Etiology of child mortality in Goroka, Papua New Guinea: a prospective two-year study

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Objective To collect accurate data on disease- and microbial-specific causes and avoidable factors in child deaths in a developing country.

Methods A systematic prospective audit of deaths of children seen at Goroka Hospital in the highlands of Papua New Guinea was carried out. Over a 24-month period, we studied 353 consecutive deaths of children: 126 neonates, 186 children aged 1–59 months, and 41 children aged 5–12 years.

Findings The most frequent age-specific clinical diagnoses were as follows: for neonates — very low birth weight, septicaemia, birth asphyxia and congenital syphilis; for children aged 1–59 months — pneumonia, septicaemia, marasmus and meningitis; and for children aged 5–12 years — malignancies and septicaemia. At least one microbial cause of death was identified for 179 (50.7%) children and two or more were identified for 37 (10.5%). Nine microbial pathogens accounted for 41% of all childhood deaths and 76% of all deaths that had any infective component. Potentially avoidable factors were identified for 177 (50%) of deaths. The most frequently occurring factors were as follows: no antenatal care in high-risk pregnancies (8.8% of all deaths), very delayed presentation (7.9%), vaccine-preventable diseases (7.9%), informal adoption or child abandonment leading to severe malnutrition (5.7%), and lack of screening for maternal syphilis (5.4%). Sepsis due to enteric Gram-negative bacilli occurred in 87 (24.6%). The strongest associations with death from Gram-negative sepsis were adoption/abandonment leading to severe malnutrition, village births, and prolonged hospital stay.

Conclusions Reductions in child mortality will depend on addressing the commonest causes of death, which include disease states, microbial pathogens, adverse social circumstances and health service failures. Systematic mortality audits in selected regions where child mortality is high may be useful for setting priorities, estimating the potential benefit of specific and non-specific interventions, and providing continuous feedback on the quality of care provided and the outcome of health reforms.

Keywords Infant mortality; Hospital mortality; Cause of death; Sepsis/mortality; Age factors; Confounding factors (Epidemiology); Prospective studies; Papua New Guinea (*source: MeSH, NLM*).

Mots clés Mortalité nourrisson; Mortalité hôpital; Cause décès; Sepsis/mortalité; Facteur âge; Facteurs de confusion (Epidémiologie), Etude prospective; Papouasie-Nouvelle-Guinée (*source: MeSH, INSERM*).

Palabras clave Mortalidad infantil; Mortalidad hospitalaria; Causa de muerte; Sepsis/mortalidad; Factores de edad; Factores de confusión (Epidemiología); Estudios prospectivos; Papua Nueva Guinea (*fuente: DeCS, BIREME*).

Bulletin of the World Health Organization 2002;80:16-25.

Voir page 24 le résumé en français. En la página 24 figura un resumen en español.

Introduction

Many developing countries, including Papua New Guinea, report aggregated data on hospital discharge diagnoses. Such data contain substantial errors, however, and may not include sufficient detail for assessing quality of care or planning specific interventions. Although they provide a broad view of the case-mix at health facilities, they do not integrate health service performance with outcomes. Infectious diseases cause 70% of the childhood mortality burden in developing countries. Pneumonia, septicaemia, meningitis, and diarrhoeal diseases, which account for more than 4 million deaths annually in children under 5 years of age (*1*), each have multiple microbial etiologies. Most community-based mortality etiology studies from developing countries have used the technique of verbal autopsy, without microbiological data. Neonatal mortality makes up more than one-third of all child deaths in developing countries; nevertheless, data on the bacterial causes of neonatal deaths are scarce, and details of the relevant diagnoses are frequently ignored in aggregated hospital mortality reports. The emergence of antibiotic-resistant bacteria in health facilities and within communities may be changing the patterns of fatal disease in developing countries. Although a high proportion of all child deaths occurring worldwide could be avoided by simple interventions, there are few published data on what the avoidable factors are or what interventions in health facilities or communities are required.

To gain a better understanding of these issues, we undertook a systematic prospective audit of child mortality in a rural hospital in Papua New Guinea. The aims of the audit were to determine: the age-specific conditions causing death; the microbiological causes of these conditions; the avoidable

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Ref. No. **00-1001**

factors contributing to deaths; and any quantifiable interactions between the conditions and pathogens causing death, and avoidable factors. It was hoped that such an audit might provide a foundation for planning and implementing reforms in child health services.

Methods

Study setting

The study was carried out at Goroka Hospital, in the Eastern Highlands Province of Papua New Guinea, which serves a predominantly rural population of 380 000 inhabitants. Approximately 2000 children and 500 neonates are admitted to the 70-bed paediatric ward of the hospital each year. Children are referred from aid posts and rural health centres, or come directly from villages. The above-mentioned audit is an ongoing activity; this article reports a prospective systematic review of consecutive deaths in children who died between 1 April 1998 and 31 March 2000.

Data collection

Whenever a child died, a single-page data sheet was completed outlining the demographic and clinical details, results of all investigations, and potentially avoidable factors. The audit included all in-patient deaths of children from birth to 12 years of age; all children who had died prior to arrival at hospital; and all children with terminal illnesses who were sent home to die. Death was verified in all cases where children were discharged to die at home. Stillborn babies were not included.

