Influence of Aetiology on Prognosis in Surgically Treated Infantile Hydrocephalus

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Modern surgical treatment of infantile hydrocephalus results in a significantly increased expectation of life for patients so treated over those in whom a conservative policy has been adopted. But in order to give as accurate a prognosis as possible, one must inquire whether the results bear any relation to the aetiology of the condition. One of us (Guthkelch, 1967) has recently described his technique of ventriculo-atrial drainage for this condition, and assessed the expectation of life, intelligence, and numbers of secondary operations required in an unselected consecutive series of 166 infants so treated. This communication analyses the results in the same series with particular reference to cause.

It is conventional to distinguish between the congenital and acquired forms of infantile hydrocephalus. In our series, congenital cases fall into 4 groups: (1) associated with spina bifida, (2) associated with cranium bifidum, (3) due to aqueduct stenosis occurring otherwise than as part of the Arnold Chiari malformation, and (4) consequent upon exit (atresia of the foramen block foramina of Luschka and Magendie).

As to the cases in which the hydrocephalus appeared to have been acquired after birth, in some there was a clear antecedent history of bacterial meningitis, while the remainder were simply examples of communicating hydrocephalus without any history of infection. The likely aetiological factors in this latter group will be discussed later.

Material and Methods

The whole series of cases has been followed up to 1968 or earlier death, and the IQs of all survivors have been estimated at least once. The Griffiths Development Scale was used for infants less than 2 years old, and for older children the Stanford-Binet Form L-M. There was good agreement between the results in those children who were tested by both methods, but we

observed a slight rise in the average quotient of all cases tested, from 78 in the first year of life to 85 in the fifth. Where more than one estimate was made the most recent has been used.

In some instances intelligence tests were made on children who have since died, but as testing was impossible in most of the early post-operative fatalities, we have sought to exclude any bias by only presenting the results of tests on currently surviving children in our analysis (Table I). In fact, had the fatal cases been included, the pattern of the results would only have been significantly affected in one particular, namely the proportion of cases of post-meningitic hydrocephalus with IQ of less than 50; this is discussed below.

The figures for epilepsy in each group have been given for survivors only, since to express these as percentages of all cases would be to include, as having apparently avoided this complication, patients who were not at risk of developing it. For similar reasons, the revision rates of the valve assemblies have been calculated after excluding all cases which died within a month of primary operation. In fact, no cases requiring revision before the lapse of one month from this also died within that period. The variations in the liability to require revision during given periods of time after ventriculo-atrial drainage has first been instituted have already been given for the group as a whole (Guthkelch, 1967). We have not found any significant difference in the revision patterns for the various types of hydrocephalus into which this series is divided.

Since the earlier paper (Guthkelch, 1967) was written, 5 more patients have died, and the intellectual status of the survivors has been reclassified in line with modern practice, the minimum normal IQ being taken as 70. These facts explain certain differences between the present Table I and Tables I and IV of the earlier study.

Results

Hydrocephalus complicating spina bifida.

Almost exactly half the entire series (82 cases) suffered from hydrocephalus complicating spina bifida. In making comparisons between this group and the others one must remember that in addition to their hydrocephalus almost all the children showed at least some degree of congenital spinal palsy, a substantial number being paraplegic, and were

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TABLE I
Aetiology and Quality of Survival in Surgically Treated Infantile Hydrocephalus

	Total Cases	Required Revision*	Surviving†	Normally‡ Intelligent (IQ/DQ ≥ 70)	Epileptic‡
<i>Congenital</i>					
Spina bifida	82	24 (30%)	65 (79%)	41 (63%)	6 (9%)
Aqueduct stenosis	18	6 (38%)	12 (67%)	6 (50%)	4 (33%)
Cranium bifidum	16	3 (20%)	12 (75%)	6 (50%)	1 (8%)
Foraminal atresia	2	—	2	2	—
<i>Acquired</i>					
Post-meningitic	13	4 (33%)	10 (77%)	5 (50%)	4 (40%)
Non-infective communi- cating	35	7 (20%)	31 (89%)	26 (84%)	4 (13%)
Totals	166	44 (29%)	132 (80%)	86 (65%)	19 (14%)

*Percentages are of cases surviving primary operation by at least one month.

†Percentages are of total cases.

