

Global, regional, and national causes of child mortality in 2008: a systematic analysis



Robert E Black, Simon Cousens, Hope L Johnson, Joy E Lawn, Igor Rudan, Diego G Bassani, Prabhat Jha, Harry Campbell, Christa Fischer Walker, Richard Cibulskis, Thomas Eisele, Li Liu, Colin Mathers, for the Child Health Epidemiology Reference Group of WHO and UNICEF*

Summary

Background Up-to-date information on the causes of child deaths is crucial to guide global efforts to improve child survival. We report new estimates for 2008 of the major causes of death in children younger than 5 years.

Methods We used multicausal proportionate mortality models to estimate deaths in neonates aged 0–27 days and children aged 1–59 months, and selected single-cause disease models and analysis of vital registration data when available to estimate causes of child deaths. New data from China and India permitted national data to be used for these countries instead of predictions based on global statistical models, as was done previously. We estimated proportional causes of death for 193 countries, and by application of these proportions to the country-specific mortality rates in children younger than 5 years and birth rates, the numbers of deaths by cause were calculated for countries, regions, and the world.

Findings Of the estimated 8·795 million deaths in children younger than 5 years worldwide in 2008, infectious diseases caused 68% (5·970 million), with the largest percentages due to pneumonia (18%, 1·575 million, uncertainty range [UR] 1·046 million–1·874 million), diarrhoea (15%, 1·336 million, 0·822 million–2·004 million), and malaria (8%, 0·732 million, 0·601 million–0·851 million). 41% (3·575 million) of deaths occurred in neonates, and the most important single causes were preterm birth complications (12%, 1·033 million, UR 0·717 million–1·216 million), birth asphyxia (9%, 0·814 million, 0·563 million–0·997 million), sepsis (6%, 0·521 million, 0·356 million–0·735 million), and pneumonia (4%, 0·386 million, 0·264 million–0·545 million). 49% (4·294 million) of child deaths occurred in five countries: India, Nigeria, Democratic Republic of the Congo, Pakistan, and China.

Interpretation These country-specific estimates of the major causes of child deaths should help to focus national programmes and donor assistance. Achievement of Millennium Development Goal 4, to reduce child mortality by two-thirds, is only possible if the high numbers of deaths are addressed by maternal, newborn, and child health interventions.

Funding WHO, UNICEF, and Bill & Melinda Gates Foundation.

Introduction

Child mortality has been declining worldwide as a result of socioeconomic development and implementation of child survival interventions, yet 8·8 million children die every year before their fifth birthday.¹ The aim of UN Millennium Development Goal 4 (MDG 4) is to reduce mortality of children younger than 5 years by two-thirds between 1990 and 2015, but many countries, especially in south Asia and sub-Saharan Africa, are not on track to meet this target.¹ An acceleration of the decline in mortality is possible with expansion of interventions targeting the important causes of death.^{2–4} In view of the short time left to meet MDG 4, demand is increasing for frequently updated national data on the causes of child mortality to guide national and global programmatic priorities and research.

Updates of total mortality in children younger than 5 years are published every year, and the most recent estimates are for 2008. WHO and UNICEF's Child Health Epidemiology Reference Group (CHERG) undertook the last comprehensive review of the causes of child mortality worldwide for 2000–03.⁵ The Countdown to 2015 Initiative

used these estimates to produce country profiles for 68 countries of low and middle income to assess their progress towards MDG 4.⁶ Availability of more recent data and improved methods will enable updated estimates of cause-specific child mortality. We present estimates of the distribution of causes of child deaths in 2008 for 193 countries, with aggregated regional and global totals.

Methods

Mortality rates in children younger than 5 years

Figure 1 summarises the process used to develop the estimates. Methods to estimate the country-specific mortality rates in children younger than 5 years (5q0) have been developed and agreed by the Inter-agency Group for Child Mortality Estimation (IGME), which consists of representatives of WHO, UNICEF, UN Population Division, World Bank, and academic institutions.^{7,8} Every year, IGME assesses and incorporates data from all available surveys, censuses, and vital registration systems to estimate change in the mortality rate of children younger than 5 years in each country.