Diagnoses were based on pre-defined criteria (*2–5*). Microbiological information was collected. Samples of blood were collected from severely ill children for bacterial culture at the time of their admission, and at any time thereafter if there was a deterioration in their condition. Children presenting with clinical signs of meningitis underwent a lumbar puncture unless there was a contraindication. For children who died from pneumonia, blood and lung aspirate cultures were done immediately after death if not already undertaken for diagnostic purposes. Specimens were taken using sterile technique, and the laboratory procedures used have been described previously (*6, 7*). When blood and lung aspirate cultures were both performed, the two specimens were inoculated into the same culture bottle to save costs. For children who died with clinical signs of septicaemia, blood was taken for bacterial culture immediately after death, if this had not been done beforehand. For children who died prior to arrival, a detailed history was taken; blood and lung aspirates were collected for culture, and a lumbar puncture was performed, where these investigations were appropriate to the history of the illness. Serological tests for human immunodeficiency virus (HIV) and syphilis, a blood film for malarial parasites, or a Widal test for *Salmonella typhi* antigens were performed post mortem if the clinical picture was appropriate. Antibiotic-resistant infections were diagnosed if bacteria that were resistant to standard antibiotics (*2, 4, 8*) were isolated from sterile sites. Deaths due to infections with antibiotic-resistant bacteria were evaluated to determine whether the infection was community- or hospital-acquired. Nosocomial infection was assigned to children who had deteriorated while in hospital after initial improvement, with new clinical signs of infection, and from whom a new pathogen was identified consistent with the new clinical signs.

Avoidable factors

Avoidable factors were defined as any event that contributed to the death but which, by means of basic or low-cost interventions, may have been avoided. We prospectively identified four categories of potentially avoidable factors.

- Factors within the community, e.g. delayed presentation of severely ill children; child neglect or abandonment; failure to access maternal care.
- Factors involving primary preventive health services, e.g. vaccine-preventable diseases; failure of disease-screening programmes.
- Failures in primary curative health services, e.g. on first health contact, the health facility was closed or out of stock of basic drugs; referral was delayed more than 7 days after presenting to a primary health facility.
- Failures at the referral hospital, e.g. major errors in obstetric care; drug-prescribing errors; nosocomial infections; oxygen administration problems; and failure to carry out standard treatment.

Nosocomial infection was considered to be potentially avoidable if the origin of sepsis indicated that, with better basic medical or nursing care, it could have been avoided. For example, an intramuscular injection-site abscess that led to bacteraemia was considered potentially avoidable, whereas a case of hospital-acquired pneumonia with no clear source was not. Hospital-acquired measles was not considered avoidable given the high patient load in the ward and the difficulty of identifying all cases prior to the development of the characteristic rash. Nosocomial measles occurred despite having an isolation room for all confirmed cases.

Death was considered to be vaccine-preventable if the child was old enough to have been immunized against the fatal disease concerned but had not been so. For example, a case of measles involving a non-immunized 10-month-old child, and neonatal tetanus where the mother had received no antenatal care, were considered potentially avoidable. Pertussis in a one-month-old was not classified as avoidable, even though with better herd immunity the infection may not have occurred. Apparent vaccine failure, e.g. measles in a fully immunized child, was not classified as vaccine-preventable, although such events raise issues about the quality of immunization services, particularly the adequacy of the cold chain.

High-risk pregnancies were defined as those that carried an increased risk to the mother or the fetus, and were identifiable at antenatal care; for example, multiple pregnancies, multigravida, pre-eclampsia, severe maternal anaemia, and previous fetal or neonatal loss.

For the purposes of the study, very low birth weight was defined as < 1.8 kg, the weight at which the complications of prematurity and intrauterine growth restriction are likely to limit survival, especially in a village setting without intervention.

Potentially avoidable factors were identified by interviewing the parents or guardians during the child's illness or after the death, reviewing referral notes, clinical records and the child's health record book, and interviewing health workers who had cared for the child.

Mortality audit

Each week a mortality audit meeting took place, attended by two consultant paediatricians, the paediatric resident medical

staff, and the nurses in the paediatric department. Each new death was discussed, the clinical, bacteriological and other laboratory data reviewed, and a consensus reached as to the causes of death and whether there were potentially avoidable factors. The weekly meeting was a forum for the systematic review of cases, for free discussion, and for teaching. Adverse events were examined in the context of available resources and local cultural issues, and quality assurance and potential interventions were discussed.

Prior to all post-mortem investigations informed consent was gained from the parents of the child. Parents were told that the investigation results would help to determine why their child had died, and to manage other children better in the future; that all test results would be available to them; and that they were free to refuse the investigations. The audit was approved and supported by the Goroka Hospital Board of Management and the Hospital Medical Advisory Committee, to which the results were reported on a 6-monthly basis

Statistical analysis

The data were entered into MSExcel and analysed using Stata Version 5.0. Raw data are presented as numbers and percentages. Logistic regression was used to investigate for and quantify associations between certain microbial pathogens, disease states, and avoidable factors. Results are presented as odds ratio (OR) and 95% confidence intervals.

Results

Study population

A total of 353 consecutive deaths were studied over 24 months: 284 deaths (80%) occurred in hospital, 28 children (7.9%) were dead on arrival at hospital, and 41 children (11.6%) with terminal illnesses were discharged from hospital to die at home. All deaths at home were confirmed. A total of 195 (55%) of the deaths involved male children. The median age was 4 months (interquartile range, 0.08–12 months): 126 (35.7%) were in the first month of life, 186 (52.6%) were 1–59 months and 41 were 5–12 years old (11.6%). Birthplace was the village for 227 (64%) children, hospital for 89 (25%), health centre for 16 (4.5%) and unknown for 21 (5.9%). Over the 24-month study period, 5331 children were officially admitted to the Paediatric Department, and the number of deaths recorded in hospital records, which make up the aggregated national database, was 248. This official figure therefore underestimates the number of deaths by 12.6% for children admitted to hospital who died in hospital; by 21.8% if children discharged to die at home are included; and by 29.7% if children dying at home but brought to hospital are also included.

Diseases causing death

The commonest clinical conditions causing death are detailed in Table 1. A total of 268 (76%) children had more than one diagnosis that contributed to death; 270 (76.5%) had clinical diagnoses of one or combinations of four communicable diseases (pneumonia, meningitis, measles, and syphilis) and three noncommunicable conditions (severe malnutrition, very low birth weight, and birth asphyxia).

