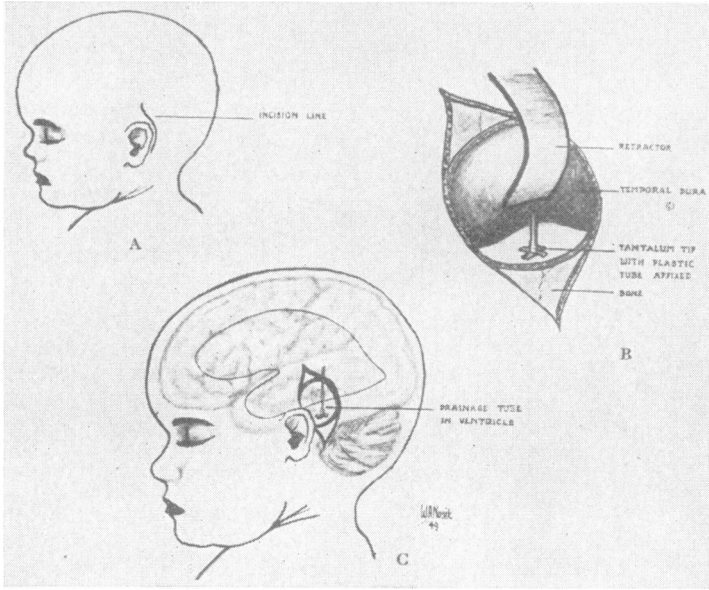


FIG. 12

Espagno, 1957; the ventriculo-(posterior) transcallosal cistern ambiens shunt (Fig. 8) of Kluzer and Geuna (1955); the ventriculo-chiasmatic cistern shunt, proposed by Feld (1951) but first performed (Fig. 9) by Burmeister (1959); the third-to-fourth ventricle shunt originally performed but discarded by Dandy (1920), revived in modified form (Fig. 10) by Leksell (1949); the ventriculo-subdural shunt (Fig. 11) of Forrest, Laurence, and Macnab (1957); and the ventriculo-mastoid shunt (Fig. 12) of Nosik (1950).

The general techniques employed in these various intracranial shunts are indicated pictorially in the reproduction of figures and photographs taken from the original descriptions of the authors (Figs. 7 to 12).

A total of approximately 118 cases treated by these various intracranial shunts, other than the ventriculo-cisternostomy of Torkildsen, have been reported in the literature, with an overall operative mortality of 21% (approximately) and initial arrest of hydrocephalus in 60% (approximately), with a maximum follow-up period for the entire group of six years. The results are summarized in Table XVII. However, the results appear better than warranted, because Burmeister has reported no operative mortality and 100% success for his ventriculo-chiasmatic cistern shunt, although his 'series' consists of one case followed for only four months.

TABLE XVII

SUMMARY OF RESULTS OF INTRACRANIAL SHUNTS OTHER THAN THE VENTRICULO-CISTERNOSTOMY OF TORKILDSEN

Shunt	*No. of Cases*	*Operative Mortality (%)*	*Successes (%)*	*Follow-up Periods (yr.)*	
				Maximum	*Average*
Ventriculo-subdural (Forrest *et al.*, 1957)	36	46	36	3	1½ (estimated)
Ventriculo-transcallosal (anterior) (Lazorthes *et al.*, 1953; 1957)	50	15	60	4	2 (estimated)
Ventriculo-transcallosal (posterior) (Kluzer *et al.*, 1955)	9	33	66	6	2
Ventriculo-chiasmatic cisternostomy (Feld, 1951; Burmeister, 1959)	1	0	100	4 mth.	4 mth.
Ventriculo-mastoidostomy (Nosik, 1950)	9	0	80	3	1½ (estimated)
Catheterization of aqueduct of Sylvius (Dandy, 1920; Leksell, 1949)	15	33	50	3	1½ (estimated)
Summary	118	21	65	6	2 (estimated)

VENTRICULO-CARDIAC SHUNTS

In 1952 Nulsen and Spitz described a shunting operation (Fig. 13) for the treatment of either obstructive or non-obstructive hydrocephalus, in which a plastic tube was led from one of the lateral ventricles of the brain of an infant suffering from hydrocephalus out through a trephine opening in the skull and thence beneath the skin into the superior vena cava, and thence into the right auricle of the heart. An essential part of this operation was use of a special valve (Holter) interposed along the course of the shunt tube in the upper neck. The valve (Fig. 14) consisted essentially of two ball valves so arranged as to permit a flow of cerebrospinal fluid through the valve toward the heart, without permitting reflux flow of blood from the heart toward the ventricle. Since the operative technique and the valve were initially described there have been minor modifications in each, although the surgical and mechanical features remain basically unchanged. At the time that Nulsen and Spitz (1952) published the first description of their technique and valve they reported that one child had been operated upon successfully and was alive, with hydrocephalus arrested, at the time of the publication two and a half years after operation.

In October 1961, before the second international congress of neurological surgery, Nulsen presented a report of 70 patients with hydrocephalus upon whom he had personally performed ventriculo-cardiac shunts, using either the original or a modified Holter valve, during the years 1956 to 1961 (Table XVIII). There was no operative mortality. Twenty-two children (30% approximately) died from hydrocephalus one to four years after operation with an average survival time of slightly over two years; 58 children (70% approximately) were still living in 1961, the survival times ranging from six months to five years, the average survival time being 2·6 years.

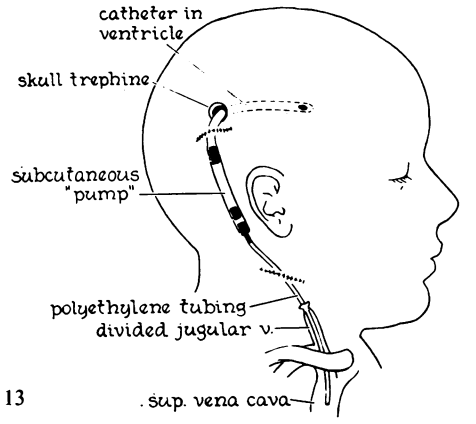


FIG. 13

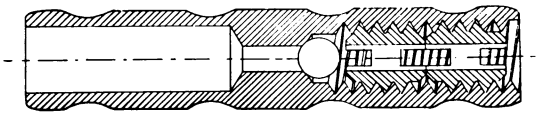


FIG. 14

FIG. 13. *Ventriculo-cardiac shunt (technique of Nulsen and Spitz, 1952). A plastic tube is led from the right lateral ventricle of the brain, extracranially and subcutaneously, and is inserted into the cardiac end of the divided jugular vein. The special Holter valve ('pump'), interposed midway along this tube, allows cerebrospinal fluid to pass toward the heart but prevents blood from passing through the valve toward the brain. (With permission of the authors and of the editor of the* Surgical Forum.)

FIG. 14. *The Holter valve (cross section) used by Nulsen and Spitz (1952) in their ventriculo-cardiac shunt. The ball is free to move toward the right to permit a normal flow of cerebrospinal fluid toward the heart. The slightest flow of cerebrospinal fluid or blood toward the left (in the direction of the brain) causes the valve to seat and obstruct further flow. (With permission of the authors and of the editors of the* Surgical Forum.)