Lancet 2010; 375: 1969–87

Published Online

May 12, 2010

DOI:10.1016/S0140-

6736(10)60549-1

See [Comment](#) page 1941

*Members listed at end of paper

Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA (Prof R E Black MD, H L Johnson PhD, C Fischer Walker PhD, L Liu PhD); London School of Hygiene and Tropical Medicine, London, UK (Prof S Cousens MA); Saving Newborn Lives/Save the Children, Cape Town, South Africa (J E Lawn PhD); University of Edinburgh Medical School, Edinburgh, UK (Prof I Rudan MD, Prof H Campbell MD); Centre for Global Health Research, Li Ka Shing Knowledge Institute, St Michael's Hospital, University of Toronto, Toronto, ON, Canada (D G Bassani PhD, Prof P Jha MD); Global Malaria Programme (R Cibulskis PhD) and Department of Health Statistics and Informatics (C Mathers PhD), WHO, Geneva, Switzerland; and Department of International Health and Development, Tulane University School of Public Health and Tropical Medicine, New Orleans, LA, USA (T Eisele MD)

Correspondence to: Prof Robert E Black, Department of International Health, Johns Hopkins Bloomberg School of Public Health, 615 N Wolfe Street, Baltimore, MD 21205, USA rblack@jhsph.edu