Etiology

The microbial causes of death are outlined in Table 2. At least one microbial cause of death was identified in 179 (50.7%) children; two pathogens were found in 30 (8.4%), and three in 7 (1.9%) children. Blood cultures were performed for 220 children, lung aspirates for 107, examination of cerebrospinal fluid (CSF) for 87, and pleural aspirate for 8. For 87 children no bacteriological investigations were undertaken for the following reasons: refusal by the parents or guardians (20), dead child taken home before permission could be requested (6), non-infective cause of death (61).

A microbial pathogen was identified in 66.2% of all children who had any signs of infection. *Streptococcus pneumoniae* was the most important pathogen, accounting for 27 deaths; 22 (81%) children had meningitis, 6 of whom also had severe pneumonia, and 5 (18.5%) had pneumonia or septicaemia without meningitis. *S. pneumoniae* accounted for half (22) of the 43 deaths from meningitis. Over the two years, sepsis due to enteric Gram-negative bacilli occurred in 106 of the 5331 admissions (2.0%) and caused 87 (24.6%) deaths. Of the 174 (49.3%) children in whom no microbial pathogens were identified, 86 had some clinical features of infection that may have contributed to death; 83 had no features of infection and clear evidence of non-infective pathology. For 5 deaths (2.9%) we could not determine the cause of death or whether infection played any part.

Only the following viruses were sought: measles virus, which was characteristic enough to identify clinically; and HIV and hepatitis B virus, for which reliable serology was available. HIV serology was performed on 35 children; 4 were positive on initial testing but only 3 were confirmed positive on repeated testing. Hepatitis B surface antigen testing was carried out on 8 children, with 2 positive results. No *Salmonella typhi* were grown from blood cultures, therefore we did not include this as a definite pathogen. However, 3 children exhibited a Widal test titre of >1:360 and clinical features of typhoid. Similarly, diagnostic precision for *Mycobacterium tuberculosis* was limited, since culture facilities for mycobacteria are not available in Papua New Guinea. However, 6 children had strong evidence of infection based on clinical features, radiological signs and a strongly reactive Mantoux test. Of these, 3 had coexistent bacterial infections: *Staphylococcus aureus* (lung aspirate), *S. paratyphi* (blood culture) and *Klebsiella pneumoniae* (parotid abscess aspirate).

Nosocomial and resistant infections

Nosocomial infections occurred in 35 (9.9%) of the children. Organisms identified were enteric Gram-negative bacilli (22), measles (9, of which 2 had Gram-negative sepsis also), *S. aureus* (2) and unknown (4). In another 11, nosocomial infection was likely to have played a major part; in 4 of these enteric Gram-negative bacilli were isolated, and in 7 bacteriological investigations were negative.

Bacteria that were resistant to antibiotics recommended by WHO for the clinical syndrome concerned were isolated in 74 (21.0%) cases. Antibiotic resistance was most common among enteric Gram-negative bacilli (67 deaths); antibiotic susceptibility data on an interim cohort have been reported previously (*9*). Other resistant bacteria were as follows: chloramphenicol-resistant *Haemophilus influenzae* type b causing meningitis (4); methicillin-resistant *S. aureus* (2); multi-resistant group B streptococcal pneumonia (1); and *S. pneumoniae* with in-vitro sensitivity to chloramphenicol but resistance to penicillin (1); failed treatment with chloramphenicol was recorded for one meningitis case. The mean duration of

Table 1. **Distribution of clinical diagnoses causing deaths for each age category** (multiple diagnoses were recorded where they occurred)

Diagnosis	All children (*n* = 353)	No. from birth to 28 days of age (*n* = 126)	No. aged 1–59 months (*n* = 186)	No. aged 5–12 years (*n* = 41)
Total	**353 (100)[a]**	**126 (100)**	**186 (100)**	**41 (100)**
Septicaemia	126 (35.7)	54 (42.9)	61 (32.8)	11 (26.8)
Pneumonia	124 (35.1)	14 (11.1)	106 (57.0)	4 (9.8)
Very low birth weight[b]	68 (19.3)	64 (50.8)	4 (2.2)	0
Marasmus	50 (14.2)	2 (1.6)	43 (23.1)	5 (12.2)
Meningitis	43 (12.2)	2 (1.6)	37 (19.9)	4 (9.8)
Diarrhoea[c]	33 (9.3)	2 (1.6)	30 (16.1)	1 (2.4)
Birth asphyxia	30 (8.5)	30 (23.8)	0	0
Anaemia	26 (7.4)	7 (5.6)	14 (7.5)	5 (12.2)
Congenital heart disease	25 (7.1)	9 (7.1)	14 (7.5)	2 (4.9)
Measles	22 (6.2)	0	22 (11.8)	0
Congenital syphilis	22 (6.2)	17 (13.5)	5 (2.7)	0
Kwashiorkor	22 (6.2)	0	20 (10.8)	2 (4.9)
Malignancy[d]	17 (4.8)	0	5 (2.7)	12 (29.3)
Multiple congenital anomalies[e]	15 (4.2)	11 (8.7)	4 (2.2)	0
Necrotizing enterocolitis	10 (2.8)	10 (7.9)	0	0
Malaria	8 (2.3)	0	5 (2.7)	3 (7.3)
Pulmonary hypertension	8 (2.3)	6 (4.8)	2 (1.1)	0
Sudden infant death syndrome	7 (1.9)	4 (3.2)	3 (1.6)	0
Tuberculosis	6 (1.7)	0	4 (2.2)	2 (4.9)
Meconium aspiration	6 (1.7)	6 (4.8)	0	0
Down syndrome	4 (1.1)	1 (0.8)	3 (1.6)	0
Typhoid	3 (0.8)	0	0	3 (7.3)

[a] Figures in parentheses are percentages.
[b] Includes intrauterine growth retardation and prematurity, all weighing <1.8 kg.
[c] Includes dysentery (4 cases).
[d] Includes acute lymphoblastic leukaemia (9 cases), brain tumours (5), non-Hodgkin's lymphoma (1), ovarian tumour (1) and retinoblastoma (1).
[e] Includes dysmorphic syndromes (11cases) and/or associated anomalies: ileal atresia (2), diaphragmatic hernia (1), omphalocoele (1), myelomeningocoele (1), hydrocephalus (1), anencephaly (1), posterior urethral valves (1), myotonic dystrophy (1) and facial clefts (2).

hospitalization before death for children with multi-resistant bacterial sepsis was 14.4 days (95% confidence interval (CI), 9.6–19.1) compared with 7.3 (95% CI, 5.7–8.9) days for children without multi-resistant bacteria ($P < 0.001$).

