THE BLOOD AND SPINAL FLUID SUGAR AND CHLORIDE CONTENT IN MENINGITIS

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It has long been recognized that the cerebrospinal fluid contains glucose and chlorides and that in meningitis their amount is reduced. This is generally supposed to be of diagnostic importance in distinguishing meningitis from certain other diseases in which there is a meningeal reaction, such as acute anterior poliomyelitis. In the present paper a study of the sugar and chloride content of the cerebrospinal fluid from children suffering from conditions other than meningitis (control series) and from cases of meningitis has been made, and the results correlated with the sugar and chloride content of the blood. The control series consisted of seventeen cases with no organic meningeal disease and from whom lumbar puncture, performed for diagnostic purposes, yielded a normal cerebrospinal fluid. Care was taken to exclude all cases in which there had been convulsions, as these have been proved to cause a marked alteration in the blood sugar content (MacLean, 1936). Of the meningitis cases there were twenty-eight with tuberculous meningitis, fourteen with meningococcal, one with pneumococcal, two with *B. coli*, two with influenzal and one with benign lymphocytic meningitis. All the cases had fasted for at least five hours before the blood and cerebrospinal fluid were taken. The blood was always obtained immediately before the lumbar puncture was performed as withdrawal of cerebrospinal fluid is known to cause a substantial rise in the blood sugar (Weichsel and Herzger, 1936).

Methods.—The blood and spinal fluid sugar was estimated by the modified Folin-Wu (1920) method on 0.2 c.c. of blood and 1 c.c. of cerebrospinal fluid. For chloride estimations, 1 c.c. of blood or cerebrospinal fluid was used under the conditions worked out by Whitehorn for performing the Volhard titration method (Van Slyke, 1924).

The percentage of sugar in the cerebrospinal fluid

Normal fluid.—From a review of the literature it appears that in normal subjects there are wide variations in the percentage of sugar in the cerebrospinal fluid. The findings obtained by various writers (table 1) show a wide range of normality, but the lowest finding is not less than 35 mgm. per cent. The results obtained in the present investigation are similar though the lowest

limit is here 50 mgm. per cent. (table 2). Possibly the wide variations may be explained by concomitant variations in the blood sugar content. It is known that, even in normal circumstances, the blood sugar is subject to wide fluctuations; thus excitement, pain or the ingestion of carbohydrate produce striking alterations and it seems reasonable to suppose that the cerebrospinal fluid sugar will show similar changes. If this is in fact the case, then, in spite of variations in the blood sugar content, the ratio of cerebrospinal fluid sugar to blood sugar should be constant. Table 3 gives the results arrived at by various workers. This shows a wide range and reference to table 2 shows an equally wide range in the cases investigated. The lowest ratio found by other workers is 0.42 while in the present series it is 0.60.

TABLE 1
THE CEREBROSPINAL FLUID SUGAR CONTENT IN NORMAL CASES

OBSERVER	C.S.F. SUGAR IN MGM. PER CENT.	
	MAXIMUM	MINIMUM
Wright, Herr and Paul (1931)	80	45
Cohn, Levinson and McCarthy (1933)	75	38
Nissen (1937)	65	35
Rimele (1938)	60	40
Goodwin and Shelley (1925)	77	40
Hendry (present series)	83	50

TABLE 2
BLOOD AND CEREBROSPINAL FLUID SUGAR CONTENT IN CASES
NOT SUFFERING FROM MENINGITIS (CONTROL SERIES)

CASE	BLOOD SUGAR MGM. PER CENT.	C.S.F. SUGAR MGM. PER CENT.	RATIO OF C.S.F. TO BLOOD SUGAR	DIAGNOSIS
1	80	67	0.83	Diabetes mellitus
2	71	56	0.78	Microcephaly
3	81	65	0.80	Pneumonia
4	100	71	0.71	Mental deficiency
5	71	61	0.86	Hysteria
6	80	60	0.75	Malnutrition
7	104	83	0.87	Mental deficiency
8	82	66	0.81	Pneumonia
9	81	69	0.85	Nephritis
10	100	76	0.76	Mental deficiency
11	92	71	0.78	Spastic diplegia
12	68	50	0.72	Tonsillitis
13	95	61	0.64	Spastic diplegia
14	79	51	0.64	Congenital lues
15	90	60	0.66	Hydrocephalus
16	95	80	0.84	Gastro-enteritis
17	76	50	0.60	Mental deficiency
Average		64	0.76	

