Neurodevelopmental outcome in meningococcal disease: a case–control study

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Abstract

***Aims*—To determine long term neurodevelopmental outcome following the spectrum of meningococcal infection.**

***Methods*—Between 1988 and 1990, 152 cases of meningococcal disease were recruited; 139 survived. Between 1998 and 1999, 115 survivors (83%) were evaluated, together with 115 sex and age matched controls. Standard measures of neurological function, coordination, cognition, behaviour, and hearing were used to assess neurodevelopmental status.**

***Results*—One case has spastic quadriplegia. Gross neurological examination was normal in all other cases and all controls. Five cases and no controls have significant hearing loss. Cases performed at a lower level than controls on measures of coordination, cognition, and behaviour. Four cases and no controls had major impairments. The adjusted odds ratios for moderate and minor impairments were 3.6 (95% CI 1.3 to 10.3) and 1.6 (95% CI 0.8 to 3.4) respectively.**

***Conclusion*—The majority of survivors from this cohort do not have gross neurological deficits. However, when objective measures of motor function, cognitive ability, and behaviour were applied significant detriments were found in meningococcal survivors.**

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Over the past 15 years there has been a gradual increase in the incidence of meningococcal disease (MCD) in childhood.[1 2] There has been extensive research into the clinical features, pathophysiology, and management of the acute illness but less is known about long term sequelae. The majority of follow up studies use mortality as their main outcome measure.[3–6] Those looking at sequelae mainly consider physical problems or hearing loss and rarely obtain information by direct assessment.[7–11]

In the only detailed prospective case–control study, Moss[12] assessed 60 survivors from the outbreak in Bolton from 1971 to 1974. He found no significant differences on detailed neurological examination or on psychometric assessment; 5% of cases showed unilateral sensorineural deafness. These data are not likely to be relevant now. This cohort suffered high mortality of 17%. There have also been changes in classification and epidemiology of MCD together with advances in paediatric intensive care unit (PICU) management.

Cases of meningococcal disease may be classified on clinical and laboratory grounds into septicaemia (approximately 30% in outbreaks), meningitis (10%), or mixed disease (60%).[13] Thus 70% of cases have meningitis as part of their illness. In a meta-analysis of 19 prospective studies involving 1434 patients with meningitis in developed countries, Baraff and colleagues[14] found an overall mortality of 4.5% and a 15% incidence of major neurological sequelae. A total of 227 of these patients had meningococcal infection; although mortality was higher (7.5%) than for other causative organisms, neurological morbidity was documented in 10%. More recent studies have documented minor neurodevelopmental problems in a further 19% of survivors of bacterial meningitis but have included only small numbers of MCD cases.[15 16] Septicaemia alone may also confer a risk of neurodevelopmental sequelae. Thirty per cent of these cases have a fulminant illness involving hypotension and coagulopathy, and require PICU care[17]; this may increase survival at the expense of morbidity.

It is likely from this evidence that survivors from MCD may be at risk of long term neurodevelopmental sequelae. We designed a prospective case–control study to test this hypothesis.

Methods

COHORT SELECTION

Between November 1988 and August 1990, 152 consecutive children with clinically suspected meningococcal disease were included in a prospective, multicentre study involving seven Merseyside hospitals. Data were collected by a single research fellow and included detailed clinical and laboratory information.[17] The diagnosis was confirmed in 124 cases (81.5%) by positive cultures (blood and/or cerebrospinal fluid) or antigen test and was defined as probable in the remaining 28 cases. Based on clinical and laboratory tests the cases were classified as having meningococcal meningitis (16 cases, 11%), meningococcal septicaemia (44 cases, 29%), or mixed disease (92 cases, 60.5%). Disease severity was assessed by the Glasgow Meningococcal Prognostic Score (GMSPS)[18 19] in 150 cases. Forty four patients had fulminant disease (GMSPS $\geq$ 8) and required PICU care; 40 of these had been included in a randomised double blind, placebo controlled trial of polyclonal antiendotoxin therapy which showed no benefit in terms of mortality. All other patients were treated according to local guidelines.