Avoidable factors

At least one avoidable factor was identified in half of all deaths (Table 3). Factors within the community were common (category A), with more than half of these being lack of availability of or failure to access maternal care. Definable failures of primary preventive and curative health services occurred for 67 deaths (19%) (categories B and C combined); most important were deaths from vaccine-preventable diseases and closed or poorly functioning primary health facilities. Potentially avoidable factors in hospital were identified for 47 (13.3) deaths and related to prescribing drug errors (including failure to follow standard treatment in common conditions), problems with oxygen administration, and sporadic or systematic breakdown of basic clinical care (category D).

Although nosocomial infections were identified for 35 deaths, we believe that there were only 6 cases where infections were potentially avoidable in view of the large patient load and available resources: bacteraemia from intramuscular injection site abscesses (4), surgical wound infection (1) and intravenous drip site infection (1).

Interactions between avoidable factors, disease states and microbial causes

Further analysis of the 87 deaths with Gram-negative sepsis showed that, compared to children who died but did not have such sepsis, these children were more likely to have been adopted or abandoned (odds ratio (OR), 6.5; 95% CI, 2.5–16.9); have kwashiorkor (OR, 2.7; 95% CI, 1.1–6.6); have had a village birth (OR, 2.6; 95% CI, 1.5–4.6); have pneumonia (OR, 2.3; 95% CI, 1.4–3.7); or have undergone a prolonged hospital stay (for duration of hospitalization of > 1 week: OR, 2.56; 95% CI, 1.6–4.2). In a multivariate analysis, village birth, informal adoption/abandonment, pneumonia, and prolonged duration of hospitalization were the only independent risk factors. The effect of village birth on the development of Gram-negative sepsis was highest for neonates (OR, 3.1; 95% CI, 1.3–7.2), where duration of hospitalization was not significant; and the effect of adoption/abandonment was highest for infants and children outside the neonatal period (OR, 7.3; 95% CI, 2.6–20.5).

We hypothesized that three underlying conditions: measles, severe malnutrition (kwashiorkor or marasmus) or

Table 2. **Distribution of age-specific deaths involving each pathogen, by age category**

Pathogen	All children (*n* = 353)	No. from birth to 28 days (*n* = 126)	No. aged 1–60 months (*n* = 186)	No. aged 5–12 years (*n* = 41)
No pathogen identified	174 (49.3)[a]	76 (60.3)	66 (35.5)	32 (78.0)
No infectious component	83 (23.5)	46 (36.5)	18 (9.7)	19 (46.3)
Streptococcus pneumoniae[b]	27 (7.6)	1 (0.8)	24 (12.9)	2 (4.9)
Treponema pallidum[b]	22 (6.2)	17 (13.5)	5 (2.7)	0
Measles virus[b]	22 (6.2)	0	22 (11.8)	0
Pseudomonas sp.[b]	22 (6.2)	3 (2.4)	19 (10.2)	0
Klebsiella sp.[b]	20 (5.7)	11 (8.7)	9 (4.8)	0
Staphylococcus aureus[b]	17 (4.8)	2 (1.6)	15 (8.1)	0
Escherichia coli[b]	16 (4.5)	4 (3.2)	12 (6.5)	0
Enterobacter sp.[b]	10 (2.8)	3 (2.4)	12 (6.5)	0
Haemophilus influenzae[b,c]	11 (3.1)	0	11 (5.9)	0
Plasmodium falciparum	7 (2.0)	0	5 (2.7)	2 (4.9)
Streptococcus sp.	7 (2.0)	0	6 (3.2)	1 (2.4)
Citrobacter freundii	5 (1.4)	3 (2.4)	2 (1.1)	0
Aeromonas sp.	5 (1.4)	4 (3.2)	1 (0.5)	0
Proteus mirabilis	4 (1.1)	1 (0.8)	1 (0.5)	2 (4.9)
Clostridium tetani	3 (0.8)	1 (0.8)	1 (0.5)	1 (2.4)
Human immunodeficiency virus[d]	3 (0.8)	1 (0.8)	2 (1.1)	0
Morganella morganii	2 (0.6)	1 (0.8)	1 (0.5)	0
Salmonella sp.	2 (0.6)	0	1 (0.5)	1 (2.4)
Hepatitis B virus[e]	2 (0.6)	0	2 (1.1)	0
Anaerobic bacilli	2 (0.6)	0	0	2 (4.9)
Bacillus sp.	2 (0.6)	1 (0.8)	1 (0.5)	0
Alcaligenes sp.	2 (0.6)	1 (0.8)	1 (0.5)	1 (2.4)
Serratia sp.	1 (0.3)	0	1 (0.5)	0
Varicella zoster	1 (0.3)	0	1 (0.5)	0
Candida albicans	1 (0.3)	0	1 (0.5)	0
Branhamella catarrhalis	1 (0.3)	0	1 (0.5)	0

[a] Figures in parentheses are percentages.
[b] Pathogens causing more than 5% of all child deaths, or more than 5% of all age-specific deaths.
[c] 10 *H. influenzae* type b, 1 non-typable *H. influenzae*.
[d] 35 HIV antibody tests done, 4 positive on first testing, 3 confirmed positive on repeat testing.
[e] 8 tests for hepatitis B done.

very low birth weight (<1.8 kg) put children at risk of Gram-negative sepsis because of impaired (or immature) gastrointestinal tract immunity and protective barrier function. Apart from kwashiorkor, none of these factors alone was significantly associated with Gram-negative sepsis. However, one or more of these underlying conditions were present in 47 of the enteric Gram-negative sepsis cases (OR for the three conditions combined, 1.9; 95% CI, 1.2–3.1; $P = 0.01$).