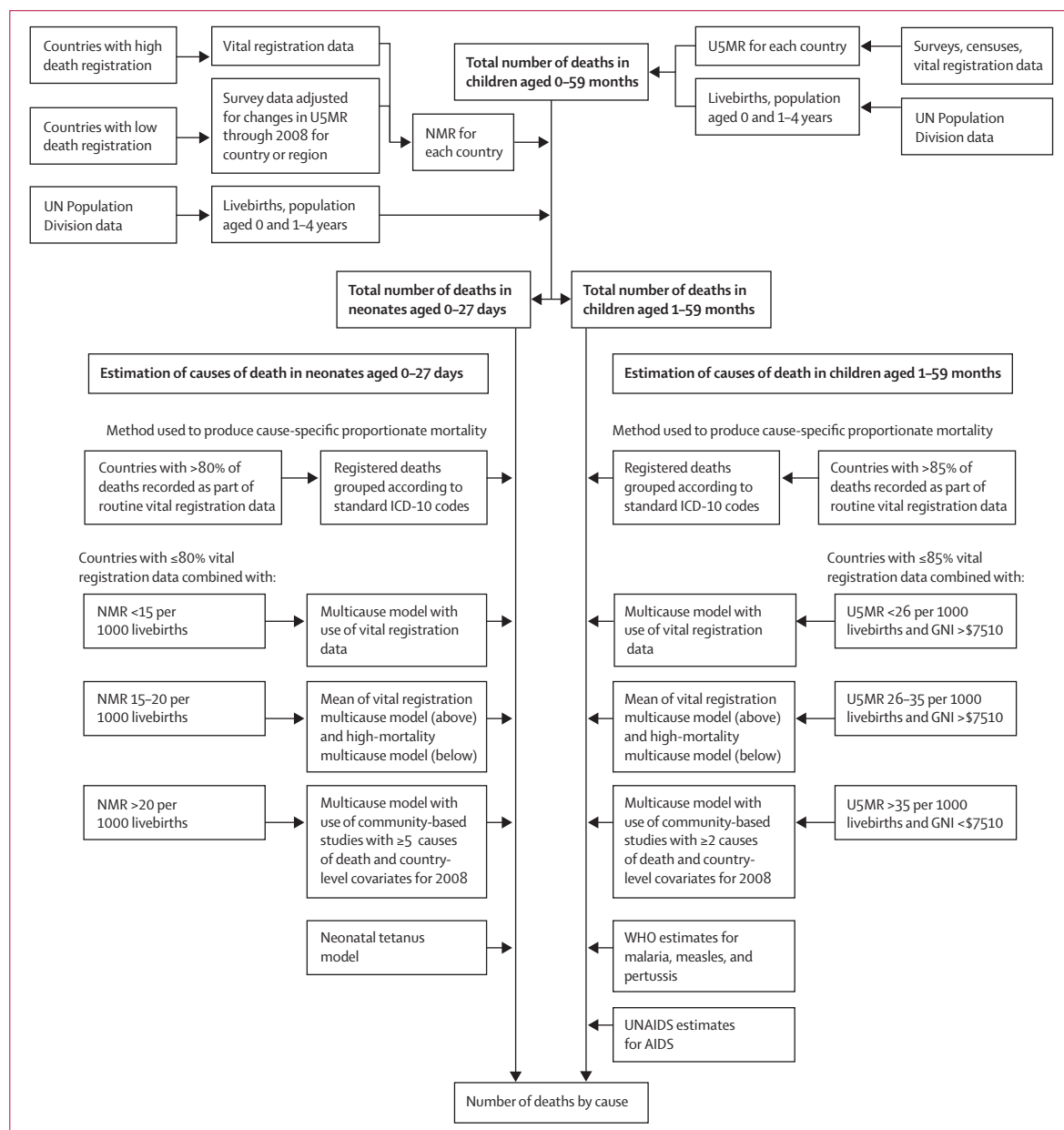


Figure 1: Overview of procedures for estimation of deaths by cause in children younger than 5 years of age
 U5MR=mortality rate in children younger than 5 years. NMR=neonatal mortality rate. GNI=gross national income per person (international dollars). ICD-10=International Classification of Diseases, 10th revision.

Child mortality estimates that we have used are generally consistent with those previously published,⁹ apart from those for several high-income countries in which death registration data became available for a more recent year. These published estimates also incorporate a new adjustment in which data for 17 countries with high HIV prevalence were revised to correct for bias in survey data from deceased mothers; such bias is particularly a problem in settings with high AIDS mortality. Data were also adjusted for misreporting of the date of birth and the estimated change in child deaths due to AIDS.¹⁰

Estimated livebirths, and de-facto numbers of children aged 0 and 1-4 years for 2008 are taken from the UN Population Division 2008 revision.¹¹ Total deaths in children younger than 5 years for 2008 were estimated by application of the IGME-estimated mortality rates for children aged 0 and 1-4 years to the de-facto population for these age-groups.

Neonatal mortality rates

Figure 1 summarises the process used to develop the estimates. Methods used to estimate mortality rates in

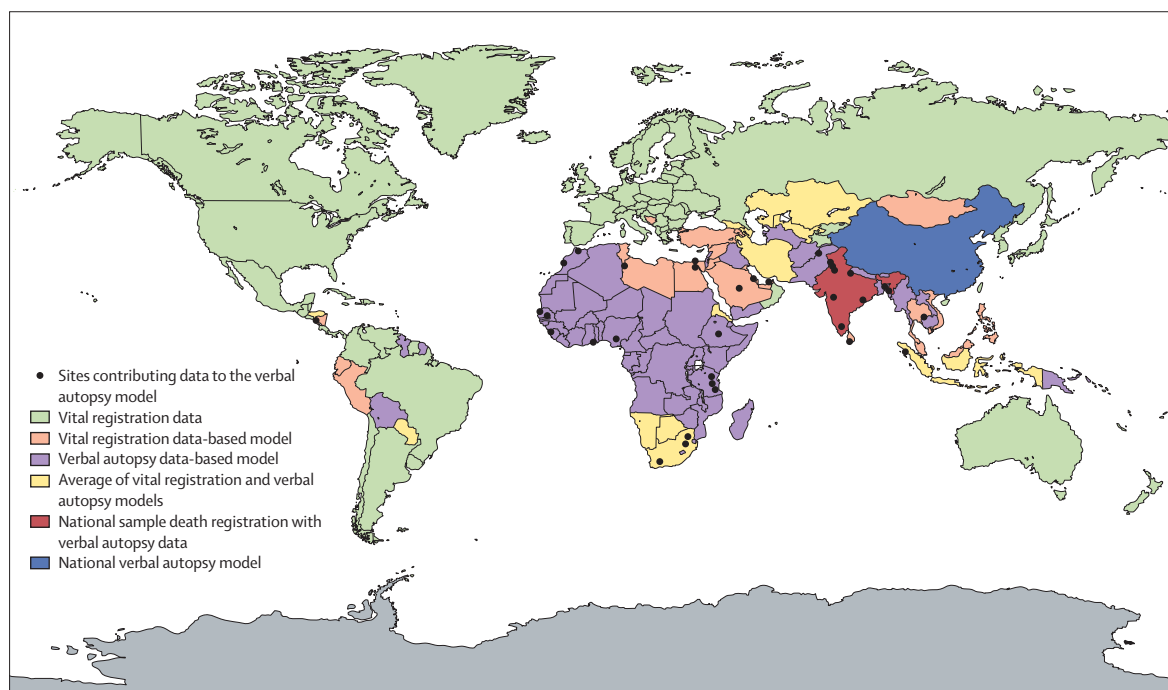


Figure 2: Methods used to estimate causes of death in neonates aged 0–27 days in 2008