Ninety cases (59%) were male; median age was 19 months (range 1 month to 15 years 3 months). A total of 139 cases survived; these form our follow up group. Age at assessment ranged from 8 years 9 months to 25 years.

FOLLOW UP

Assessments took place between September 1998 and February 2000.

Cases

Cases were traced via the local health authority, the Office of National Statistics, or the patient database at the Royal Liverpool Children's Hospital (RLCH). General practitioners (GPs) were contacted first to ensure that it was appropriate to approach the family. Information about the study was then sent with a request for consent.

Controls

Controls were recruited via the GP list of the index case. Once consent was obtained from a case we contacted their GP to aid with control recruitment. If this was not successful the local Family Health Service Authority was asked to participate. Information about the study was sent to the three patients on the GP list who were of the same sex and had the closest date of birth to the index case. In 90% of cases we were able to recruit at least one age, sex, and GP matched control for each case. In 12 cases we were unable to do this but were able to recruit a well matched control from a case for which we had received two or three positive replies. Apart from previous meningococcal disease there were no exclusion criteria.

Written consent was obtained prior to testing. Approval was gained from the RLCH and local research and ethics committees.

OUTCOME MEASURES

Apart from audiology the assessments were performed by a trained research fellow (JF). Assessments either took place at RLCH or at school, depending on preference. Cases and controls were seen within two weeks of each other but not on the same day. Test order remained constant throughout the study.

Neurological examination

A standardised neurological examination of cranial and peripheral systems was performed. This was followed by assessment of six neurological soft signs following the protocol devised by Stokman and colleagues.[20] The signs assessed were steriognosis, graphaesthesia, dysdiadokokinesis, mirror movements, motor speed, and involuntary movements. Scores were obtained for each individual soft sign and a total summary score was calculated for each subject. High scores indicate more soft signs.

The Movement Assessment Battery for Children (ABC)

The Movement ABC[21] is a battery of tests designed to assess motor and coordination skills in children. The test involves eight tests of motor function (three of manual dexterity, two of ball skills, and three of static and dynamic balance). The battery is age standardised and results in an overall impairment score between 0 and 40 with high scores indicating poorer function. Scores above the 95th percentile are considered to indicate definite motor problems.

The Wechsler Intelligence Scale for Children, third edition, UK (WISC-III^{UK})

The first eight subtests of the WISC-III^{UK} were administered.[22] Verbal (VIQ), performance (PIQ), and total IQ (TIQ) scores were calculated and expressed as standardised scores (mean 100, SD 15).

Test of visual–motor integration (VMI)

The VMI test[23] evaluates the ability to copy a sequence of geometric forms of increasing complexity. Raw scores are age corrected and expressed as standardised scores (mean 100, SD 15).

Behaviour

In subjects attending school the long form of Connor's Rating Scales–Revised (CRS-R)[24] was administered to the child's parent/guardian and to their teacher. These scales are designed to assess attention deficit hyperactivity disorder (ADHD) and related behavioural problems. The questions relate directly to the Diagnostic and Statistical Manual of Mental Disorders, fourth edition (DSM IV). Age standardised *t* scores (mean 50, SD 10) are produced for each behaviour type with scores over 70 indicating a possible problem.

Parental and teacher questionnaires

Parental questionnaires were used to obtain detailed sociodemographic information. Parents were also asked about any ongoing medical problems, history of seizures, and school problems.

Questionnaires were sent to teachers at the same time as the CRS-R to obtain information on school performance and any identified special needs within school.

Audiology

The majority of hearing assessments were performed at RLCH Hey by trained audiologists. Children unable to attend were screened at school by the research fellow and any abnormal tests were repeated at RLCH.

Hearing acuity levels were established for each ear by pure tone audiometry. Conductive deafness was differentiated from sensorineural loss by bone conduction studies and tympanometry. Severity of hearing loss was defined as mild (20–40 dB), moderate (41–70 dB), severe (71–95 dB), or profound (>95 dB).