TABLE XVIII

RESULTS OF VENTRICULO-CARDIAC SHUNTS PERSONALLY OPERATED UPON AND REPORTED BY NULSEN (1961)

No. of Cases	*Operative Deaths*	*Failure to Arrest Hydrocephalus and Subsequent Death*		*Survival Periods*	*Patients Living (August 1961)*
70	0	1st post-operative year	11 cases	5 yr.	2 cases
		2nd post-operative year	5 cases	4 yr.	15 cases
		3rd post-operative year	2 cases	3 yr.	8 cases
		4th post-operative year	4 cases	2 yr.	8 cases
		Total	22 cases (30% approximately)	1 yr. or less	15 cases
				Total	48 cases (70% approximately)
		Maximum survival 4 yr.		Maximum follow-up 5 yr.	
		Average survival 2 yr.		Average survival 2·6 yr.	

Spitz, in a personal communication to Macnab, and quoted by Macnab in 1958, stated that he had personally operated on 212 cases with 96% 'success'. Unfortunately Spitz has never published any of his results after his preliminary description of his technique reported with Nulsen in 1952 in which one successful case, surviving for two and a half years, was mentioned.

In 1957 Pudenz, Russell, Hurd, and Shelden described a new surgical technique for a ventriculo-cardiac shunt using valves of original design (Border; Heyer), with the valve placed within the right auricle of the heart (Fig. 15). These valves (Fig. 16) were calibrated to allow flow of cerebrospinal fluid into the auricle during diastole but would not allow blood in the auricle to enter the valve at any time. Accompanying the original description of these valves and of their original operative technique was the report of one case successfully operated upon, living and well one year following operation. In 1958 Pudenz reported on 15 cases of hydrocephalus treated with this technique without any operative deaths and with successful arrest of the hydrocephalus in nine of the cases (60%), with survival periods ranging from two months to 14 months. In 1960 Pudenz reported results in 21 patients operated upon by his technique with no operative mortality and successful arrest of the hydrocephalus in 16 cases (75% approximately) followed for periods ranging from one to two years. In that communication Pudenz reported that the original case operated upon and reported in 1957 had died of hydrocephalus two years after operation.

In 1960 Sayers, using the Spitz-Holter valve and the technique devised by Spitz and Nulsen, reported results in 156 cases of hydrocephalus which he

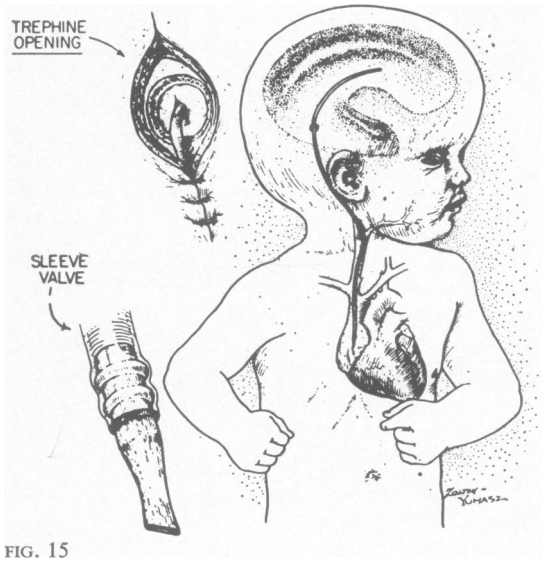


FIG. 15

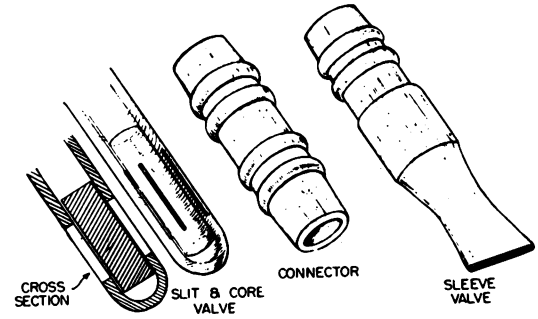


FIG. 16

FIG. 15 *Ventriculo-cardiac shunt (technique of Pudenz* et al., *1957). A plastic tube is led from the right lateral ventricle of the brain extracranially and subcutaneously to the jugular vein and into the atrium of the right auricle of the heart. At the cardiac end of the tube is a valve (Border, Heyer), which allows flow of cerebrospinal fluid into the heart but prevents cardiac blood from entering the shunt tube. (With permission of the authors and of the editor of the* Journal of Neurosurgery.)

FIG. 16. *Valves used by Pudenz* et al. *(1957) at the cardiac end of their ventriculo-cardiac shunt. The original 'sleeve' valve (Border) is on the right. The improved silicone 'slit-and core' valve (Heyer) used more recently is on the left. (With permission of the authors and of the editor of the* Journal of Neurosurgery.)

personally had treated, with an operative mortality of 18% and arrest of hydrocephalus in 63% of cases, with follow-up periods ranging from a few months to two and a half years.

In 1959 Carrington, also using the Holter valve and the Spitz-Nulsen technique, reported his results in 50 cases; there was an operative mortality of 6% with arrest of hydrocephalus in 68% of cases for periods ranging from a few months to one and a half years.

In 1959 Anderson, using the Heyer valve and the technique of Pudenz, reported his results in the treatment of 48 cases of hydrocephalus; there was an operative mortality of 6% with arrest of hydrocephalus in 58% of the cases, the longest follow-up period being two years.

In general, therefore, the literature at the time of this review contained reports of 345 cases of hydrocephalus treated by ventriculo-cardiac shunts with an average operative mortality of 2 to 3% and with initial arrest of hydrocephalus in approximately 65% of cases followed for a maximum survival period of five years (one case) and an average survival period for the group of approximately one and a half years.

LATE COMPLICATIONS OF VENTRICULO-CARDIAC SHUNTS Like all cerebrospinal fluid shunts employing rubber, plastic, or metal tubes to convey cerebrospinal fluid from the cerebrospinal fluid system to other parts of the body, the shunt tubes are prone to become obstructed, either with particulate matter collecting within the tube, or as a result of adhesions forming at one or the other end of the tube. In addition, ventriculo-cardiac shunts have their own particular complications which are frequent and serious, namely, thrombosis of the jugular vein or of the superior vena cava, and septicaemia and meningitis. A summary of the incidence of these complications reported by a number of proponents of ventriculo-cardiac shunts is given in the following condensed table (Table XIX).

Nulsen, in 1960, showed that the caval thromboses and the septicaemias occurring after ventriculo-cardiac shunts are largely dependent upon the position of the end of the shunt tube or valve within the left auricle of the heart; if the end is too high, that is, too close to the caval junction, thromboses are apt to occur; if the end of the shunt tube or valve is too low, that is, near the opening of the portal vein into the auricle, septicaemia is likely to develop. Nulsen has even been able to equate the 'correct', the 'too high', and the 'too low' positions of the cardiac end of the shunt to levels of the bodies of certain specific thoracic vertebrae as seen in