‡Percentages are of cases surviving to time of writing.

therefore liable to develop the complications of spinal paralysis, particularly pressure sores and chronic or recurrent infection of the urinary tract. At first it seemed surprising that the mortality in this group (21%) was only trivially higher than that of the rest of the series (19%), not least because the cases were, as already mentioned, consecutive and unselected. The probable explanation is that relatively few cases were referred in the earlier years of the study, and this in turn may have led to a lower late mortality (Table II) than would otherwise have been the case. 41 (63%) of the survivors appear to be of normal intelligence, and even this figure may be an underestimate, since in all children who were less than 2 years old at the time of testing, the Griffiths Development Scale was used. In this test locomotor function is one of 5 subscales on which the Development Quotient (DQ) is calculated, so that paraplegic children necessarily have a low score. 19 children are subnormal with IQ or DQ between 50 and 70. There are 5 children with

IQ < 50, but in 2 of these there were special predisposing circumstances. One was born to a mentally defective epileptic mother, and one had had a prolonged and near-fatal attack of ventriculitis due to infection of his myelocoele.

Seven children died of hydrocephalus or of the complications of ventriculo-atrial drainage: 4 deaths were known to be due to systemic infections, in 5 the cause was uncertain, and there was 1 case of fatal status epilepticus. Revision operations have been required in 24 cases (30%).

Aqueduct stenosis. Deformities of the aqueduct of Sylvius are found in many types of congenital malformation of the CNS. In this section 'aqueduct stenosis' refers to that variety of hydrocephalus in which, without obvious associated deformities such as cranium bifidum or spina bifida, or acquired disease (e.g. tumour), there was ventriculographic evidence of obstruction of the upper end of the aqueduct. It is known that at necropsy on cases of birth injury one can sometimes find obstruction of the aqueduct by blood clot or brain debris, but there was in the present series no example of hydrocephalus due to aqueduct stenosis occurring *de novo* after proven birth injury, though of course in some instances of aqueduct stenosis the head becomes so much enlarged before birth that normal delivery becomes difficult or impossible. There is one survivor in the present series whose fontanelle was deliberately perforated by the obstetrician during the second stage of labour, an estimated 150 ml. CSF being withdrawn before the baby was delivered.

Clinically, the most striking feature of this group of 18 cases (12% of the series) was the number of

TABLE II
*Pattern of Survival:
Hydrocephalus Complicating Spina Bifida*

Time from Operation (yr.)	Possible Survivors	Died During the Year
0-1	82	13
1-2	69	1
2-3	59	1
3-4	36	0
4-5	29	1
5-6	18	1
6-7	10	0
7-8	2	0
8-9	1	0

patients in whom the head became grossly enlarged without signs of acutely increased intracranial pressure, or indeed of much concern on the part of their parents. 2 babies had head circumferences of 52 and 49 cm., respectively, at the age of 1 month, a third of 50 cm. at 2 months, and another of 50 cm. at 6 months. Another boy (K.J.) was referred at 2½ years with a head circumference of 60 cm., and even so his parents were only worried by his backwardness and would not admit that his head was unduly large. The parents of another patient refused to allow treatment until, at the age of 6 years, and with a head circumference of 60 cm., he suddenly became blind. One patient was described as a 'normal, but not very bright boy' until he developed attacks of headache and vomiting when nearly 12 years old. His head circumference was then 61 cm., and x-rays showed the characteristically small, flat posterior fossa of aqueduct stenosis—a diagnosis that was confirmed by ventriculography.

Three cases (including K.J.) were originally treated by a combination of ventriculo-cisternostomy and spino-peritoneal drainage. (It was found that the former procedure alone was never satisfactory in infantile hydrocephalus, presumably because the distension of the brain in infancy, and perhaps before birth as well, obliterates the subarachnoid space over the cerebral hemispheres, and so interferes with the development of the normal absorptive mechanisms. When only a ventriculo-cisternostomy was performed, large collections of CSF gathered under the wound and the situation had to be restored by a spino-peritoneal shunt.) These 3 children later developed signs of recurrent increased pressure, and a Holter valve was inserted at periods of 1, 2, and 5 years respectively after their original combined drainage, since when 2 have survived 7 years, and the third 3 years. 2 further cases were originally treated by other methods—in 1 case ventriculo-subdural drainage by means of Forrest's disc, in the other ventriculo-atrial drainage by the Pudenz-Heyer valve. Consequently there were only 13 children with aqueduct stenosis in whom the Holter valve was inserted as a primary procedure. There were 2 operative deaths and 3 failures of control, but in the other 8 children there was an immediate arrest of enlargement of the head and their present head sizes are within or near to normal limits.

Six aqueduct-stenosis patients have died. Besides the 2 operative deaths already mentioned, 2 developed symptoms of recurrent increased pressure of such suddenness and gravity that they died before readmission to hospital. The fifth case died after having undergone multiple operations in another unit on account of difficulties with the valve

assembly, while the sixth, presenting as a case of vomiting and pyrexia with a patent valve, proved at necropsy to have an infected subdural effusion.