STATISTICAL ANALYSIS

Bivariate analysis was either by χ^2, Mann–Whitney, or independent sample *t* test for appropriate levels of data. Multivariate analysis was performed by logistic regression for conditional variables and by linear regression for continuous variables. In the stepwise procedure we used standard criteria for entry and removal of variables with $p = 0.05$ for entry

and p = 0.1 for removal. The regression models included social class, number of siblings, number of adult carers, parental further education, and type of housing as possible confounding variables. Analysis was performed using SPSS.

Results

RECRUITMENT

Of the 152 original cases, 139 survived the acute infection (mortality 9%). We traced 132 survivors; 115 cases (83%) agreed to assessment. In a further 17 cases who did not agree to participate we excluded major neurodevelopmental disability by parental and GP questionnaires. In this way we obtained some outcome data on 95% of the survivors.

Table 1 summarises the acute features of the cases that were assessed compared to those who could not be traced or who refused consent. It may be seen that cases not followed up were more likely to be male and tended to be older at the time of diagnosis. All of the cases of pure meningitis were assessed with no major differences in the other diagnostic categories. The cases not examined tended to have a lower maximum GMSPS and only two cases of fulminant disease were not seen; questionnaires excluded major problems in these cases.

A total of 115 age and sex matched controls were assessed; 103 of these attended the GP of the index case and the other 12 were recruited from cases with more than one positive response.

Table 1 Comparison of cases assessed with those not followed up

	Follow up	
	Yes (n = 115)	*No (n = 24)*
Number of males (%)	62 (64)	19 (79)
Median age at diagnosis in months (IQR)	16 (7–50)	82 (24–124)
Number in diagnostic group (%)		
Septicaemia only	28 (24)	9 (38)
Mixed disease	71 (62)	15 (62)
Meningitis only	16 (14)	0 (0)
Median GMSPS (IQR)	5 (2–8)	3 (2–5)
Number of fulminant cases (%)	29 (25)	2 (8.3)

IQR, interquartile range.

Table 2 Comparison of demographic features of cases with controls

	Cases (n = 115)	*Controls (n = 115)*	*p value*
Median age (IQR)	133 (121–161)	133 (121–161)	0.95 (MWU)
Males	62	62	1.00 (χ^2)
Right handed	102	105	0.64 (χ^2)
Glasses	89	91	0.75 (χ^2)
Single parent	22	15	0.21 (χ^2)
Parents separated	33	30	0.66 (χ^2)
One/both parents with university education	11	20	0.08 (χ^2)
Social class			
I	1	3	
II	21	21	
III	47	52	0.31 (MWU)
IV	13	14	
V/UE	33	25	
Housing			
Own	66	71	
Rent, private	14	8	0.40 (χ^2)
Rent, council	35	35	
Number of sibs			
0	13	9	
1	44	56	
2	40	20	0.72 (MWU)
3	18	14	
4	9	3	
>4	1	3	

IQR, interquartile range; MWU, Mann–Whitney U test.

Table 3 Results of the Movement ABC

	Cases (n = 115)	*Controls (n = 115)*	*p value (MWU)*
Manual dexterity, median (IQR)	4.5 (1–7.5)	3 (1–6)	0.14
Ball skills, median (IQR)	1 (0–3)	0 (0–2)	0.17
Balance, median (IQR)	1.5 (0–4)	1 (0–3)	0.44
Total ABC, median (IQR)	7 (3–13)	6 (3–10)	0.14

IQR, interquartile range; MWU, Mann–Whitney U test.

DEMOGRAPHIC VARIABLES

Table 2 summarises the demographic variables of cases and controls. Total matching for sex and close matching for age was achieved. Similar numbers of cases and controls were right handed (assessed by hand used to write) and similar numbers were prescribed glasses. From the sociodemographic data, although no differences reached statistical significance, it can be seen that controls tended to come from more privileged backgrounds in terms of social class, housing, and parental education. Numbers of siblings were similar for both groups. Any differences in demographic variables were later included in the multivariate analysis.