There is a possible explanation of this apparent lack of correlation between the blood and cerebrospinal fluid sugar content. If changes in the blood sugar content are not immediately reflected in the cerebrospinal fluid sugar content,

TABLE 3

THE RATIO OF CEREBROSPINAL FLUID SUGAR TO BLOOD SUGAR
IN NORMAL CASES

OBSERVER	RATIO OF C.S.F. TO BLOOD SUGAR	
	MAXIMUM	MINIMUM
Wilcox and Lyttle (1923)	0.70	0.50
Levinson (1925)	0.75	0.50
Greenfield (1930)	0.65	0.45
Cohen (1936)	0.93	0.52
Stewart (1928)	0.82	0.42
Hendry (present series)	0.87	0.60

in other words if there is a lag in the transference of sugar from the blood to the cerebrospinal fluid, then, in the event of there being a sudden change in the blood sugar percentage, any correlation that may exist will not show itself until some time after this change takes place. To test this hypothesis an opportunity occurred to raise the blood sugar level rapidly by giving intravenous glucose and subsequently to examine the spinal fluid and the blood. It is known that when glucose is given intravenously there is a sudden rise in the blood sugar content up to about 300 mgm. per cent., followed by a rapid fall so that at the end of about one hour it has returned to approximately the normal level (Crawford, 1938). In table 4 the results of this experiment are shown. From this it will be seen that the ratio of fasting cerebrospinal

TABLE 4

BLOOD AND SPINAL FLUID SUGAR CONTENT AND RATIO OF CEREBRO-
SPINAL FLUID TO BLOOD SUGAR IN FASTING STATE AND ONE AND
A HALF HOURS AFTER 0.5 GM. GLUCOSE PER KILO. OF BODY WEIGHT
GIVEN INTRAVENOUSLY

FASTING STATE			1½ HOURS AFTER 35 C.C. 20 PER CENT. GLUCOSE INTRAVENOUSLY		
BLOOD SUGAR MGM. PER CENT.	C.S.F. SUGAR MGM. PER CENT.	RATIO OF C.S.F. TO BLOOD SUGAR	BLOOD SUGAR MGM. PER CENT.	C.S.F. SUGAR MGM. PER CENT.	RATIO OF C.S.F. TO BLOOD SUGAR
95	61	0.64	105	87	0.82

fluid sugar to blood sugar was 0.64. An hour and a half after the intravenous injection of 35 c.c. of twenty per cent. glucose in saline the blood sugar was 105 mgm. per cent. and the cerebrospinal fluid sugar 86 mgm. per cent., giving a ratio of 0.82. From this experiment it seems probable that variations in the ratio of cerebrospinal fluid to blood sugar are dependent on variations in

the blood sugar content and delay in their manifestation in the cerebrospinal fluid.

Tuberculous meningitis.—All investigators report a reduced spinal fluid sugar in tuberculous meningitis and the majority mention that this value varies with the stage of the disease. Neale and Esslemont (1928) quote several cases in which there was complete absence of sugar, a finding which is confirmed by Bokay (1929). Mogilnicki (1930), on the other hand, states that it is never completely absent and Soedjono's (1938) results support this. Nissen (1937) quotes 40 mgm. per cent. as the lower limit of normal cerebrospinal fluid sugar and finds that ninety-one per cent. of his tuberculous cases yield values below 30 mgm. per cent., whilst Tcherkassov and Jolkver (1935) find the majority (sixty-one per cent.) of their results under 20 mgm. per cent. These last three observers mention the finding of a raised blood sugar in the later stages of the disease. The findings from the literature are shown in table 5.