Complications of very low birth weight were a common cause of death (68), contributing to half of all neonatal deaths. Of the 126 neonates who died, the mothers of those with very low birth weight were much less likely to have attended any antenatal care (OR, 9.0; 95% CI, 3.6–22.7). There are many confounding factors, however.

Discussion

In this study seven clinical conditions accounted for 76% of all deaths; nine microbial pathogens accounted for 41% of all childhood deaths, and for 76% of all deaths that had any infective component; the mortality burden from sepsis due to enteric Gram-negative bacilli was large relative to its overall incidence; and half of all deaths had one or more avoidable factor.

Comparison with routinely collected data

The only cause-specific data routinely collected in Papua New Guinea are aggregated hospital discharge diagnoses and hospital mortality-by-cause data. The huge numbers of hospital admissions, and the limited data-collection skills, resources and technology result in cumulative errors in the nationwide database. This study showed that the official hospital data, even at the point of collection, underestimated the true number of child deaths seen at the hospital in the study period by 12–29%. Errors of simplification also occur in official mortality-by-cause data. In official national data for 1990–94, the only recorded causes of neonatal admission and mortality were "perinatal conditions" and unspecified "other" (*10*). Similarly limited detail on the causes of neonatal deaths is also seen in verbal autopsy reports from other countries (*11*).

Table 3. **Distribution of avoidable factors identified in deaths, by age category**

Potentially avoidable factors	All children (*n* = 353)	No. from birth to 28 days (*n* = 126)	No. aged 1–59 months (*n* = 186)	No. aged 5–12 years (*n* = 41)
Deaths with no avoidable factors	176 (49.9)	53 (42.1)	95 (51.1)	28 (68.3)
A. Avoidable factors within the community or family	94 (26.6)	–	–	–
Delayed presentation (>7 days after becoming unwell)	28 (7.9)	9 (7.1)	15 (8.1)	4 (9.8)
Informal adoption of infants, or child abandonment, leading to marasmus or kwashiorkor	20 (5.7)	2 (1.6)	17 (9.1)	1 (2.4)
Tribal fight killings	4 (1.1)	0	2 (1.1)	2 (4.9)
Skin and soft tissue incisions as part of village remedy, leading to septicaemia	1 (0.3)	1 (0.8)	0	0
Physical abuse by parent	1 (0.3)	0	0	1 (2.4)
Baby asphyxiated in bag while mother was absconding from hospital	1 (0.3)	0	1 (0.5)	0
Failures to access maternal care	51 (14.4)			
• No antenatal care in high-risk pregnancy	43 (12.2)	42 (33.3)	1 (0.5)	0
• Village delivery of high-risk mother	10 (2.8)	10 (7.9)	0	0
• Prolonged ruptured membranes (>48 h) at home leading to severe neonatal sepsis	6 (1.7)	6 (4.8)	0	0
• Prolonged labour (> 48 h) before presenting to health facility leading to birth asphyxia	5 (1.4)	5 (3.9)	0	0
• Haemorrhage from poorly tied umbilical cord	1 (0.3)	1 (0.8)	0	0
B. Failures in preventive health services	47 (13.3)	–	–	–
Vaccine-preventable diseases	28 (7.9)	1 (0.8)	26 (14.0)	1 (2.4)
No screening tests for maternal syphilis	19 (5.4)	17 (13. 5)	2 (1.1)	0
C. Failures in primary curative health services	20 (5.7)	–	–	–
Health facility closed or lack of standard drugs	11 (3.1)	1 (0.8)	8 (4.3)	2 (4.9)
Delayed referral (> 7 days after presenting to primary health facility)	5 (1.4)	0	5 (2.7)	0
Absconded from health centre because no care given	5 (1.4)	1 (0.8)	3 (1.6)	1 (2.4)
D. Failures at the referral hospital	47 (13.3)			
Avoidable nosocomial infection	7 (2.0)	0	7 (3.8)	0
Oxygen problem				
• Transfer of baby with cyanosis and severe respiratory distress without oxygen	5 (1.4)	2 (1.6)	3 (1.6)	0
• Hospital ran out of oxygen leading to fatal hypoxia	1 (0.3)	0	1 (0.5)	0
• Lumbar puncture without giving oxygen in hypoxic infant with meningitis	1 (0.3)	0	1 (0.5)	0
Antibiotic problem				
• Failure to commence or wrong use of standard antibiotics	12 (3.4)	3 (2.4)	9 (4.8)	0
Antimalarial problem				
• Failure to commence quinine or failure to give a glucose source with quinine in cerebral malaria	2 (0.6)	0	1 (0.5)	1 (2.4)
Other procedural error				
• Inappropriate management of obstructed labour	6 (1.7)	6 (4.8)	0	0
• Prolonged wait of severely ill child in outpatient department	2 (0.6)	1 (0.8)	1 (0.5)	0
• Inappropriate early discharge from labour ward of sick newborn	3 (0.8)	3 (2.4)	0	0
• Incorrect nasogastric tube placement	2 (0.6)	0	2 (1.1)	0
• Failure to correct severe anaemia	2 (0.6)	0	2 (1.1)	0
• Failure to recognize severe dehydration	2 (0.6)	0	2 (1.1)	0
• Failure to drain abscess in child with septicaemia	2 (0.6)	0	1 (0.5)	1 (2.4)
• Doctors refused to attend patient	1 (0.3)	0	1 (0.5)	0
• Failure to recognize iatrogenic bowel perforation after abdominal surgery	1 (0.3)	0	1 (0.5)	0

With such data it will be difficult to develop specific programmes aimed at lowering neonatal mortality, which makes up 35% of all childhood deaths. On the other hand, non-specific programmes aimed at improving access to, and uptake of skilled maternal care (the lack of which was a factor in 39.6% of all neonatal deaths) may be more effective than a vertical programme for the prevention of congenital syphilis (13.5% of neonatal deaths), for example.