NEUROLOGICAL FINDINGS

One case has microcephaly and spastic quadriplegia with epilepsy and cortical blindness. This child had a congenital cerebrovascular malformation which, when complicated by meningococcal disease, led to these severe sequelae. A second child has poorly controlled epilepsy with mixed seizure type; this is associated with moderate learning difficulties and behaviour problems. No controls have epilepsy.

Apart from the child described above with cerebral palsy, gross neurological examination was normal in all other cases and all controls.

On the soft sign battery, cases tended to higher scores than controls for each test and for total score. These differences were not statistically significant.

THE MOVEMENT ABC

Table 3 summarises scores on the movement ABC. Cases scored higher than controls on all three subgroups and the summary score, although these differences were not statistically significant. However, when the number of subjects with scores above the 95th percentile is analysed it may be seen that 16.5% of cases compared to 4.3% of controls had scores indicative of a significant problem (adjusted odds ratio 4.1, 95% CI 1.4 to 11.6).

PSYCHOMETRIC TESTS

Table 4 summarises the results of the VMI and IQ tests. Controls obtained higher mean scores on all four parameters and these remained significant following multivariate analysis. On average cases scored 6.4 (95% CI 2.7 to 10.1) points lower than controls for total IQ; similar figures were obtained for the verbal and performance subsets and the VMI.

Table 4 Results of psychometric testing

	Mean scores (SD)		*Difference (IQ points)*		
	Cases (n = 115)	*Controls (n = 115)*	*Raw*	*Adjusted* (95% CI)*	*p value*
VMI	93.4 (12.5)	99.2 (12)	5.8	5.1 (2.0–8.3)	0.002
VIQ	92.7 (16.3)	100 (16.2)	7.3	5.4 (1.7–9.2)	0.005
PIQ	94.8 (16.0)	102 (15.2)	7.2	5.9 (2.0–9.7)	0.003
TIQ	92.9 (16.3)	101.1 (15.8)	8.2	6.4 (2.7–10.1)	0.001

*Adjusted for social class, number of sibs, number of adult carers, parental further education, and type of housing.
VMI, visual–motor integration; VIQ, verbal IQ; PIQ, performance IQ; TIQ, total IQ.

BEHAVIOUR

Three cases and one control have a formal diagnosis of ADHD. Behaviour rating scales were sent to the parents and teachers of 99 cases and 100 controls (not sent to any who had left school or to the case with cerebral palsy). Response rates were 98% for parents of cases and 99% for parents of controls. Teacher response rate was 86% for both groups. Complete data (both questionnaires) were returned for 85% of cases and 86% of controls. Table 5 summarises the results. Both parents and teachers scored cases significantly higher than controls for cognitive problems, global problems, and the ADHD measures. Considering diagnostic criteria, subjects were considered to have a possible DSM-IV diagnosis if both teacher and parent questionnaires were scored at over 70 for any of the ADHD measures. This applied to eight cases (9.5%) and no controls in whom full data were available.

EDUCATIONAL NEEDS

The case with spastic quadriplegia attends a school for physically handicapped children. One other case and one control attend schools for children with emotional and behavioural difficulties. Nine cases and three controls have a statement of educational needs (adjusted odds ratio 2.9, 95% CI 0.7 to 11.3). Twenty nine cases and 14 controls are at other stages of the special needs code of practice (adjusted odds ratio 2.5, 95% CI 1.2 to 5.4).

AUDIOLOGY

Pure tone audiograms were performed in 109 cases and 55 controls. Two cases had bilateral severe to profound sensorineural loss and use hearing aids. There were three unilateral losses, two severe to profound, and one moderate. The prevalence of these significant losses was 4.6% and all had been diagnosed previously. In a further eight cases we found unilateral high frequency losses which were mild in four cases and moderate in three. One control (born prematurely) had a mild high frequency loss; no other sensorineural losses were detected in this group. Six cases and two controls had mild unilateral or bilateral conductive losses.