neonates (aged 0–27 days) have been revised and updated for 2008. The previous WHO method for estimation¹² has been revised to incorporate the effect of the projected change in the mortality rate of children younger than 5 years from the years for which data are available until 2008. The WHO database of mortality rates in pairs of neonates and children younger than 5 years that were recorded from death registration systems and nationally representative household surveys has been updated to include 3263 country-year datapoints across 167 countries and all WHO regions, of which 966 country-years are from survey data.¹³

For countries without high coverage of death registration but with suitable survey data, we applied a regression model to data from 1990 onwards, after adjustment to match the estimated trend in the mortality rate of children younger than 5 years, according to the equation:

$$\log(\text{Pr}[\text{NMR}/1000]) = \alpha + \beta_1 \times \log(\text{Pr}[\text{U5MR}/1000]) + \beta_2 \times (\log(\text{Pr}[\text{U5MR}/1000]))^2 + \beta_3 \times X_i$$

where NMR is neonatal mortality rate, U5MR is mortality rate in children younger than 5 years, X_i is one for country i and zero otherwise, and β_3 is a country-level fixed effect. For countries without data for mortality rates in both neonates and children younger than 5 years, this regression model was run with aggregated regional data with regional fixed effects, rather than country-level fixed effects, to predict the 2008 mortality-rate ratio of neonates to children younger than 5 years.

Analysis and application of vital registration data

Data from vital registration systems on causes of deaths for neonates and children aged 1–59 months were extracted from the WHO mortality database, with adjustment for incomplete coverage if needed.⁸ We included countries from the database in the analysis if they had adequate registration of deaths (80% for neonates, 85% for children aged 1–59 months). Data closest to 2008 were used, but for very small countries (mostly islands in the Caribbean and Pacific), we used a mean of the number of deaths during the 3 years (in one case 5 years) closest to 2008 to obtain a more stable estimate of mortality by cause. In a few cases, causes of deaths in neonates and children aged 1–59 months were imputed from totals for children aged 0–4 years. For this imputation, we used the mean cause-specific ratio of neonatal deaths to deaths in children aged 1–59 months from other countries, accounting for 0.4% (0.037 million/8.795 million) of deaths in children younger than 5 years.

Causes of deaths were categorised according to the International Classification of Diseases, 10th revision (ICD-10; webappendix pp 1–3). Some deaths that were coded to causes inappropriate for the neonatal period were reassigned (webappendix pp 4–6). Additionally, we reassigned neonatal deaths as congenital abnormalities if they were classified according to ICD-10 as due to endocrine disorders, nutritional and metabolic diseases, or diseases of the nervous, digestive, circulatory, musculoskeletal, and genitourinary systems, because these disorders are probably caused by congenital