Early benefits of the audit

The most immediate benefit of the audit has been a reduction of avoidable factors within Goroka Hospital; benefits related to community-based factors have been less tangible. In the first 6 months of the audit there were 99 deaths, of which 22 (22%) had avoidable in-hospital factors. In the final 6 months reported here there were 84 deaths, of which 6 (7%) had in-hospital avoidable factors (Fisher's exact test, $P = 0.007$). There was no change over time in the proportion of deaths that had any avoidable factors (47% in the first 6 months compared with 46% in the final 6 months), suggesting that a hospital-based audit will have limited early impact on total preventable deaths. However, the audit assisted in the identification of several community-based problems that were previously underrecognized, including congenital syphilis as a major cause of neonatal deaths in this area (*12*), and a major measles epidemic. In the three years prior to December 1998, there had not been a recorded death from measles at the hospital. Over the period May-August 1999, measles was the commonest cause of death. Prompt institution of comprehensive community-based measures halted the epidemic (*13*). Since November 1999 there have been no further deaths from measles at Goroka or reported throughout the Eastern Highlands Province. Therefore the audit assisted us in tracking the emergence of an epidemic, planning a comprehensive strategy and evaluating its effect, and confirming the resolution of the epidemic. Plans are now underway for the problem of congenital syphilis to be addressed by the piloting of a rapid screening test for syphilis that could be used in all health centre antenatal clinics.

Enteric Gram-negative sepsis

Sepsis due to enteric Gram-negative bacilli occurred in one-quarter of all deaths. The very high mortality from these infections reflects the virulence of the bacteria, the severity of underlying conditions and high levels of resistance to standard antibiotics. Apart from Gram-negative bacilli causing diarrhoea (predominantly *S. typhi*, *Shigella* sp. and *Escherichia coli*, estimated to cause 2 million under-five deaths annually worldwide), Gram-negative sepsis is rarely mentioned in global assessments of important diseases in developing countries (*9*). Only 9 (10.3%) of the 87 children in this study who died from Gram-negative sepsis had diarrhoea. In a recent etiological study in Papua New Guinea only 7 enteric Gram-negative bacilli were isolated from 968 young infants with reportedly severe infection, but it is unlikely that the majority of these infants were very ill. Only 343 (35%) required admission to hospital and only 8 died (0.8%) (*14*). Conversely in a rural area of the Gambia during the malaria season, enteric Gram-negative bacilli were a common cause of septicaemia and pneumonia (*15*). In our study, the association between informal adoption/abandonment and Gram-negative sepsis suggests that the type of malnutrition that occurs after separation from the biological mother puts children at greater risk of death from this condition. Although the association between kwashiorkor and the Gram-negative sepsis was significant in a univariate analysis, it was not independent of adoption/abandonment in a multivariate analysis. Possible factors in the pathogenesis of Gram-negative sepsis in adopted/abandoned babies are absence of breast milk from an early age, eating food contaminated with enteric bacteria during the period of immunological immaturity, and poor general hygiene resulting from neglect by the adoptive parents. The strong association between village births and Gram-negative sepsis suggests that unclean deliveries may be one source of enteric Gram-negative bacilli among neonates. Poor sanitation in villages, many of which do not have basic pit-latrine toilets, may also contribute to the high incidence. Duration of hospital stay is a surrogate indicator for exposure to broad-spectrum antibiotics, severity of initial illness and risk of cross-infection. Despite the association between duration of hospital stay and death from Gram-negative sepsis, respectively, 28% and 51% of 87 children with Gram-negative sepsis died within 3 days and 1 week of admission, respectively, suggesting a community origin for many of these infections. Of the 87 infections, 22 (25.3%) were definitely and another 4 possibly hospital-acquired, although even in definite cases the sources were not always identifiable. For neonates, where the major risk factor for Gram-negative sepsis was village birth, duration of hospital stay was not a risk factor: 50% of 30 neonates with the condition died within 5 days, and 76% within one week. Colonization with enteric Gram-negative bacilli may occur at or near the time of birth (in the gastrointestinal tract and/or the nasopharynx (*15*)). Intercurrent illnesses, particularly those impairing gastrointestinal tract mucosal protection, and antibiotics lead to selection for resistant strains, bacterial overgrowth, and systemic invasion. Therefore, although cross-infection accounts for a significant number of fatal Gram-negative infections, so do infections with endogenous pathogens. This highlights the importance of identifying underlying risk factors and the difficulties of controlling these pathogens. The answer to the significant problem of Gram-negative sepsis will not be found by using more powerful antibiotics, many of which are unaffordable in developing countries, but rather by basic interventions to control risk factors, both in and out of hospitals.

Congenital syphilis

Positive maternal syphilis serology has been shown previously to be a risk factor for neonatal death in other rural developing countries (*16*). Congenital syphilis was a major cause of mortality in neonates in our study. The mothers of half of the babies dying from syphilis received no antenatal care, and 36% delivered in villages. A screening programme for maternal syphilis may be an effective intervention, but must be coupled with increased coverage of skilled maternal care (*12*).

Limitations of the audit

As is common in observational studies, there are weaknesses in this study: the data are largely hospital-derived; the assignment of avoidable factors requires a subjective interpretation of events; there was no control group of surviving children; and some investigations were only carried out when the clinical picture was suggestive, with a potential for missing subclinical cases.