TABLE 5
THE CEREBROSPINAL FLUID SUGAR CONTENT IN TUBERCULOUS
MENINGITIS

OBSERVER	C.S.F. SUGAR IN MGm. PER CENT.	
	MAXIMUM	MINIMUM
Neale and Esslemont (1928)	72	0
Mogilnicki (1930)	36	8
Soedjono (1938)	75	10
Tcherkassov and Jolkver (1935)	20	—
Nissen (1937)	30	—
Hendry (present series)	86	5

As regards the variations in cerebrospinal fluid sugar level during the course of the disease, Soedjono (1938) quotes four distinct phases : (a) when there is a gradual fall in cerebrospinal fluid sugar to 18 or 20 mgm. per cent. ; (b) a few days during which the value fluctuates between 10 and 40 mgm. per cent. ; (c) a rise to normal limits of 50 to 65 mgm. per cent. ; and (d) a repetition of phase (b).

No blood sugar estimations are given for comparison. Weichsel and Herzger (1936) regard diminution in cerebrospinal fluid sugar as a diagnostic sign occurring twenty-five to thirty days before death. This decrease follows the rise in globulin and the increase in cell count. They find that about two weeks before death, there may be a slight increase in sugar content before the final drop to 10–20 mgm. per cent. and give the ultimate ratio of cerebrospinal fluid sugar to blood sugar as 0.12–0.08.

Mogilnicki (1930) in reviewing seventy-two cases, attributes the finding of a high blood sugar content to the occurrence of convulsions. These, after a time lag, raise the cerebrospinal fluid sugar value, and, as will be seen later, such cases furnish a cerebrospinal fluid sugar well within normal limits and emphasize the necessity for withdrawing blood as nearly as possible at the same time as the cerebrospinal fluid in order to obviate misinterpretation of an unexpectedly high cerebrospinal fluid sugar content.

In the present investigation twenty-eight cases of tuberculous meningitis have been studied in children whose ages ranged from four months to eight and

a half years. On an average, the blood and cerebrospinal fluid were examined every two or three days. In a few cases one estimation only was carried out, the children being in a late stage of the disease when admitted to hospital and dying before a second examination could be made. In the cases in which more than one estimation was possible the longest interval between the first and the last was twenty-two days and the shortest one day. This difference in time between first and final findings must be borne in mind, as, in the cases in which the interval is short, both estimations represent the condition in the late stage of the disease, whilst, in the cases in which there is a considerable interval, the first estimation represents the condition at an early stage and the last at a late stage. In table 6 the initial and final blood sugar and cerebrospinal fluid sugar values are shown.

TABLE 6

THE CEREBROSPINAL FLUID AND BLOOD SUGAR IN TUBERCULOUS MENINGITIS

NAME	FIRST ESTIMATIONS			TIME INTERVAL IN DAYS	FINAL ESTIMATIONS		
	SUGAR IN MGM. PER CENT.		RATIO OF C.S.F. SUGAR TO BLOOD SUGAR		SUGAR IN MGM. PER CENT.		RATIO OF C.S.F. SUGAR TO BLOOD SUGAR
	BLOOD	C.S.F.			BLOOD	C.S.F.	
M.I. ..	—	7	—	8	73	22	0.30
A.A. ..	77	14	0.18	—	—	—	—
K.K. ..	143	36	0.25	—	—	—	—
M.M. ..	105	27	0.24	3	84	32	0.38
J.G. ..	87	20	0.23	1	75	11	0.14
P.R. ..	74	22	0.27	—	—	—	—
A.McR.	93	63	0.67	—	—	—	—
C.B. ..	50	12	0.24	1	89	20	0.22
V.M. ..	106	35	0.32	4	190	30	0.16
M.McM.	88	24	0.27	2	175	34	0.13
P.S. ..	100	24	0.23	3	87	10	0.11
J.B. ..	75	18	0.21	4	63	14	0.22
S.D. ..	78	47	0.60	15	116	24	0.20
R.McN.	274	86	0.31	14	85	16	0.18
J.H. ..	78	14	0.18	4	85	36	0.42
J.McG.	123	36	0.29	3	70	13	0.17
M.McG.	128	37	0.28	22	127	12	0.08
A.N. ..	—	15	—	13	—	17	—
C.D. ..	75	16	0.21	3	83	11	0.13
W.B. ..	83	27	0.32	6	68	14	0.20
M.S. ..	—	12	—	3	83	5	0.06
D.McK.	76	19	0.24	—	—	—	—
E.H. ..	76	12	0.16	4	87	8	0.09
M.L. ..	120	58	0.47	—	—	—	—
W.L. ..	67	8	0.12	1	51	11	0.21
R.C. ..	91	13	0.14	2	83	6	0.07
A.A. ..	72	6	0.08	2	109	15	0.14
A.McD.	68	21	0.30	5	108	20	0.18