OUTCOME SUMMARY

Subjects were classified according to table 6 as having mild, moderate, or severe impairments. Those with severe problems often require special educational placement whereas those with moderate impairments may manage in mainstream school with additional support. Children with mild problems may perform worse than their peers and may have special needs within school.

Based on these criteria, four cases (3.5%) and no controls had major impairments. Eighteen cases (15.7%) and five controls (4.3%) had moderate problems (adjusted odds ratio 3.6, 95% CI 1.3 to 10.3). Twenty two cases and 14 controls had one or more minor problems (adjusted odds ratio 1.6, 95% CI 0.8 to 3.4).

Considering diagnostic groups of the 16 meningitis cases all survived and were assessed. One (6%) had severe disabilities, three (19%) had moderate problems, and the remaining 12 (75%) were normal or had mild problems.

There were 43 cases of pure septicaemia and 37 survived (mortality 14%). Twenty eight survivors were assessed: two (7%) had severe problems, five (18%) had moderate problems, and 21 (75%) were normal/had mild problems.

From the 93 mixed cases, 86 survived (mortality 7.5%). Seventy two survivors were

Table 5 Results of behaviour rating scales

	Parent questionnaire			*Teacher questionnaire*		
	Median t scores (IQR)			*Median t scores (IQR)*		
Behaviour type	*Cases (n = 97)*	*Controls (n = 99)*	*p value (MWU)*	*Cases (n = 85)*	*Controls (n = 86)*	*p value (MWU)*
Oppositional problems	54 (47–65)	48 (45–56)	0.000	48 (46–58)	46 (45–53)	0.072
Cognitive problems	51 (46–64)	48 (43–52)	0.000	57 (48–68)	50 (44–60)	0.006
Social problems	45 (45–56)	45 (45–50)	0.307	46 (45–52)	46 (45–51)	0.55
Global problems	53 (47–70)	49 (44–58)	0.000	55 (47–64)	49 (44–58)	0.025
Inattentive ADHD*	51 (44–63)	46 (42–51)	0.000	54 (46–66)	50 (44–59)	0.004
Hyperactive-impulsive ADHD*	58 (49–74)	51 (46–59)	0.000	49 (45–60)	47 (45–54)	0.049
Total ADHD*	55 (47–69)	48 (44–55)	0.000	55 (54–65)	49 (43–57)	0.003

*Corresponds to DSM-IV diagnostic criteria.
IQR, interquartile range; MWU, Mann–Whitney U test.

Table 6 Level of impairment

Level of impairment	*Physical/medical*	*Hearing loss*	*Total IQ*	*Movement ABC*
Severe	Cerebral palsy Uncontrolled seizures Blindness	Bilateral Severe–profound	<50	
Moderate	Limb amputation	Unilateral Moderate–profound	50–69 (0.1–2%)	>17 (>98%)
Mild	Digital amputation	High frequency	70–75 (2–5%)	14–17 (95–98%)

assessed: one (1%) had severe problems, 10 (14%) had moderate problems, and 61 (85%) were normal/had mild problems.

The cases with significant problems were therefore distributed between the diagnostic groups with no significant differences.

Discussion

The majority of survivors from this cohort do not have gross neurological deficits. However, when objective measures of motor function, cognitive ability, and behaviour were applied significant differences were found between the meningococcal survivors and the control group. These children usually attend mainstream school but because of these problems may perform worse than their peers and need additional support.

This study has examined detailed neurodevelopmental outcome in a large well defined prospectively enrolled cohort. Follow up rates are high with full assessments in 83% and questionnaire data in a further 12%. Cases not assessed tended to be older at presentation and had less severe disease. It is unlikely that cases with severe sequelae were missed. All assessments were performed by a single research fellow following appropriate training.

There are two major areas where bias may have arisen. Firstly, the research fellow organised recruitment and therefore was not blind to the status of subjects. However, blinding would have been logistically difficult. Parents often attended the assessments and were keen to discuss both the original and follow up studies.