Hospital-based microbial cause-specific mortality data may not be representative of deaths that occur among children who never receive health care. Standard antibiotics will cure the majority of cases of pneumonia due to *S. pneumoniae* and *Haemophilus influenzae*. These bacteria are the major causes of child mortality worldwide, causing fatal illnesses in a proportion of cases that do not receive treatment or receive inadequate treatment. Although we found that *S. pneumoniae* was the most important pathogen, mortality from pneumococcal disease will be substantially underestimated in hospital-based studies relative to the overall burden of mortality. Most children for whom blood or lung aspirate cultures were performed post mortem had received antibiotics, and we did not test the serum for antimicrobial activity in those children who had died before arrival or those for whom blood cultures were performed at the time of presentation. This will have resulted in a bias towards Gram-negative bacteria and staphylococcal isolates, which are less sensitive to standard antibiotics (penicillin, trimethoprim-sulfamethoxazole and chloramphenicol) than are pneumococcal and *Haemophilus* isolates. Most of the children in this study who died from pneumococcal and *Haemophilus* infection had meningitis, although in developing countries the major burden of mortality from these bacteria is from pneumonia (*17*). Our data suggest that even if developing countries could achieve good curative health services, control of deaths from bacterial meningitis will only be achieved by a primary prevention strategy. A pneumococcal vaccine that is effective in young infants and is affordable by poor countries is urgently required, as is the introduction of the conjugate *H. influenzae* vaccine.

Lack of access to treatment as an avoidable cause of death may also have been underestimated in our audit (although we found this to be a common problem). Community-based studies mostly use retrospective verbal autopsies (*11, 18–22*). The period examined may extend retrospectively 3–10 years from the time of interviewing, so recall bias may limit accuracy. Moreover, the sources of error, particularly disease misclassification (*21, 23*) are such that estimated disease-specific mortality rates are approximate at best, and specific questions on avoidable factors are not included. Because community-based studies rarely include microbiological data, little can be concluded from them about microbial-specific mortality. It is estimated that 60–80% of deaths in highland Papua New Guinea, as in other developing countries, occur outside hospitals. Since Goroka Hospital is the only paediatric service within the Eastern Highlands Province we feel that, with certain exceptions, the fatal diseases and their microbial causes documented here closely represent those that occur throughout the whole of the highlands.

The collection of a control group of surviving children would have added considerably to the work required to run the weekly audit, and it would have been difficult to have appropriately matched controls since those who died commonly had complex presentations and illnesses. The lack of a control group of surviving children reduces the informative value of our risk factor analysis for Gram-negative sepsis and very low birth weight from the point of view of prevention of death, since the controls we used also died (of other illnesses). However, our analysis assists in understanding biological and epidemiological causation. Conclusions on avoidable factors in deaths are also limited: for example, absence of antenatal care appeared to be a common etiological factor in neonatal deaths. We cannot say, without a control group of survivors, that deaths would have been prevented if more mothers had attended clinics, as the quality of care provided may be low.

The application of tests to children only if clinical signs were suggestive may mean that we missed some subclinical cases of HIV and syphilis, and some carriers of hepatitis B. Although financial limitations restricted the number of tests we could do, we tested all children who were suspected of having these diseases, based on their clinical presentation. Where the clinical presentation was uninformative, such as where children had died at home, testing was also carried out. It is unlikely that we missed many cases where these diseases contributed substantially to the cause of death, and it is unlikely that we have underestimated the current burden of childhood mortality from HIV, for example. This audit is closely integrated in the daily clinical activities within our department and in our view it would not have been good practice to carry out every investigation on every child, regardless of the clinical probability of disease.

Deaths were not classified as avoidable if avoidance would have required new vaccines, new drugs or new technology. Only those that could have been avoided with better public health measures, community education and participation, and improved basic clinical care were included. Health care failures occurred because basic health services did not exist (where they should have), were not accessed, or (apparently less commonly) because they failed to deliver the correct or adequate management for the particular problem. These failures occurred in preventive and curative health services, and at the primary and referral levels. Individuals were not invariably to blame; many failures occurred because of inadequacies in the entire system of health care delivery, which also includes the perception of that system by individuals and the community. Identifiable factors include poor support for and supervision of primary health care workers, and anomalies in resource distribution, all of which lead to low morale, and poor motivation and performance. These issues have been commented on previously (*24*). It is not appropriate to say that all the deaths identified as having avoidable factors should not have occurred. Many deaths would only have been avoided by addressing multiple factors, and although some deaths could have been avoided through health service reforms, such reforms may not have had the same impact in different regions because of differences in cultural approaches to life and death. In addition, many of the avoidable factors we identified will not be addressed by the health services (e.g. certain reasons for delayed presentation, physical abuse by parents, or tribal fighting). This emphasizes the need for a multisector approach to health.

Conclusions

This study suggests that major reductions in child mortality would result from even very basic health reforms. These include increasing immunization coverage, opening closed health facilities, improving village sanitation, attracting more women to formal maternal care, treating maternal syphilis, and implementing support programmes to ensure successful breastfeeding by the biological mother. These interventions will be difficult to achieve in a resource-poor developing country. We hope, however, that there will be resolve for

reform of health services in the highlands of Papua New Guinea, with priorities and resource distribution that reflect the most common avoidable causes of child deaths. Systematic mortality audits in other regions where child mortality is high may be useful for setting priorities, estimating the potential benefit of specific and non-specific interventions, and providing continuous feedback on the outcome of health reforms. Audit provides a useful tool for promoting health workers' awareness of the need for quality improvements in the health service. ■

Acknowledgements

We gratefully acknowledge the hard work and dedication of the nursing staff of the Goroka Paediatric Department who cared for more than 5000 children admitted during the course of this study; 95% of these children survived. Particular thanks go to Sisters A. Kauba, L. Mohabe, P. Wari and S. Kapari for supporting and contributing to the audit. We thank the Chief Executive Officer of Goroka Hospital, the Chairman of the Goroka Hospital Board of Directors, the Eastern Highlands Province Health Adviser, and the Director of the Papua New Guinea Institute of Medical Research for permission to publish the audit findings. We also thank WHO and the Papua New Guinea Health Department for financial support, and R. Ivivi and M. Yohannes of the Papua New Guinea Institute of Medical Research for technical assistance. We are grateful to the families involved who, during times of great sadness, helped us to learn more about why their children died. T. Duke thanks A. Duke for her constant support.