Taking a sugar concentration in the cerebrospinal fluid of 50 mgm. per cent. as the lower limit of normality, twenty-five of the twenty-eight cases showed

initial values below normal, and taking 0.60 as the lower limit of the ratio of cerebrospinal fluid sugar to blood sugar, twenty-three of the cases showed a ratio below this figure at the first examination. In twenty-two of the cases the blood and cerebrospinal fluid sugar was estimated more than once, and in the final examinations of these, which were in each case made within one or two days of death, all gave a cerebrospinal fluid sugar concentration of less than 50 mgm. per cent. and a ratio of cerebrospinal fluid sugar to blood sugar of between 0.06 and 0.42. In fourteen of these cases the ratio of cerebrospinal fluid sugar to blood sugar had fallen between the first and last estimations. Fig. 1 illustrates the progressive fall in the cerebrospinal fluid sugar content

FIG 1

CASE OF TUBERCULOUS MENINGITIS SHOWING THE RISING BLOOD SUGAR CONTENT, THE FALLING CEREBO-SPINAL FLUID SUGAR CONTENT AND THE DIMINISHING CEREBO-SPINAL FLUID SUGAR : BLOOD SUGAR RATIO AS THE DISEASE ADVANCES.

and the diminishing ratio of cerebrospinal fluid sugar to blood sugar in a typical case. Of the three cases which showed a normal cerebrospinal fluid sugar value two gave a ratio of cerebrospinal fluid sugar to blood sugar of less than 0.60, suggesting that the relatively high sugar content of the cerebrospinal fluid was due to disturbance in the blood sugar concentration.

This is well exemplified in the case of R. McN., a child aged two and a half years who, on admission to hospital, did not show signs typical of meningitis. He had been having continuous convulsions for one and a half hours before admission and a lumbar puncture was performed half an hour later. The

cerebrospinal fluid sugar was 86 mgm. per cent., a figure well above the normal value and, as an isolated observation, a strong point against the case being one of meningitis, but the blood taken at the same time gave a sugar concentration of 274 mgm. per cent. and the ratio of cerebrospinal fluid sugar to blood sugar was 0.31. In this case, hyperglycaemia induced by the convulsions had led to a marked and misleading increase in the concentration of sugar in the cerebrospinal fluid, but in spite of this, the ratio of cerebrospinal fluid sugar to blood sugar lay well below the normal limit.

Of the two cases which gave a ratio of 0.60 or over, one with a ratio of 0.67 died before a second estimation could be made, but the other, with an initial ratio of 0.60 showed a ratio of 0.41 on the second examination and of 0.20 fifteen days subsequent to the first examination. The results from this case are shown in fig. 1.

In the majority of cases a cerebrospinal fluid sugar concentration below 50 mgm. per cent. is strong presumptive evidence of meningitis, but a high finding must be viewed with caution unless a concomitant blood sugar estimation is carried out, for variations in this have an influence on the cerebrospinal fluid sugar content. The ratio of cerebrospinal fluid sugar to blood sugar is always below normal and is therefore of greater diagnostic value.

Purulent meningitis.—Most workers are agreed that in the early stage of purulent meningitis, the cerebrospinal fluid sugar is in small amount or completely absent.