TABLE XIX

RESULTS WITH VENTRICULO-CARDIAC SHUNTS

Surgeon	*Operations*		*Initial Results*		*Late Complications*				*Survival Periods*	
	No. of Cases	*No. of Operations*	*Operative Mortality*	*Arrest of Hydrocephalus*	*Obstruction of Shunt*	*Septicaemia or Meningitis*	*Thrombosis of Jugular Vein or Superior Vena Cava*	*Total Complications*	*Maximum (yr.)*	*Estimated Average (yr.)*
Nulsen, (1952-1961) (Holter valve)	70	135	0 (0%)	48 (70%)	33 (40%)	13 (20%)	19 (25%)	65 (95%)	5	2½
Sayers (1960) (Spitz-Nulsen technique; Holter valve)	156	415	28 (18%)	98 (63%)	47 (30%)	36 (23%)	5 (3%)	88 (56%)	2½	1½
Carrington (1959) (Spitz-Nulsen technique; Holter valve)	50	60	3 (6%)	34 (68%)	10 (20%)	3 (6%)	—	13 (26%)	1½	3/4
Pudenz (1957-1960) (Heyer valve)	21	24	0 (0%)	16 (75%)	3 (14%)	0	0	3 (14%)	2	1
Anderson (1959) (Pudenz technique; Heyer valve)	48	64	3 (6%)	20 (58%)	12 (25%)	7 (14%)	—	19 (39%)	2	2
Summary	345	698	6%	66%	28%	12%	6%	46%	5	2·1 *(estimated)*

TABLE XX

RELATIONSHIP OF CARDIAC END OF SHUNT TO LATE COMPLICATIONS REPORTED BY NULSEN (1960)

Level of 'Catheter Tip' in Radiographs of Thorax	*No. of Cases*	*Caval Thrombosis*	*Septicaemia*	*Incidence (%)*
T_4 (or above)	10	8	0	80
T_5-T_6	25	0	0	0
T_7 (or below)	18	0	13	72

x-ray films of the thoracic spine after the shunt tube has been put in place within the left auricle of the heart.

The normal growth of the infant will inevitably tend to pull the cardiac end of the shunt up into the superior vena cava, and this in turn will automatically cause thrombosis of the superior vena cava with closure of the cardiac end of the shunt by organized blood clot. Nulsen has found that removal of an obstructed tube from a thrombosed superior vena cava and its replacement with a fresh and patent tube is almost surgically impossible, so that he now (1961) recommends elective annual removal of the cardiac end of the shunt and its replacement by a longer shunt, for an indefinite number of years. Nulsen has expressed (1961) the hope that 'more accurate placement and anchoring of equipment checked by skull and chest radiographs will obviate many revisions, but they will still be required with time in rapidly growing infants. Happily, their need can be predicted by following the position of radio-opaque catheters, and re-operation accomplished electively before there has been a fresh cerebral insult from elevated intracranial pressure'.

VENTRICULO-PLEURAL SHUNTS

In 1954 Ransohoff described ventriculo-pleural shunts, which he had performed in six patients with no operative mortality and arrest of hydrocephalus in all cases during seven-month to nine-month follow-up periods. In this operation a plastic tube was led out from one of the lateral cerebral ventricles through a small trephine opening in the occipital region of the skull, thence beneath the scalp and subcutaneous tissues of the neck and beneath the subcutaneous tissues paramedial to the upper thoracic spine to approximately the fifth intercostal space, and thence through a small opening in the intercostal muscles into the pleural cavity (Fig. 17). The method is applicable to the treatment of both obstructive and non-obstructive hydrocephalus. In 1960 Ransohoff *et al.* reported that they had performed ventriculo-pleural shunts in 83 patients with only 4% operative mortality and with 65% successful arrest of hydrocephalus during a maximum follow-up period of three years.

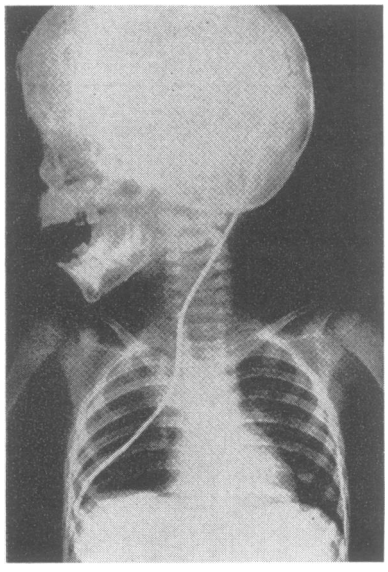


FIG. 17. *Ventriculo-pleural shunt of Ransohoff (1954). Radiograph showing the course of the shunt tube running subcutaneously from the right cerebral ventricle to the right pleural cavity. (With permission of the author and of the editor of the* Journal of Neurosurgery.)

Carrea, Audi, Girado, and Cortelezzi (1958) reported 25 cases of ventriculo-pleural shunts with an operative mortality of 12% and arrest of hydrocephalus in 40% of their cases, followed for periods ranging from one to three years.

LATE COMPLICATIONS While these shunts have resulted in a high percentage of initial successes, they have shown a great tendency to become obstructed after they have been in operation several months. This obstruction may occur within the ventricle where the free end of the tube may become entangled with the choroid plexus or imbedded in the wall or floor of the ventricle; by partial withdrawal of the tube from the ventricular cavity through the movements of the child's head and neck; within the long length of the plastic tube between ventricle and pleural cavity due to accretion of particulate matter on the inner wall of the tube; or within the pleural cavity by the development of scar tissue around the free end of the tube.

Although Ransohoff reported 'success' in 65% of his cases, it was necessary for him to perform a total of 154 operations in his 83 patients during follow-up periods ranging from seven months to three years after his initial ventriculo-pleural shunt had been performed.

Carrea in his series of 25 ventriculo-pleural shunts lost nine patients as a result of massive hydrothorax, and three patients through obstruction of the tube; and his longest survival period was only two and a half years.

It will be seen from the above statement that the number of patients suffering late serious complications with the ventriculo-pleural shunts ranges from 50% to 100%. The approximately 50% of Carrea's patients who developed complications all died of the complications; Ransohoff was able to save the lives of his patients by prompt re-operations. It must be pointed out furthermore that these serious complications developed within a relatively short follow-up period after the initial operation; it is natural to assume that as time passes and the

factors responsible for these complications continue to operate, the incidence of late serious complications will progressively increase.

VENTRICULO-PERITONEAL SHUNTS

In 1955 Scott, Wycis, Murtagh, and Reyes described a ventriculo-peritoneal shunt for the treatment of both obstructive and non-obstructive hydrocephalus.[1] In this operation a plastic tube was led out of one of the lateral ventricles of a hydrocephalic child through a trephine opening in the occipital region of the skull and thence beneath the scalp and subcutaneous tissues to a point beneath the costal margin and thence through the abdominal wall into the abdominal cavity (Fig. 18). These authors reported operations in 32 patients with death in hospital after the shunting operation in three patients (10%), with initial success in arresting hydrocephalus in approximately 50% of patients.

Later in 1955 Jackson and Snodgrass also described a technique for ventriculo-peritoneal shunts, and reported their results in treating hydrocephalus by this method in 62 patients. They had no operative mortality; failure to arrest the hydrocephalus in 27 patients (44%); and 24 patients (38%) alive one to four years after initial operation, although in only 17 (30%) of these surviving patients was the hydrocephalus arrested.

Also, still later in 1955, Chaptal, Gros, Jean, Campo, and Vlahovitch reported their results with ventriculoperitoneal shunts in 17 infants with communicating hydrocephalus, claiming 'good results' in five cases (29%) followed for periods ranging from three months to 32 months.

In 1959 Luyendijk and Noordijk described a modification (Fig. 19) of the standard ventriculo-peritoneal shunt, the chief feature of which was the addition, at the peritoneal end of the shunt tube, of a fluted 'petticoat' of thin flexible sheet plastic material, the purpose of which was to minimize the sealing off of the peritoneal end of the shunt by adhesions and scar tissue. They reported operations in 22 infants without any operative deaths, and with successful arrest of hydrocephalus in 13 of their cases (60% approximately) for follow-up periods ranging from one to two years.