Conflicts of interest: none declared.

Résumé

Etiologie de la mortalité chez l'enfant à Goroka (Papouasie-Nouvelle-Guinée) : étude prospective de deux ans

Objectif Recueillir des données exactes sur les causes (classées par maladies et par étiologies microbiennes) et les facteurs évitables de décès chez l'enfant dans un pays en développement.

Méthodes Une enquête prospective systématique sur les décès d'enfants enregistrés à l'Hôpital de Goroka, dans les régions montagneuses de Papouasie-Nouvelle-Guinée, a été réalisée. Sur une période de 24 mois, nous avons étudié une série consécutive de 353 décès d'enfants : 126 nouveau-nés, 186 enfants de 1 à 59 mois et 41 enfants de 5 à 12 ans.

Résultats Les diagnostics les plus fréquents, par âge, étaient les suivants : chez les nouveau-nés de très faible poids de naissance, septicémie, hypoxie à la naissance et syphilis congénitale ; chez les enfants de 1 à 59 mois, pneumonie, septicémie, marasme et méningite ; chez les enfants de 5 à 12 ans, affections malignes et septicémie. Au moins une cause microbienne de décès a été identifiée chez 179 enfants (50,7 %) et deux ou plus chez 37 enfants (10,5 %). Neuf agents pathogènes microbiens étaient à l'origine de 41 % de l'ensemble des décès d'enfants et de 76 % des décès dus à une cause infectieuse. Des facteurs potentiellement évitables ont été identifiés pour 177 décès (50 %). Parmi les plus fréquents figuraient : absence de soins anténatals lors de grossesses à haut risque (8,8 % de l'ensemble des décès), consultation très tardive (7,9 %), maladie évitable par la vaccination (7,9 %), adoption informelle ou abandon d'enfant conduisant à une malnutrition sévère (5,7 %), et absence de dépistage de la syphilis maternelle (5,4 %). Un état infectieux dû à des entérobactéries à Gram négatif était à l'origine de 87 décès (24,6 %). Les facteurs les plus fortement associés aux décès dus à des bactéries à Gram négatif étaient l'adoption ou l'abandon conduisant à une malnutrition sévère, la naissance dans un village et un séjour prolongé à l'hôpital.

Conclusion La réduction de la mortalité chez l'enfant passera par la lutte contre les causes les plus fréquentes de décès : maladies, agents pathogènes microbiens, conditions sociales défavorables et insuffisance des services de santé. Des enquêtes systématiques sur la mortalité dans des régions où la mortalité chez l'enfant est élevée peuvent être utiles pour fixer les priorités, évaluer l'intérêt potentiel d'interventions spécifiques ou non, et assurer le retour permanent d'information sur les résultats des réformes du secteur de la santé.

Resumen

Etiología de la mortalidad infantil en Goroka (Papua Nueva Guinea): estudio prospectivo de dos años

Objetivo Reunir datos precisos sobre las causas específicas – enfermedades y agentes microbianos – y los factores evitables implicados en la mortalidad infantil en un país en desarrollo.

Métodos Se llevó a cabo un estudio prospectivo sistemático de las defunciones infantiles en el Hospital de Goroka, en las tierras altas de Papua Nueva Guinea. A lo largo de un periodo de 24 meses, analizamos las circunstancias de 353 defunciones infantiles consecutivas: 126 recién nacidos, 186 niños de entre 1 y 59 meses, y 41 niños de 5–12 años.

Resultados Los diagnósticos clínicos por edades más frecuentes fueron los siguientes: entre los recién nacidos de muy bajo peso al nacer, septicemia, asfixia durante el parto y sífilis congénita; entre los niños de 1–59 meses, neumonía, septicemia, marasmo y meningitis. Y entre los niños de 5 a 12 años, procesos malignos y septicemias. Se descubrió como mínimo una causa microbiana de defunción en 179 (50,7%) niños, y dos o más en 37 (10,5%). Nueve patógenos microbianos causaron el 41% de todas las muertes infantiles, y el 76% de todas las muertes en que concurrió un proceso infeccioso. Se identificaron factores potencialmente evitables en 177 (50%) defunciones. Los factores más frecuentes fueron los siguientes: falta de atención prenatal en embarazos de alto riesgo (8,8% de todas las defunciones), presentación muy tardía (7,9%), adopción informal o abandono del niño, con resultado de malnutrición grave (5,7%), y ausencia de cribado de la sífilis materna (5,4%). En 87 casos (24,6%) hubo septicemia por bacilos entéricos gramnegativos. Los factores más estrechamente asociados a las muertes debidas a sepsis por gramnegativos fueron las adopciones/abandonos con resultado de malnutrición grave, los partos rurales y las estancias hospitalarias prolongadas.

Conclusión El grado de reducción de la mortalidad infantil dependerá de la capacidad para abordar las causas más frecuentes de defunción, lo que comprende problemas de salud, agentes patógenos, circunstancias sociales adversas y fallos de los servicios

de salud. La realización de estudios sistemáticos de la mortalidad en determinadas regiones de mortalidad infantil elevada puede ser de gran ayuda para establecer prioridades, estimar los beneficios potenciales de intervenciones específicas e inespecíficas, y proporcionar retroinformación continua sobre los resultados de las reformas sanitarias.

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