Levinson and Cohn (1936) reporting five cases of meningococcal meningitis, examined before injection of serum, found cerebrospinal fluid sugar values ranging from zero to a maximum of 23 mgm. per cent. with an average of 9 mgm. per cent. Three cases of influenzal and five of streptococcal meningitis showed absence of sugar. Ford (1937) mentions a cerebrospinal fluid sugar of 10 mgm. per cent. or less. Neale and Esslemont (1928) find an initial low reading with some fluctuations from day to day until recovery when the cerebrospinal fluid sugar rises to the normal level. In two fatal cases it disappeared entirely. Soedjono (1938) remarks on a constant fall in the cerebrospinal fluid sugar in purulent meningitis and a low content which is most marked shortly before death.

Fourteen cases of meningococcal meningitis have been studied, and the blood and spinal fluid sugar levels found on admission are set out in table 7. None of the cases received serum; all were treated with prontosil. From this it will be seen that the cerebrospinal fluid sugar concentration ranged, on admission, from 0–52 mgm. per cent., with an average of 15 mgm. per cent. The ratio of cerebrospinal fluid sugar to blood sugar varied from 0.08–0.48 with an average of 0.19. If recovery took place, the sugar content slowly increased and after a varying period, usually less than a week, ran its normal parallel course to the blood sugar. The latter is usually raised in the first stage of the disease as at this time convulsions commonly occur. Fig. 2 illustrates a typical case in which recovery took place. One case of pneumococcal, two of *B. coli* and two of influenzal meningitis were also investigated. The children were all critically ill and died soon after admission. The sugar content of the cerebrospinal fluid was reduced to zero in every case.

TABLE 7

THE BLOOD AND CEREBROSPINAL FLUID SUGAR AND CHLORIDE CONTENT DURING THE ACUTE STAGE OF MENINGOCOCCAL MENINGITIS

NAME	BLOOD SUGAR MGM. PER CENT.	C.S.F. SUGAR MGM. PER CENT.	RATIO OF C.S.F. SUGAR TO BLOOD SUGAR	BLOOD NaCl MGM. PER CENT.	C.S.F. NaCl MGM. PER CENT.	RATIO OF C.S.F. NaCl TO BLOOD NaCl
B.T. ..	84	35	0.41	465	716	1.54
A.M. ..	—	10	—	379	616	1.62
M.H. ..	91	Absent	—	363	640	1.49
J.F. ..	80	10	0.12	414	616	1.48
M.L. ..	63	12	0.19	517	643	1.24
A.W. ..	111	52	0.46	413	610	1.47
I.S. ..	—	12	—	—	646	—
T.F. ..	53	17	0.32	445	635	1.42
J.F. ..	113	10	0.08	476	648	1.36
M.G. ..	69	Less than 5	0.08	427	585	1.36
R.I. ..	65	Less than 5	0.08	338	623	1.83
M.F. ..	125	5	0.04	395	640	1.64
A.H. ..	91	44	0.48	366	630	1.72
T.M. ..	65	Less than 5	0.08	498	630	1.28

FIG. 2.

CASE OF MENINGOCOCCAL MENINGITIS SHOWING THE FALL IN THE BLOOD SUGAR CONTENT AND THE RISE IN THE CEREBRO SPINAL FLUID SUGAR CONTENT AS RECOVERY TAKES PLACE

As a demonstration of the value of estimating the cerebrospinal fluid sugar and, in particular, the ratio it bears to the blood sugar for differential diagnosis, the following cases may be mentioned.

Case 1.—J.H. was a case of abdominal tuberculosis. On account of persistent nuchal rigidity in addition to the other clinical findings, he was lumbar punctured five times between the onset of the stiffness of the neck and death nine days later. The blood and cerebrospinal fluid findings are shown in table 8. From this it will be seen, that with the exception of the results on

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May 22, 1938, the cerebrospinal fluid sugar content and percentage ratio were within normal limits. No meningitis was found on post-mortem examination.