In 1956 Picaza reported his experiences with lumbar subarachnoid-peritoneal shunts for the treatment of communicating hydrocephalus only. He first operated upon 23 cases in which the peritoneal end of the shunt was introduced into the peritoneal cavity through the anterior or anterolateral abdominal wall. In this series there were five operative deaths (21%) with arrest of hydrocephalus in 11 cases (46%), with follow-up periods ranging from one to four years. He then reported a second series of cases in which the peritoneal end of the shunt was led directly through the posterior wall of

[1]These writers very generously credited Cohn with having first performed this operation, although Cohn never reported any cases in the literature.

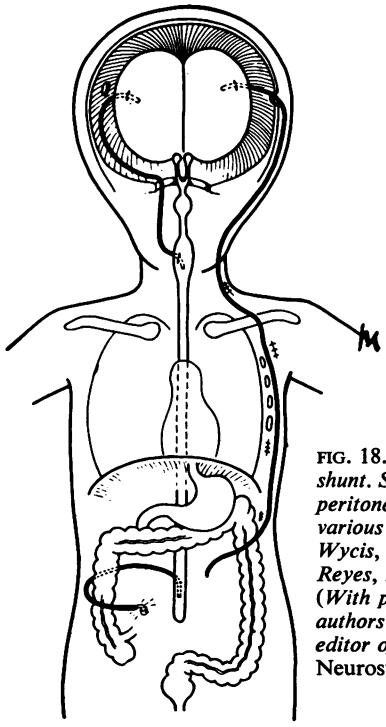


FIG. 18. *Peritoneal shunt. Standard anterior peritoneal shunts of various types (Scott, Wycis, Murtagh, and Reyes, 1955). (With permission of the authors and of the editor of the* Journal of Neurosurgery.)

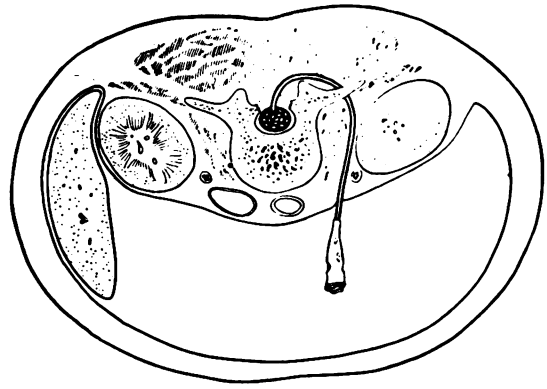


FIG. 19. *Peritoneal shunt. The 'petticoat' (anterior) peritoneal shunt of Luyendijk and Noordijk (1959). (With permission of the authors and of the editors of* Acta Neurochirurgica (Wien).)

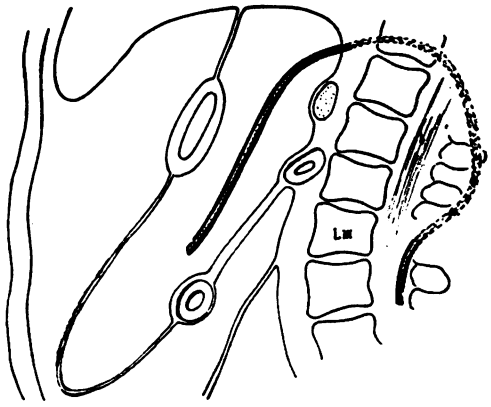


FIG. 20. *Peritoneal shunt. The lumbar subarachnoid-posterior peritoneal shunt of Picaza* (1956). (*With permission of the author and of the editor of the* Journal of Neurosurgery.)

the abdominal cavity and into the posterior peritoneal space (Fig. 20). He employed this technique in 10 patients without any operative mortality and with the hydrocephalus arrested in nine cases (90%) for follow-up periods ranging from one to four years.

LATE COMPLICATIONS IN PERITONEAL SHUNTS All of these shunts have shown a strong tendency to become occluded at the peritoneal end of the shunt, requiring re-operation to free the tubing of obstruction.

Scott *et al.* (1955) performed 67 operations upon 32 patients followed from one to four years; despite the high incidence (50%) of late complications requiring re-operation, the authors state that 'ventriculo-peritoneal and lumbar subarachnoid peritoneal shunts have controlled the hydrocephalus in (only) a small percentage (9%) of our cases over a maximum follow-up period of four years'.

Jackson and Snodgrass were forced to perform 112 operations in order to keep the peritoneal shunts functioning in 62 patients during a maximum follow-up period of four years. These authors state that only 24 of the 65 original shunts remained open for as long as one year; and that during each successive year following the original operation the percentage of functioning shunts became progressively less. At the time of their report (1955), with follow-up periods ranging from one to four years, these authors state that 'only 39% of their patients had been benefited over a long period of time' (*i.e.*, maximum of four years).

Matson, in 1956, in a general review of his experience in the treatment of hydrocephalus, reported that he had performed peritoneal shunts in 64 children but that during a relatively short follow-up period he found it necessary to perform 155 operations to keep the shunts functioning. He concluded his discussion of peritoneal shunts with this statement: 'Although an occasional shunt works well from the beginning, the overall percentage of success is discouragingly meagre'.

Chaptal *et al.* (1955) reported only 29% of their shunts functioning three to 32 months after they had been established.

Luyendijk and Noordijk in 22 infants had no operative deaths, and it must be assumed had initial success in all of their cases; however, during a follow-up period of one to two years 42% of the shunts had developed obstructions resulting in permanent failure of the method to arrest hydrocephalus.

Picaza, using the lumbar subarachnoid-anterior peritoneal shunt, experienced 32% of late complications and permanent failure of the shunts to function. In his modified lumbar subarachnoid posterior peritoneal shunt, however, he reported only 10% complications during follow-up periods of from one to four years.

SUMMARY OF PERITONEAL SHUNTS All reports indicate a strong tendency for this shunt to become obstructed; the necessity of repeated 'revisions' to remove the obstruction; a high incidence (30% to 50%) of permanent failures of the shunt; and with the longest reported follow-up, with successful arrest of the hydrocephalus four and a half years and the (estimated) average duration of arrest of hydrocephalus of two years.

SHUNTS INTO EPITHELIALIZED DUCTS

In 1958 Smith, Moretz, and Pritchard described ventriculo-cholecystostomy, in which a plastic tube was led from one of the lateral ventricles of the brain down and into the peritoneal cavity, and thence into the gall bladder or cystic duct. A special mechanical valve was added to the tube just before it was introduced into the gall bladder or cystic duct, which would allow the cerebrospinal fluid to enter the biliary duct but which would prevent reflux of the bile up the shunt tube and into the cerebral ventricles (Fig. 21). Smith reported 10 cases of hydrocephalus treated in this manner with only one operative death (10% mortality) and with arrest of hydrocephalus in nine cases (90%) followed for a maximum period of two years.