Of the 16 survivors of the initial operation, 6, including 1 who has since died of increased pressure, have required at least one reoperation, and in 1 the hydrocephalus is uncontrolled, but her physical and mental state is too poor to justify a further surgical procedure. The pattern of survival is shown in Table III.

The most disappointing feature of this group is that of the 12 survivors only 6 are within the normal range of intelligence; 2 are educationally subnormal (ESN), and 4 children, having IQs of 50, 38, 21, and 14, respectively, are gravely handicapped. 4 survivors, including 1 child of normal intelligence, suffer from epilepsy.

TABLE III
*Pattern of Survival:
Congenital Aqueduct Stenosis*

Time from Operation (yr.)	Possible Survivors	Died During the Year
0-1	18	4
1-2	14	1
2-3	12	0
3-4	10	0
4-5	8	0
5-6	7	1
6-7	4	0
7-8	4	0
8-9	1	0

Cranium bifidum with hydrocephalus. Occipital encephaloceles are commonly complicated by hydrocephalus, the pathogenesis of which is often far from clear. In some cases the cerebellar hemispheres are replaced by a number of folds of primitive neural material reminiscent of the state of development of the hind-brain of the fetus at 3-4 months of intrauterine life. This tissue lines the sac of the encephalocele, carrying with it a diverticulum of the 4th ventricle. When the swelling is amputated, hydrocephalus rapidly supervenes in about two-thirds of cases, whether the ventricular diverticulum is left open within the posterior fossa, preserved intact, or even ligatured *en masse* together with the neck of the dural sac. It is difficult to believe that these occipital sacs, some of which are quite small, can absorb any large amount of CSF, but evidently the operative procedure can upset the dynamics of the CSF circulation in the same way as may happen after repair of a spina bifida cystica.

There were 16 cases of cranium bifidum with hydrocephalus in the present series. 4 have died, 3 of them from the effects of increased intracranial

TABLE IV
Pattern of Survival:
Hydrocephalus Complicating Cranium Bifidum

Time from Operation (yr.)	Possible Survivors	Died During the Year
0-1	16	2
1-2	14	2
2-3	12	0
3-4	9	0
4-5	5	0
5-6	4	0
6-7	1	0

pressure: in 1 of these the hydrocephalus was never adequately controlled, 2 suffered a sudden obstruction of the atrial catheter, and the fourth child died from bilateral subdural haematomata. The pattern of survival is shown in Table IV.

Of the survivors, 4 are ineducable with very low IQs, though 6 are within the normal range; 2 are ESN. It is unlikely that delay in treatment was an important factor in determining the ultimate level of mental function in this group, for the head circumference at the time of institution of ventriculo-atrial drainage was on average only 2.5 cm. above normal for age. Of the operated cases, 4 have required reoperation and 1 suffers from epilepsy.

One further point; we have seen 9 cases of cranium bifidum in which there was such massive protrusion of brain tissue and evidence of amentia that no treatment was possible. So far as their cranial capacities are concerned such babies are by definition microcephalic, but their encephaloceles tend to enlarge with time, and at necropsy their ventricles are always found to be dilated. Consequently the total picture of cranium bifidum with encephalocele and ventricular dilatation is considerably graver than an analysis of surgically treatable cases would lead one to expect. This subject has

TABLE V
Pattern of Survival:
Post-meningitic Hydrocephalus

Time from Operation (yr.)	Possible Survivors	Died During the Year
0-1	13	1
1-2	12	0
2-3	12	0
3-4	11	2
4-5	8	0
5-6	6	0
6-7	3	0
7-8	1	0

recently been reviewed by Lorber (1967) with whose conclusions we are in agreement.

Exit foramen block. Surprisingly, only 2 examples of this condition occurred in the series reported here. They have survived 7 and 4 years, respectively, with IQs of 90 and 96. Neither suffers from any complications and neither has required a further operation.

Post-meningitic hydrocephalus. In the writers' experience this has become a rare condition. Only one new case, too recent for inclusion in the present series, has been referred since November 1962. Doubtless both the increased awareness among physicians of the atypical and often perplexing clinical features of neonatal meningitis and advances in therapy are responsible for this.

In respect of survival, the prognosis is fairly good (Table V): out of 13 cases, 10 are still alive. 4 of the survivors show signs of severe brain damage, 2 having IQs below 50, but 6 are within the normal range of intelligence (maximum IQ 113). The incidence of epilepsy is high (4 cases).