TABLE 8

BLOOD AND CEREBROSPINAL FLUID SUGAR CONTENT IN A CASE OF ABDOMINAL TUBERCULOSIS SUSPECTED OF HAVING MENINGITIS

DATE	BLOOD SUGAR MGM. PER CENT.	CEREBROSPINAL FLUID SUGAR MGM. PER CENT.	RATIO OF C.S.F. SUGAR TO BLOOD SUGAR
16.5.38	92	70	0.75
19.5.38	78	66	0.84
20.5.38	112	98	0.87
22.5.38	93	28	0.30
25.5.38	64	66	1.03

Case 2.—I.K. had hilum tuberculosis, and a history of vomiting, constipation, anorexia and listlessness raised the suspicion of meningitis. The cerebrospinal fluid sugar was 71 mgm. per cent., and the ratio of cerebrospinal fluid to blood sugar 0.90.

Case 3.—J.R. was a case of benign lymphocytic meningitis. Table 9 shows the blood and cerebrospinal fluid findings. In this case the diagnosis on admission was doubtful on clinical findings alone but the cerebrospinal fluid sugar content and the percentage ratio afforded strong evidence against its being a case of true meningitis.

TABLE 9

BLOOD AND CEREBROSPINAL FLUID SUGAR CONTENT IN A CASE OF BENIGN LYMPHOCYTIC MENINGITIS

DATE	BLOOD SUGAR MGM. PER CENT.	CEREBROSPINAL FLUID SUGAR MGM. PER CENT.	RATIO OF C.S.F. SUGAR TO BLOOD SUGAR	CELLS
27.6.38	128	85	0.66	Lymphocytes
28.6.38	—	81	—	Lymphocytes
2.7.38	—	66	—	Lymphocytes
11.7.38	—	54	—	Lymphocytes
14.7.38	77	51	0.69	Lymphocytes

Two cases of anterior poliomyelitis were also examined. The results of sugar estimations on blood and spinal fluid are set out in table 10. In these two cases, as in case 3, the cerebrospinal fluid sugar content and the ratio of cerebrospinal fluid sugar to blood sugar were not reduced below the normal limits.

TABLE 10

BLOOD AND CEREBROSPINAL FLUID SUGAR CONTENT IN TWO CASES OF POLIOMYELITIS

CASE	BLOOD SUGAR MGM. PER CENT.	C.S.F. SUGAR MGM. PER CENT.	RATIO OF C.S.F. SUGAR TO BLOOD SUGAR
1	54	50	0.92
2	153	137	0.96

Percentage of chlorides in blood and cerebrospinal fluid

Normal cases.—Most workers are agreed that, in adults, the normal chloride content of the blood varies between 450 and 600 mgm. per cent., and of the cerebrospinal fluid between 700 and 750 mgm. per cent. and that as a rule the results for children are similar, though Stewart (1928) gives 636–763 mgm. per cent. as the range for the cerebrospinal fluid chloride in the latter cases. Table 11 gives a few of the results of other workers. This shows that the normal blood chloride lies between 450–660 mgm. per cent. and cerebrospinal fluid chloride between 636–783 mgm. per cent.

TABLE 11
THE NORMAL VALUES FOR BLOOD AND CEREBROSPINAL FLUID CHLORIDE

OBSERVER	BLOOD NaCl MGM. PER CENT.	C.S.F. NaCl MGM. PER CENT.
Hawk and Bergein (1938)	450–500	—
Finkelstein and Merson (1934)	500–600	720–740
Soedjono (1938)	475–550	700–750
Stewart (children) (1928)	—	636–763
Neale and Esslemont (1928)	—	696–783
Hendry (children) (present series)	355–543	635–770

In the present investigation cerebrospinal fluid chloride and blood chloride were estimated in forty children who had no sign of meningeal involvement. The blood chloride was found to range from 355–543 mgm. per cent. and the cerebrospinal fluid chloride from 635–770 mgm. per cent. The low readings can be explained by the fact that many of these cases were dehydrated infants and children admitted with a history of vomiting, diarrhoea and convulsions and were lumbar punctured for diagnostic purposes. In every case in which the blood chloride was low, a lowered reading was also found in the cerebrospinal fluid. These results correspond with the findings of Finkelstein and Merson (1934), Linder and Carmichael (1928) and Nowika (1924) who hold that blood and spinal fluid chloride run a parallel course. In order to prove this from the present series, the ratio of cerebrospinal fluid chloride to the blood chloride was calculated in each case. This was found to range from 1.32–1.91 with a ratio of 1.60–1.65 in a third of the cases and the average at 1.59. As most of these cases were lumbar punctured once only, no serial figures are available.