In 1954 Harsh described ventriculo-salpingostomy in which a plastic tube was led from one of the ventricles subcutaneously to the abdominal cavity, and inserted into the distal end of a transected

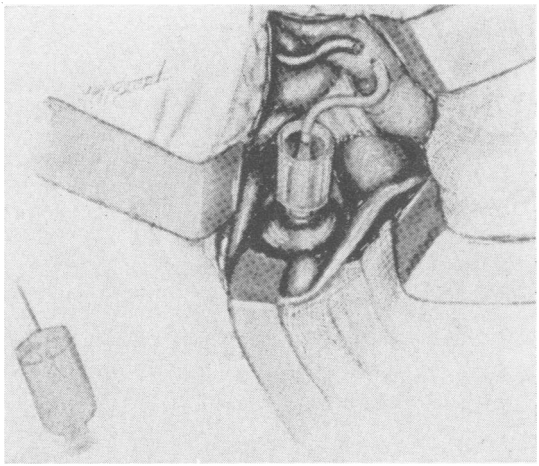


FIG. 21. *Shunts to epithelialized ducts. Shunt to the gall bladder and biliary ducts (Smith* et al., *1958). A plastic valve at the biliary end of the shunt permits flow of cerebrospinal fluid into the gall bladder while preventing flow of bile toward the ventricle or spinal subarachnoid spaces. (With permission of the authors and of the editor of the* Journal of Neurosurgery.)

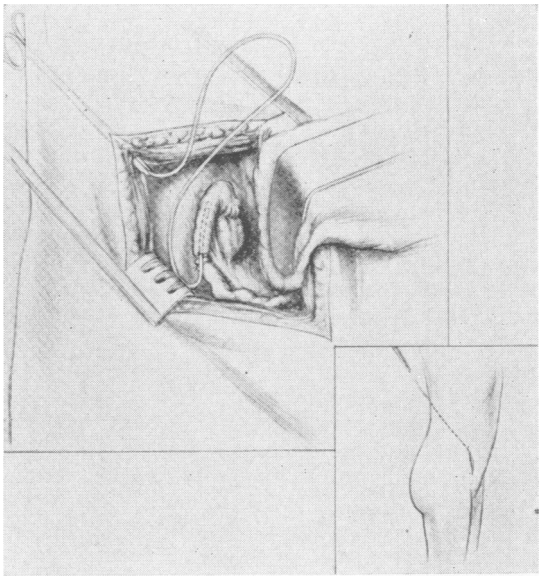


FIG. 22. *Shunts to epithelialized ducts. Shunt to the Fallopian tubes (Harsh, 1954). (With permission of the author and of the editor of the* Journal of Neurosurgery.)

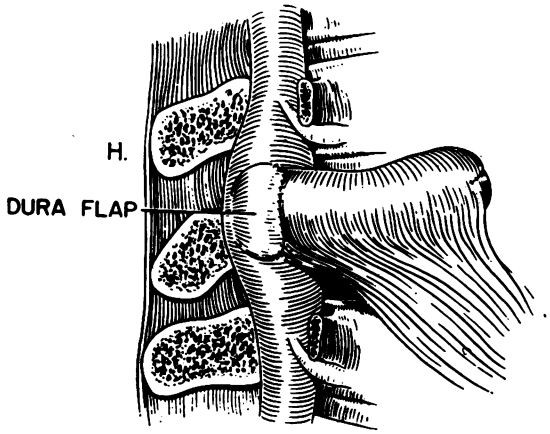


FIG. 23. *Shunts to epithelialized ducts. Shunt to a loop of the ileum. (Neumann* et al., *1959). (With permission of the authors and of the editor of* Plastic and Reconstructive Surgery.)

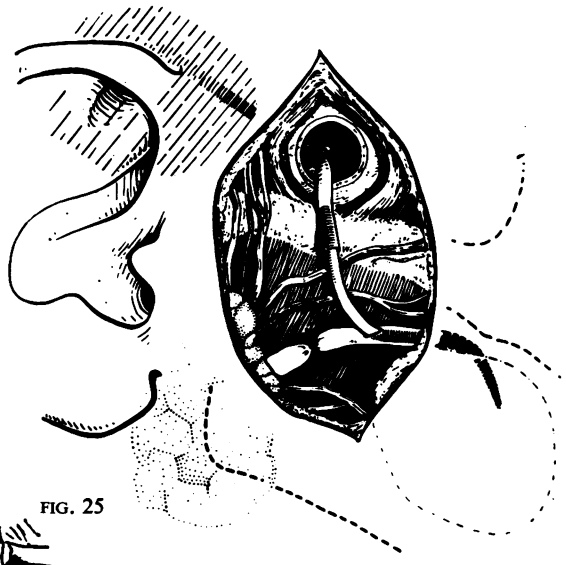


FIG. 25

FIG. 24. *Shunts to epithelialized ducts. Shunts to the thoracic (lymphatic) duct (Yokoyama* et al., *1959). (With permission of the authors and of the editors of* Folia Psychiat. Neurol. Jap.)

FIG. 25. *Shunts to epithelialized ducts. Shunt to a salivary duct (Stenson's) (Parkinson and Jain, 1961). (With permission of the authors and of the editor of the* Canadian Journal of Surgery.)

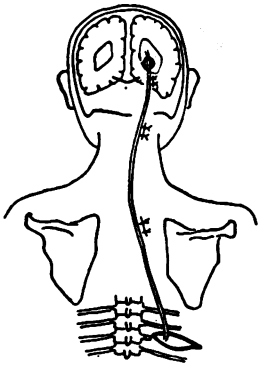
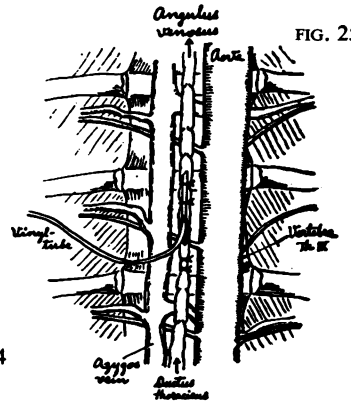


FIG. 24



Fallopian tube (Fig. 22). He reported having performed this operation in four cases of obstructive hydrocephalus without a single operative death, and with arrest of hydrocephalus in three cases during a maximum follow-up period of six months. Harsh also described a lumbar subarachnoid salpingostomy performed for communicating hydrocephalus, in which a plastic tube was led from the lumbar subarachnoid space into one of the Fallopian tubes. He reported eight such operations with one death (12% mortality) and with arrest of hydrocephalus in seven cases (88%) followed for a maximum period of 12 months.

In 1959 Neumann, Hoen, and Davis described lumbar arachnoid-ileostomy, in which a plastic tube was led from the lumbar subarachnoid space into an isolated and sterilized loop of the ileum (Fig. 23). This operation had been carried out successfully in one patient with an apparent arrest of hydrocephalus during a follow-up period of seven months.

In 1959 Yokoyama, Aoki, Tatebayashi, Hirai, Matsumoto, and Fukushima described a shunt from the cerebral ventricles into the thoracic duct (Fig. 24). Three patients were operated upon; all died within two weeks with obstruction of the thoracic duct.

In 1961 Parkinson and Jain described a shunt from the cerebral ventricles into Stenson's duct (Fig. 25). Three patients were operated upon by them; all died about three months after operation, with occlusion of Stenson's duct by granulation tissue.

LATE COMPLICATIONS Since the original descriptions of the five shunts into epithelialized ducts above described were published, no further reports have appeared in the literature.

A personal communication, however, received from Harsh (July, 1960), read in part as follows: 'One of the four ventriculo-salpingostomy shunts (originally reported as successful in 1954) was subsequently converted into a uretero-thecal anastomosis because of repeated failure of the salpingo-thecal shunt. In general this pattern has been our experience in subsequent patients . . . we have virtually abandoned the ventriculo-salpingal shunt in non-communicating types of hydrocephalus'.