Of the 3 fatalities one was due to recurrent increased intracranial pressure, no details are known of 1, and the third was due to an error of judgement in inserting a valve before the original infection had been properly eradicated. 4 cases have required reoperation, of which only 1 still survives. The number of cases is too small to make any deduction about the relative frequency of post-meningitic hydrocephalus after different infecting organisms, not least because in 5 cases no firm bacteriological diagnosis was made. *Strep. pyogenes*, *N. meningitidis*, and *Esch. coli* were implicated twice, *Ps. proteus* and *Strep. pneumoniae* once each respectively.

Non-infective communicating hydrocephalus. There were 35 cases of non-infective hydrocephalus in which ventriculography showed no block within the ventricular system. In none of these was the head noticed to have been enlarged at the time of delivery: 17 were born prematurely, i.e. at or before the 35th week of gestation and in 10 of these labour was deliberately induced because of maternal pre-eclampsia. 7 full-term babies had shown clinical signs of intracranial damage at the time of birth, the diagnosis having been verified by lumbar or ventricular puncture in the neonatal period; in 1 of these sagittal sinus thrombosis was suspected and confirmed by venography. 2 cases arose as a result of subarachnoid haemorrhage—one as part of a haemorrhagic syndrome, the other of

uncertain cause—and another arose as a complication of craniotomy for a congenital cyst of the frontal lobe. In only 8 cases has no predisposing cause been identified.

In terms of head size for age, the group as a whole was no less abnormal than those previously considered, and the revision rate has been similar. So there is no reason to suppose that the degree of obstruction of the CSF circulation was less severe or that intervention was advised unnecessarily often; indeed several children were treated conservatively for a while in the hope that the disturbance of intracranial pressure would settle down without operation, but ultimately required it. Compared with those for other groups, however, the results have been altogether more promising.

There have been 4 fatalities (11%), the survival pattern being shown in Table VI. 2 children died of valve bacteraemia, 1 of them after a survival of more than 7 years, the third of rupture of the oesophagus unrelated to her hydrocephalus, and the

a higher level than those born full-term but suffering a known birth injury. We could not find any evidence in this group of a relation between level of intelligence and head size measured either at the time of insertion of the valve or at latest follow-up, even when the small subgroups were analysed separately. But since in most cases serial pre-operative measurements were necessarily lacking, operation being indicated at the time of first referral, the possibility that rate of enlargement is a factor in determining ultimate intellectual level is not excluded. Of 3 children with IQ < 50, there seemed to be exceptional predisposing circumstances in 2: 1 associated with a haemorrhagic state, the other with frequent and severe epileptic attacks who may well have suffered anoxic brain damage in one or more of these.

There was one occasion on which the routine assessment of intelligence had an unexpected clinical application. A child who had required the insertion of a valve 3 weeks after birth passed his first milestones at the normal time, but when brought up for psychometric assessment at the age of 8 months (his hydrocephalus being completely under control) his DQ was found to be 32. In view of the discrepancy between this finding and his previous progress, and despite the absence of any history of fever, vomiting, failure to feed, etc. he was re-admitted to hospital forthwith, but died within a couple of days of septicaemia secondary to colonization of the valve with *Staph. albus*.

Discussion

Our figures suggest that among the five aetiologicaly different types of infantile hydrocephalus in which the numbers are sufficient for comparison, one, namely the non-infective communicating variety, has a lower mortality than the others, but that otherwise there is little difference in their patterns of survival. Throughout the whole series just over two-thirds of all deaths occurred during the first year after the original insertion of the valve, and nearly half the remainder during the second year. Thereafter there has been only a small continuing death rate.

In this series, the members of which were first submitted to ventriculo-atrial drainage between April 1958 and December 1964, 29% of all cases have required revision, whereas for a similar series operated upon between 1961 and 1965, Hemmer (1967) reported a figure of 62%. The reasons for the difference are not wholly clear but in Hemmer's series 40% of all cases treated were revised within 6 months, whereas our figure was only 11%. The highest percentage of cases

TABLE VI
*Pattern of Survival:
Non-infective Communicating Hydrocephalus*

Time from Operation (yr.)	Possible Survivors	Died During the Year
0-1	35	2
1-2	33	1
2-3	31	0
3-4	22	0
4-5	18	0
5-6	15	0
6-7	12	1
7-8	7	0
8-9	5	0

remaining child of a febrile illness which developed during an outbreak of benign lymphocytic choriomeningitis in his home town. We know that the mother of this last patient was suffering from this infection at the time of his death, but since necropsy was not permitted, the possibility that the child himself died of an infected valve is not excluded.