Tuberculous meningitis.—Investigation of the literature on the chloride content of cerebrospinal fluid in tuberculous meningitis shows that most workers look on 500–690 mgm. per cent. as the expected range. All agree that there is a progressive diminution with the progress of the disease.

Nowika (1924), Linder and Carmichael (1928) and Fowweather (1930) believe that the low cerebrospinal fluid chlorides indicate a general reduction in body chlorides. Neale and Esslemont (1928) mention a general agreement

between the relative blood and cerebrospinal fluid chloride content but do not establish any strict ratio for meningitic or non-meningitic cases. Nissen (1937) finds that the values for cerebrospinal fluid chlorides and sugar tend to run parallel. From table 12 it appears that cerebrospinal fluid chloride in tuberculous meningitis may lie between 450 and 680 mgm. per cent.

TABLE 12

THE CEREBROSPINAL FLUID CHLORIDE CONTENT IN TUBERCULOUS MENINGITIS

OBSERVER	C.S.F. NaCl IN MGm. PER CENT.	
	MAXIMUM	MINIMUM
Soedjono (1938)	600	450
Fowweather (1930)	640	590
Finkelstein and Merson (1934)	680	—
Neale and Esslemont (1928)	673	500
Hendry (present series)	757	543

The present series comprises twenty-eight cases. In many of these the spinal fluid chloride was estimated on several occasions, but in table 13 only the first and last estimations are shown. From this it will be seen that on the first examination the chloride ranged between 689 and 549 mgm. per cent. and shortly before death between 757 and 561 mgm. per cent. The average ratio of cerebrospinal fluid chloride to blood chloride both in the early and in the late stage was 1.55. These identical average ratios, which correspond so closely to the average normal ratio of 1.59, strongly suggest that any reduction in the cerebrospinal fluid chloride content in tuberculous meningitis is not due to the meningeal condition, but to reduction of chloride in the blood. The fact that there is also reduction in the urinary chlorides strengthens this supposition. Reference to fig. 3 shows the course of blood and spinal fluid chloride and sugar content from a typical case and demonstrates the parallelism of the chloride throughout the disease in contrast to the ever increasing difference in the two sugar curves. Referring to the tables (6 and 13) showing the results of sugar and chloride estimations in blood and cerebrospinal fluid on admission and shortly before death, it will be noticed that, at the onset, a low cerebrospinal fluid sugar content and ratio is a much more constant finding than a lowered chloride content and a more satisfactory test from a diagnostic point of view.

Meningococcal meningitis.—In meningococcal meningitis, the chlorides are of little diagnostic value although prognostically their rise indicates the likelihood of recovery. Most workers find the cerebrospinal fluid chloride content diminished on admission, but to a lesser extent than in tuberculous meningitis. In the present series, the cerebrospinal fluid chloride on admission ranged from 716–585 mgm. per cent., the blood chloride from 498–338 mgm. per cent. and the ratio from 1.83–1.24 with an average of 1.41. This last value, as in tuberculous meningitis, approximates to the normal. Most cases showed a gradual rise in cerebrospinal fluid chloride content with clinical improvement,

a rise parallel to that of the blood chloride. This rise in the cerebrospinal fluid chloride content was never so dramatic as the increase in sugar content and often fluctuated from day to day without any apparent change in the clinical condition. Fig. 4 is a typical example. The ratio of cerebrospinal fluid chloride to blood chloride remained remarkably constant during the course of the illness in every case.