Neumann (August, 1962) reported in a personal communication that his single patient with an arachnoid-ileostomy died from recurrent hydrocephalus about two years after operation.

SUMMARY OF EXPERIENCE WITH SHUNTS INTO EPITHELIALIZED DUCTS In general, with each of these methods, the number of cases reported and the length of the follow-up observations do not warrant a valid evaluation of the methods. The maximum reported survival for any visceral shunt is two years, the (estimated) average two to three years.

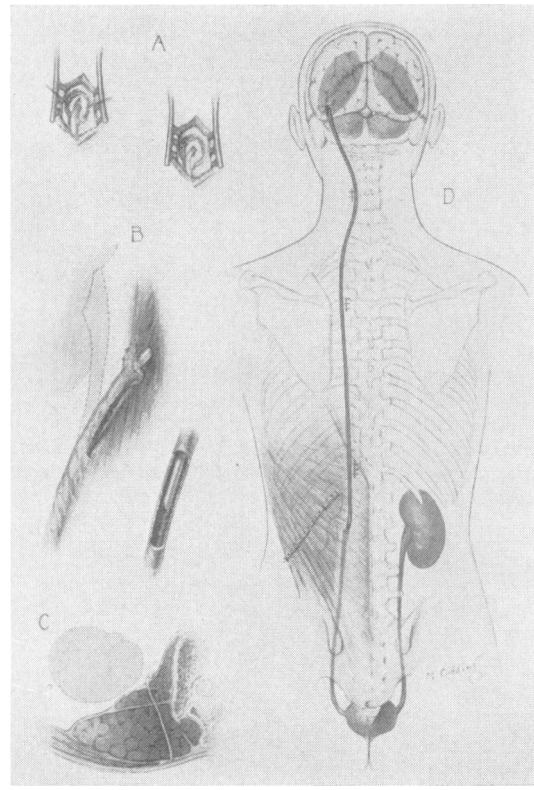


FIG. 26. *Ureteral shunt. The ventriculo-ureteral shunt of Matson (1951).* (*With permission of the author and of the editor of the* Journal of Neurosurgery.)

URETERAL SHUNTS

In 1951 Matson described a ventriculo-ureteral shunt (Fig. 26) designed for the treatment of obstructive hydrocephalus. A plastic tube was led from one of the lateral cerebral ventricles subcutaneously to the perirenal area on one side of the body; the kidney on that side of the body was then removed and the distal end of the plastic shunt tube was inserted into the open end of the distal portion of the transected ureter. At the time that Matson described this operation (1951) he reported seven cases treated by this method with an operative mortality of 15% and apparent initial success in 85% of the cases.

In 1953 Matson described a lumbar-ureteral shunt (Fig. 27) designed for treatment of communicating hydrocephalus. In this operation a

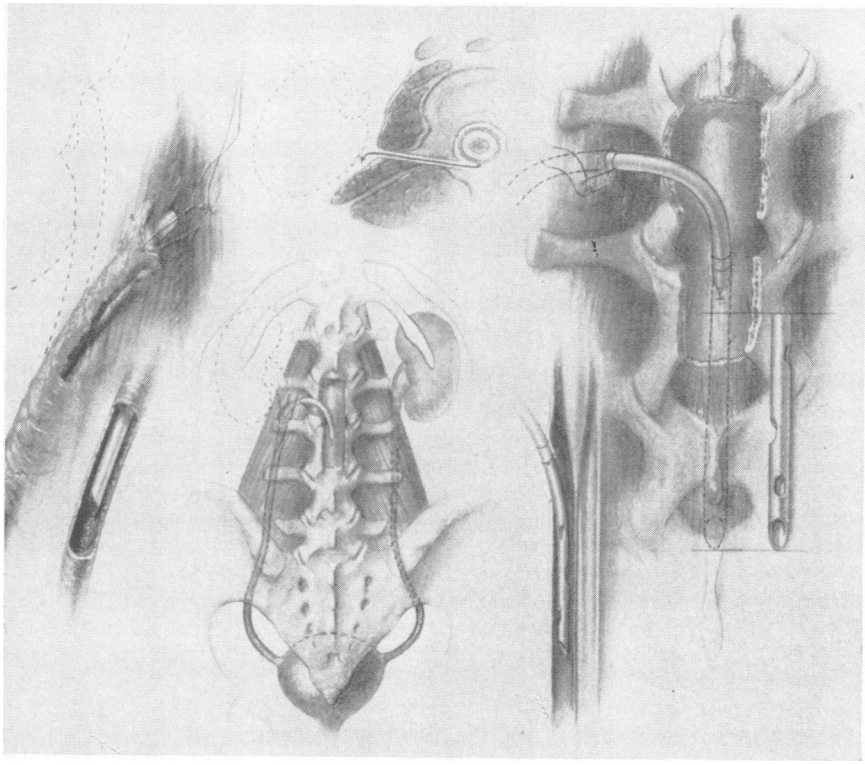


FIG. 27. *Ureteral shunt. The lumbar ureteral shunt of Matson (1953). (With permission of the author and of the editor of the* Journal of Neurosurgery.)

plastic tube was led from the lumbar subarachnoid space and inserted into the distal end of one transected ureter after the kidney on that side had been removed. In 1956 Matson reported that he had performed this operation in 108 patients with an operative mortality of only 1% and with 'successful' arrest of hydrocephalus in 70 cases (65%) of the series followed over a period of three months to seven years after their operations, the estimated average survival being three and a half years.

LATE COMPLICATIONS OF URETERAL SHUNTS In 1956 Matson reported that he had abandoned the ventriculo-ureteral shunt because of 'frequent complications'.

The lumbar ureteral shunt has its own unique set of complications (Table XXI) which include the sacrifice, in an infant, of one sound kidney, and the continuous excretion of body fluids and electrolytes into the urine for the life time of the patient, requiring constant vigilance and prompt and intelligent intervention if grave emergencies and even fatalities are to be avoided.

In addition, there is the serious potential risk in later life resulting from the elective extirpation in a child of one healthy kidney.

TABLE XXI

LATE COMPLICATIONS OF LUMBAR SUBARACHNOID-URETER SHUNTS REPORTED BY MATSON (1956)

Number of patients	108
Obstruction of shunt	18 (16%)
Meningitis	8 (8%)
Metabolic crises	21 (20%)
Total of late complications	47 (44%)

In 1960 Matson stated in print that he then employed the lumbar ureteral shunt only if 'the hydrocephalic infant has two good kidneys, two intelligent parents, a well-trained paediatrician quickly available, and a good hospital close at hand'. Otherwise, he employs one of the atrial shunts.