Three children, all of whom have survived more than 6 years with a ventriculo-atrial shunt, had previously been treated by spino-peritoneal drainage with good effect, and are now aged 12, 12, and 10 years, with IQs 152, 119, and 110, respectively. The revision rate after insertion of the Holter valve has been low—7 cases or 20%.

The mean level of intelligence of the 31 survivors is higher than in the obstructive and post-meningitic cases, those associated with premature delivery due to maternal pre-eclampsia showing on average

requiring operations was found in the group suffering from aqueduct stenosis, but though hydrocephalus complicating spina bifida appears to be more likely than other forms to remit spontaneously (Laurence and Coates, 1962, 1967) the rate of revision after surgical treatment proved to be quite high both in this series and in the experience of Forrest, Hole, and Wynne (1966).

The reason that so few aqueduct stenosis cases have normal intelligence may be partly that this condition sometimes occurs as one of a number of associated malformations of the CNS which are incompatible with normal intelligence. Such a syndrome has been described by Edwards, Norman, and Roberts (1961). But of 3 surviving children with IQs over 80, 2 were operated upon very early, namely at the age of 2 months or less, while the third is the mild case mentioned above which was not referred for operative treatment until the age of 12 years. This suggests that in other cases the brain may originally have been capable of normal function but suffered severe damage through rapid and excessive expansion of the ventricles early in life, and that this process can be checked by early operation (cf. Lorber and Zachary, 1968).

If we had not excluded all fatal cases from the survey of intelligence, the numbers of children at each intelligence level would have been significantly affected in the post-meningitic group. Here it has happened that 2 patients who survived more than 3 years have died in the past 18 months. Their IQs (not included in our results) were 44 and 48, respectively; so that had they lived a little longer the proportion of normally intelligent survivors would have been reduced to 50%, 33% having IQs below 50. These findings are similar to those of Lorber and Pickering (1966), and we agree with them that the most important reason for the low intelligence levels of survivors is the brain damage resulting directly from the bacterial infection.

Our results suggest that several factors, working singly or together, may determine severe mental defect in treated infantile hydrocephalus: (1) developmental anomalies of the structure of the brain, (2) previous bacterial infection, (3) mechanical damage caused by overdistension of the ventricles or by birth injury. The surgical restoration of normal intracranial pressure cannot annul the effects of these.

It is impossible to make a direct comparison between the results presented here and those of Lorber and Zachary (1968), since our classification differs somewhat from theirs. But if it be assumed, as internal evidence in their paper suggests, that their

cases of *primary congenital hydrocephalus* correspond with our *non-infective communicating, foraminal atresia*, and *aqueduct stenosis* groups, then the mortality rates are almost identical and the percentages of normally intelligent survivors are similar (84% in their series, 75% in ours) and differ only because of our large proportion of mentally retarded aqueduct stenosis cases.

We agree with them that once the suspicion of hydrocephalus is confirmed, there is (except when it complicates spina bifida) rarely room for a conservative policy; almost all the cases will ultimately require operation and the longer it is deferred, the greater the risk of a bad result in terms of intellectual function, though obviously this risk must be balanced against that of the mortality and morbidity due to ventriculo-atrial drainage in each individual case.

One must be cautious in drawing any conclusions about the incidence of epilepsy, not least because this can first appear many years after increased intracranial pressure has been brought under control. Two groups show a considerably higher frequency than the others: among cases of congenital hydrocephalus those due to aqueduct stenosis, and among the acquired cases those complicating bacterial meningitis. The latter is not unexpected, since epilepsy is known to occur after this disease; for the former we have no explanation unless it be that the extreme expansion of the brain which had already occurred in some cases, and to which reference is made in the text, had caused mechanical damage to the cortex with subsequent scarring.

Summary

A series of 166 cases of infantile hydrocephalus treated by ventriculo-atrial drainage has been studied with particular reference to the effect of aetiology on survival and intelligence.

Non-infective communicating hydrocephalus carries the best prognosis and cases of this sort treated surgically require less frequent secondary operations.

The incidence of post-meningitic hydrocephalus has greatly diminished since 1962; the intelligence level of some of the survivors is low, and they have a high incidence of epilepsy.

In this series, cases of hydrocephalus due to congenital aqueduct stenosis tended to be referred for treatment very late, after excessive head expansion had already occurred. This may have contributed to poor results in terms of the intelligence of the survivors and their liability to epilepsy.

80% of all the patients treated are still alive. Two-thirds of the fatalities occurred within one

year of the institution of treatment and nearly half the remainder during the second year.

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