TABLE 13

THE CHLORIDE CONTENT OF THE BLOOD AND CEREBROSPINAL FLUID
IN TUBERCULOUS MENINGITIS

NAME	FIRST ESTIMATIONS		TIME INTERVAL IN DAYS	FINAL ESTIMATIONS		RATIO OF C.S.F. NaCl TO BLOOD NaCl	
	NaCl IN MGM. PER CENT.			NaCl IN MGM. PER CENT.			
	BLOOD	C.S.F.		BLOOD	C.S.F.		
M.I. ..	—	610	—	8	408	670	1.39
A.A. ..	425	578	1.33	—	—	—	—
K.K. ..	381	589	1.54	—	—	—	—
M.M. ..	406	608	1.47	3	372	578	1.55
J.G. ..	393	590	1.50	1	407	597	1.22
P.R. ..	405	635	1.55	—	—	—	—
A.McR.	371	625	1.55	—	—	—	—
C.B. ..	343	568	1.65	1	345	586	1.69
V.M. ..	391	666	1.65	4	409	716	1.75
M.McM.	412	689	1.64	2	420	757	1.80
P.S. ..	371	640	1.72	3	418	689	1.64
J.B. ..	414	651	1.57	4	497	644	1.29
S.D. ..	364	660	1.78	15	350	609	1.71
R.McN.	421	647	1.53	14	423	599	1.41
J.H. ..	388	690	1.55	4	365	585	1.60
J.McG.	367	554	1.50	3	338	573	1.40
M.McG.	408	635	1.55	22	359	600	1.66
A.N. ..	—	689	—	13	—	543	—
C.D. ..	361	593	1.66	3	371	636	1.71
W.B. ..	491	662	1.34	6	391	658	1.68
M.S. ..	—	595	—	3	404	626	1.54
D.McK.	328	577	1.75	—	—	—	—
E.H. ..	328	549	1.67	4	313	561	1.79
M.L. ..	368	567	1.54	—	—	—	—
W.L. ..	373	590	1.58	1	339	569	1.42
R.C. ..	429	621	1.44	2	452	630	1.39
A.A. ..	322	546	1.38	2	352	621	1.49
A.McD.	388	556	1.43	5	—	566	—

Other types.—Two cases of *B. coli*, two of influenzal and one of pneumococcal meningitis showed a similar reduction to that found in meningococcal meningitis.

Conclusions

1. In the normal subject variations in the cerebrospinal fluid sugar content are dependent on variations in the blood sugar level, but changes in the latter are not immediately reflected in the cerebrospinal fluid.

FIG. 4
TYPICAL CASE OF MENINGOCOCCAL MENINGITIS SHOWING THE
PARALLEL COURSE OF THE BLOOD AND CEREbro-SPINAL FLUID CHLORIDES
AND THE RETURN TO NORMAL LEVEL OF THE CEREbro-SPINAL FLUID SUGAR

2. The lower limit for cerebrospinal fluid sugar content in normal cases is 50 mgm. per cent. and the ratio of cerebrospinal fluid sugar to blood sugar 0.6.

3. In tuberculous meningitis, the cerebrospinal fluid sugar content is reduced as is also the ratio of cerebrospinal fluid sugar to blood sugar; the reduction in both becomes more marked as the disease progresses. If convulsions occur, the cerebrospinal fluid sugar level may be raised to apparently normal limits, but the blood sugar is also raised and the ratio of cerebrospinal fluid sugar to blood sugar remains below normal.

4. In meningococcal meningitis, the cerebrospinal fluid sugar is reduced and may be almost entirely absent and the ratio of cerebrospinal fluid sugar to blood sugar is below normal. As recovery takes place, the cerebrospinal fluid sugar content and the ratio of cerebrospinal fluid sugar to blood sugar return to normal.

5. The cerebrospinal fluid chloride content is reduced in all forms of meningitis but this is due to a reduction in the blood chloride content.

6. Chloride reduction in the early stages of tuberculous meningitis is less constant than reduction in the cerebrospinal fluid sugar content.

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