LUMBAR SUBARACHNOID TO LUMBAR EPIDURAL SHUNT

In 1955 Hakim, Jiménez, and Rosas reported five cases of shunts performed by them from the lumbar subarachnoid space to the lumbar epidural space with no operative mortality and 100% success during a follow-up period of two and a half years. In 1958 Fulcher and Enomoto (Fig. 28)

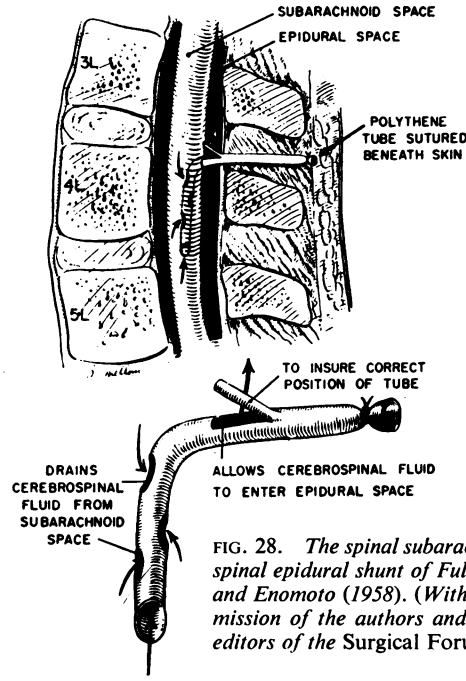


FIG. 28. *The spinal subarachnoid-spinal epidural shunt of Fulcher and Enomoto (1958). (With permission of the authors and of the editors of the* Surgical Forum.)

reported results in the treatment of eight patients with communicating hydrocephalus by this type of shunt.

LATE COMPLICATIONS OF LUMBAR SUBARACHNOID EPIDURAL SHUNTS Although Hakim *et al.* reported 100% success with their five cases of lumbar subarachnoid epidural shunts during a follow-up of two and a half years, Fulcher and Enomoto on the other hand reported that in eight cases, none of the eight shunts remained patent for longer than four weeks.

SUMMARY OF DATA, CONCLUSIONS, AND COMMENTS

The present study was undertaken to determine which types of operation for the relief of hydrocephalus give the better results: the simple 'physiological' operations, originally proposed in principle by Dandy (1918-1922), which do not require the use of mechanical tubes and valves; or the 'shunt' operations, more recently developed (1939-1959), and now currently popular, which do require the use of mechanical tubes and valves.

TABLE XXII

COMPARISON OF OPERATIVE RESULTS IN THE TREATMENT OF HYDROCEPHALUS

Type of Operation	*No. of Cases*	*Initial Results*		*Late Complications*				*Follow-up Periods (yr.)*		*Remarks*
		Operative Mortality (%)	*Arrest of Hydrocephalus (%)*	*Occlusion Shunt (%)*	*Meningitis, Septicaemia (%)*	*Miscellaneous (%)*	*Total (%) (approx.)*	*Maximum*	*Average (estimated)*	
Operations not requiring mechanical tubes or valves										
Third ventriculostomy	529	15	70	—	—	2	2	25	5	
Cauterization choroid plexus	91	15	60	—	—	3	3	23	10	18 cases over 10 yr., 5 cases over 20 yr.
Summary	620	15	65	—	—	2·5	2·5	25	7½	
Operations requiring mechanical tubes and valves (the shunts)										
Intracranial shunt (Torkildsen)	136	30	58	50 (approximately)	—	—	50	22	2	14 cases over 5 yr.
Intracranial shunts (other authors')	118	21	60	—	—	—	—	6	2[1]	
Cardiac shunts	345	6	62	28	12	Thrombosis superior vena cava 6	46	5	1½[1]	
Pleural shunts	108	8	53	100	—	—	100	3	1½[1]	
Peritoneal shunts	230	13	55	58	—	—	58	4	2[1]	
Ureteral shunts	108	1	65	16	8	Metabolic crises 20	44	7	3½[1]	
Shunts into epithelialized ducts	29	6	50	50	—	—	50	2	2/3[1]	
Spinal subarachnoid to spinal epidural shunts	13	0	75	50	—	—	50	3	1½[1]	
Summary	1,087	10	60	50	3	3·5	57	22	1½[1]	

[1]Estimated.

SUMMARY OF DATA

Table XXII provides a summary of cases described in the literature.

A survey of the literature, just completed, yielded reports of 618 cases of hydrocephalus treated by operations which do not require the use of rubber, plastic or metal tubes, or valves placed within the body of the patient; of these, 527 were third ventriculostomies, performed for the relief of obstructive (non-communicating) hydrocephalus and 91 were destructions of the choroid plexuses, performed for the relief of non-obstructive (communicating) hydrocephalus.

The same survey yielded reports of 1,087 cases of hydrocephalus treated by operations requiring the use of mechanical tubes and valves, permanently implanted within the body of the patient, the so-called cerebrospinal fluid 'shunts'.

The operative mortality and the initial success in relieving hydrocephalus was essentially the same in these two large groups, the operative mortality being approximately 15% and the initial successes approximately 60% to 65%.

The incidence of severe late complications, however, is 10 to 20 times greater after the 'shunting' operations, which required mechanical tubes and valves than after the simple 'physiological' operations which did not require such mechanical devices. Most types of shunting operations were followed by late complications of such severity as to cause death of the patient, require re-operation, or otherwise critically endanger the patient's life. The incidence of such complications varied from 35% to 100% of the cases treated, depending on the type of shunt used. In striking contrast, the overall incidence of serious late complications after the simple 'physiological' operations, namely, third ventriculostomy and endoscopic cauterization of the choroid plexuses, was only 3% to 5%.

CONCLUSIONS

The superiority of those operations for the treatment of hydrocephalus which do not require the use of mechanical tubes and valves, namely third ventriculostomy and endoscopic cauterization of the choroid plexuses, over those operations which do require mechanical tubes and valves, appears to be clearly established; for while operative mortality and initial successes are essentially equal in the two groups, the incidence of serious late complications is approximately 10 to 20 times greater after the 'shunting' operations than after the physiological operations.

The reasons for the low incidence of late complications following simple 'physiological' operations not requiring mechanical tubes or valves are quite clear. In cases of pure obstructive hydrocephalus treated by a correctly performed third ventriculostomy, if the openings made surgically through the greatly thinned-out lamina terminalis and floor of the third ventricle (Scarff, 1951) (Fig. 29) remain open for as long as two to three weeks, the edges of the opening will, by that time, have become completely epithelialized by the union of the ependyma from the third ventricle and the pia mater from the subarachnoid cisterns (White, 1939) (Fig. 30). Once the edges of the openings have been thus epithelialized, the ventriculostomy will never close (Stookey and Scarff, 1936) (Fig. 31). These facts have also been confirmed by the observations of Guillaume and Mazars (1950).

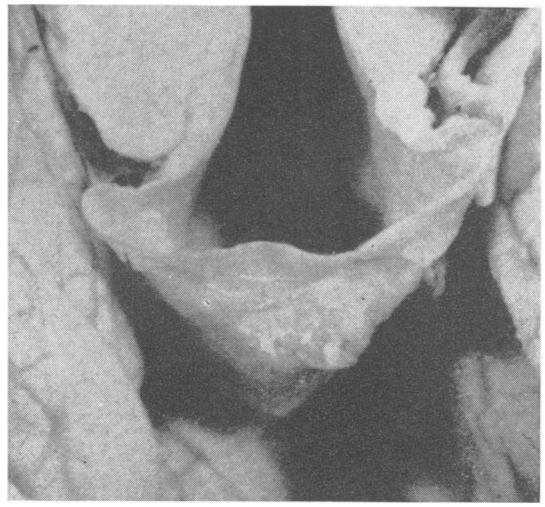


FIG. 29. *The attenuated floor of the third ventricle in a typical case of obstructive hydrocephalus.*

The hypothalamic nuclei have been either displaced laterally or actually destroyed by the intraventricular pressure which explains the absence of 'hypothalamic' symptoms following the puncture.

The thinness of the floor of the ventricle at the site of the puncture minimizes the chances of closure (Scarff, 1951). (*With permission of the editor of the* Journal of Neurosurgery.)