As with any case–control study, control recruitment may introduce bias. Many similar studies use classroom controls. However, we did not know how many cases attended special schools and we had a significant number of cases who had left school. Another option would have been to use sibling controls, but age and sex matching is a problem and significant numbers had no siblings. In order to recruit controls who were representative of the population and closely age and sex matched we recruited from the GP list of the index case. Three letters were sent and we generally received at least one reply. There may be systematic differences between those who reply and those who do not; however, we have no data to analyse this. Ninety per cent of controls were recruited in this way. In the remaining 10% we were able to recruit age and sex matched controls from cases where we had two or more positive replies. Given the limitations of our control selection the groups are well matched in most areas and we accounted for any known differences in the analysis.

The only comparable study is that of Moss.[12] He studied 60 survivors from 1971–74 from a cohort which had a 17% mortality. He showed no difference in terms of detailed neurological examination but did not use any specific measures of motor and coordination skills such as the Movement ABC. On psychometric testing Moss showed a "tendency towards lower performance and lower IQ" although this was not statistically significant. Significant sensorineural hearing loss was found in 3.3%, similar to the 4.3% in our cohort. Our recruitment began 14 years after Moss and total mortality was 9%. This cohort was recruited after the present outbreak began in 1985 and cases may not be comparable with those between 1971 and 1974. It may also be that, as a result of advances in rapid diagnosis and management, severe cases survived in the later cohort but at the expense of sequelae. We also used different tests and included measurements of behaviour to pick up subtle deficits not detected by Moss.

This study provides valuable information for clinicians and families about long term neurodevelopmental sequelae following meningococcal disease. Follow up is difficult as most problems were subtle and require detailed assessment.

Many will find the results of this study reassuring but it must be remembered that this cohort was from over 10 years ago. In a recent cohort from the same region the mortality from fulminant disease had reduced from 30% to 10%. There is anecdotal evidence of an increase in amputations and major neurological sequelae. This study needs to be repeated to document the effects of advances in intensive care management.

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TRANSATLANTIC TOPIC

What's up (or down and out) in US healthcare

It is always difficult to summarise trends in US healthcare. But it's worth a shot—in no particular order:

- Cost is up. Healthcare expenditures are once again increasing by 6–8% or more annually
- The number of uninsured Americans remains embarrassingly high—45 million—or 1 in 6 US citizens
- A new programme has been developed: the State Child Health Insurance Program, which should reduce the number of children without insurance. There is growing consensus that all children should have health insurance. Unfortunately, there is no movement to ensure that all their parents, or for that matter, all citizens, should have health insurance
- Oral antibiotic use is down
- Immunisation rates are up, as well as the number of vaccines, and more are coming
- President Bush has announced that biomedical research will be spared any budgetary cuts
- Our National Institutes of Health have already enjoyed significant increases in budget over the past few years. The current budget is $20 billion. It is likely to reach $30 billion in 2–4 years. Hopefully, we will spend the money wisely
- Although the genome project has been widely championed in the popular press, it is less clear when there will be direct benefit for patients
- Although the US experimented with staff model health maintenance organisations and true managed care for a few years, it appears the experiment is over. Many plans are once again allowing patients ready access to specialists and emergency room care
- The cost of prescription drugs continues to increase dramatically. In the coming months, Congress will debate various plans to provide pharmacy benefits for the elderly, but whether a plan emerges and what form it will take is uncertain
- The cost of Medicare, our healthcare plan for the elderly, continues to increase dramatically, in part because of pharmacy costs. It is not clear if these increases can be contained
- The health of most Americans is good, but large socioeconomic and ethnic disparities in care and health status still exist
- Our love affair with technology and specialty care continues
- Medical errors are alive and well and have become a national priority
- Learning from the rest of the world, once again we have recognised the importance of breast feeding. Initiation rates are up, and duration is longer in selected groups
- The promise of information technology—computers in the healthcare work place—is finally beginning to be realised
- Every new President brings their own new health agenda. Beyond providing prescription benefits for the elderly and increasing the budget for the NIH, the priorities of President Bush are not yet clear.

H BAUCHER
US Editor