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

The reasons for the high incidence of severe late complications following the various 'shunting' operations are equally simple. It is axiomatic that

FIG. 30. *Lamina terminalis six weeks after puncture. The edges of the stoma are already completely epithelialized by union of the ependyma and pia (White, 1939). (With permission of the author and of the editor of the* Yale Journal of Biology and Medicine.)

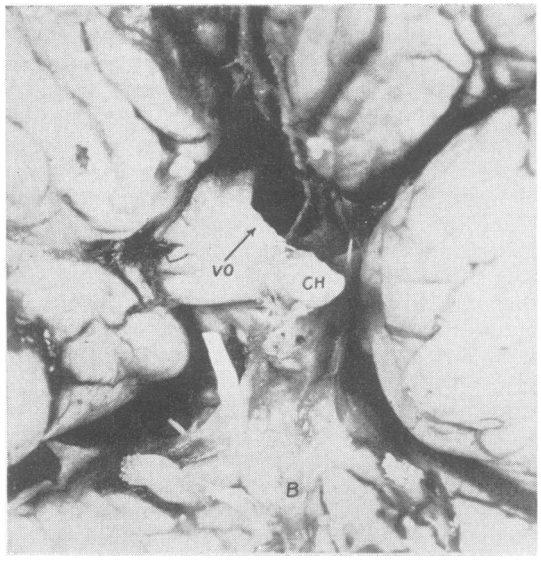


FIG. 31. *Lamina terminalis nine months after puncture. The epithelialized edges of the stoma still show no tendency to close (Stookey and Scarff, 1936). (Reproduced from the* Bulletin of the Neurological Institute of New York.)

whenever any hard foreign body, whether of rubber, plastic, glass, or metal, such as is used for 'shunt' tubes or valves, is implanted within the body, there inevitably is set up a local inflammatory reaction by the tissues of the host in contact with the foreign body, which results in proliferation of granulation tissue and ultimately in the formation of fibrous tissue about the foreign body. While the chemical irritation of a foreign body to the tissues of the host may be reduced by substituting plastics for rubber, the mechanical irritation of the foreign body still remains. In addition, cerebrospinal fluid is laden with proteins and minerals, which gradually are deposited as particulate matter on the inner surfaces of the tubes and valves, contributing to their obstruction or malfunction. This tendency is further accelerated whenever an end of a shunt tube or valves is bathed by mineral-rich bile, urine, or blood, as occurs with the biliary, ureteral, and cardiac shunts. In addition, in the ureteral shunts, the continuous loss of body electrolytes constitutes a unique and serious hazard to the life of the patient. All of these adverse factors, it must be stressed, are inherent in the shunts and cannot be eliminated by technical refinements.

The cerebrospinal fluid shunts which appear to function best are the intracranial shunts, especially the ventriculo-cisternal shunt of Torkildsen, the anterior transcallosal shunt of Lazorthes, and the posterior ventriculo-transcallosal shunt of Kluzer. These intracranial shunts, it will be noted, have certain features in common which set them apart from other shunts, namely, (1) the shunt tube itself is relatively short, measuring only a few inches in length; (2) both ends of these shunts are bathed in cerebrospinal fluid; and (3) the shunt is unaffected by the growth of the child, as it inevitably is with the cranio-somatic shunts. Even so, only four of 11 (37%) of Torkildsen's own cases of benign aqueduct stenosis with initial success in relieving hydrocephalus survived more than five years; death in the other seven cases (63%) presumably was due to late obstruction of the tube with recurrence of hydrocephalus. Although Lazorthes and his colleagues reported no late complications in their series of anterior ventriculo-transcallosal shunts, the longest follow-up of any of their cases was only four years with an estimated average survival of only two years, which still leaves ample opportunity for late complications to develop. Kluzer's nine successful cases of posterior transcallosal shunt, without late complications, are of especial interest for the reason that the obstructive hydrocephalus in each of his cases was caused by a pinealoma which was given *x*-ray therapy after operation. Since it is well known that pinealomas are often extremely sensitive to

irradiation and may not recur for many years after radiation therapy, it may fairly be questioned whether the long-term relief in these cases was due to the continued patency of the shunt tubes or to shrinkage of the pinealomas by the *x*-ray treatments.

COMMENTS

This survey suggests that more effort should be directed to mastering and refining the two basic and simple physiological operations for the treatment of hydrocephalus, namely, third ventriculostomy for the obstructive type, and endoscopic cauterization of the choroid plexuses for the non-obstructive (communicating) type. That refinement and improvement of these two basic operations is possible has been demonstrated by the fact that I was able, because of increased experience and facility with endoscopic cauterization of the choroid plexuses, between my 1942 series and my 1952 series, to reduce the operative mortality for this procedure from 15% to 5%, and to increase my percentage of permanent arrests from 50% to 80%. Similarly, in respect of the anterior technique for third ventriculostomy, while Stookey and myself, who originated the operation, experienced an operative mortality of 15% and successful arrests of hydrocephalus in only 55% of our cases (Scarff, 1951), Morello, and Migliavacca, because of refinements of technique, anaesthesia and post-operative care, were able to report, in 1959, an operative mortality of only 3% and successful long-term arrest of hydrocephalus in 75% of their cases, which had been followed from two to 11 years.

The development and standardization of an endoscopic technique for third ventriculostomy, along lines pioneered but never properly developed by Mixter (1923), by myself in 1936, and more recently by McNickle (1947) and by Dereymaeker (1951) is worthy of effort.

The causes of initial immediate failure after correctly performed third ventriculostomy should be looked into. Such a failure, evident within the first seven to 10 days after operation, cannot possibly be due to 'healing' of the ventriculostomy stoma by tissue regrowth. It seems probable that these failures occur in patients who are suffering from both obstructive and non-obstructive (communicating) hydrocephalus. Fortunately, defective absorption from the subarachnoid spaces can easily be proved by measuring (colorimetrically) the percentage of a measured amount of phenolsulphonphthalein introduced into the spinal subarachnoid space which is excreted in the urine during a two-hour period, Dandy and Blackfan (1913, 1914; Dandy, 1919, 1929). If this test shows a significant reduction in the absorption of dye from the subarachnoid system endoscopic cauterization of the choroid plexuses should be promptly performed.

Finally, there is need for development of new tests to help the surgeons determine more reliably than at present the probable ultimate 'intellectual potential' of a hydrocephalic child. The thickness of the cerebral cortex has been proved not to be a reliable indicator of an infant's intellectual potential (Scarff, 1952, 1959). Routine biopsy at operation of the cortices of hydrocephalic infants, with cell counts and cytoarchitectural studies, might reveal congenital defects in the cell content and organization of the brain which would provide a basis of valuable prognostic information and aid greatly in the selection of cases suitable for surgical intervention.

SUMMARY

An historical and critical review has been made of the various types of operations which have been developed for the treatment of hydrocephalus, and of the results obtained with each type of operation.

The operative mortality and the initial success were found to be essentially the same with all types of operation. However, the incidence of severe late complications was found to be many times greater after most 'shunt' operations than after third ventriculostomy and after cauterization of the choroid plexuses.

This survey indicates that the best results in the treatment of obstructive hydrocephalus have been obtained with third ventriculostomy, and that the best results in the treatment of non-obstructive hydrocephalus have been obtained by endoscopic cauterization of the choroid plexuses.

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