See Online for webappendix

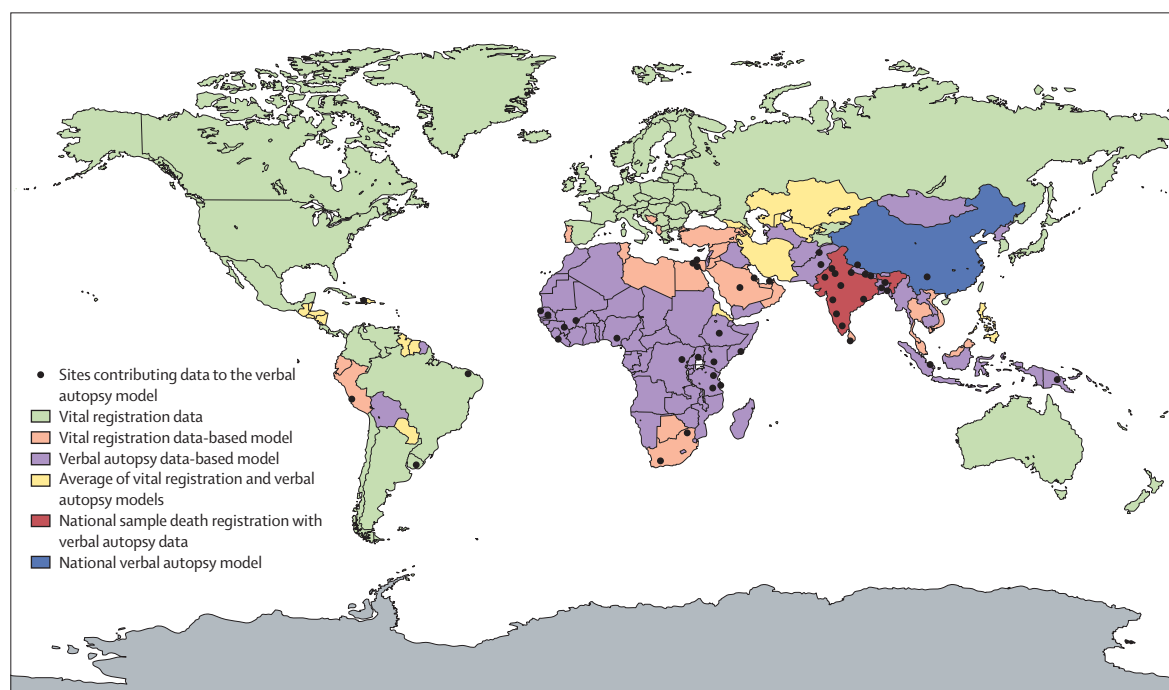


Figure 3: Methods used to estimate causes of death in children aged 1–59 months in 2008

malformations. Deaths reported with ill-defined causes (ICD, 9th revision, chapter 16, or 10th revision, chapter 18, on symptoms, signs, and abnormal clinical and laboratory findings not classified elsewhere) were reassigned to other causes in proportion to the number of reported deaths. The term birth asphyxia refers to intrapartum-related neonatal deaths, excluding preterm births and lethal congenital abnormalities. This term will be used to allow comparison with previous reports, but we recognise recommendations to change to terms such as “death from intrapartum-related causes”¹⁴ that might eventually become widely adopted.

A model was developed for countries with low neonatal mortality and no useable death registration data by use of death registration data for low-mortality countries with adequate registration, as previously reported.^{15,16} This model was used for countries with less than 15 neonatal deaths per 1000 livebirths, and the high-mortality model, described below, was used for countries with more than 20 neonatal deaths per 1000 livebirths. For countries with 15–20 neonatal deaths per 1000 livebirths, both models were fitted and a mean of the two results was used.

For countries with inadequate death registration, and with fewer than 26 deaths in children younger than 5 years per 1000 livebirths or gross national income (GNI) per person at purchasing power parity of more than \$7510 (international dollars), we estimated proportional causes of death in children aged 1–59 months with a multicausal multinomial logistic regression model that used death registration data from

97 countries to identify causes of death in children aged 1–59 months. This model included covariates for mortality rates in children younger than 5 years, GNI per person, and regional indicator variables for Europe and Latin America and the Caribbean, according to WHO regional classifications. For countries with inadequate death registration, and with 26–35 deaths in children younger than 5 years per 1000 livebirths and GNI per person of more than \$7510, we took the mean of estimates from this model with those from the model used for high-mortality countries, described below, to estimate the causes of death in children aged 1–59 months.

Estimation of causes of deaths in high-mortality countries without complete vital registration data

To estimate causes of neonatal deaths, the multicausal model for neonatal deaths^{15,16} was revised to include additional study data from sites contributing data (figure 2), and was rerun with updated covariate data for 2008. Cause-specific results were adjusted country-by-country to fit the estimated number of neonatal deaths for 2008.

We also estimated causes of deaths in children aged 1–59 months. A full description of the methods in countries with incomplete death certification, 35 or more deaths in children younger than 5 years per 1000 livebirths, and GNI per person of \$7510 or less is provided elsewhere.¹⁷ In brief, we analysed 81 datapoints from community-based mortality studies in which at least two causes of death had been reported in children aged 1–59 months (figure 3). Eligible studies were identified from systematic searches of

	Estimated number (UR; millions)
Neonates aged 0–27 days	
Preterm birth complications	1.033 (0.717–1.216)
Birth asphyxia	0.814 (0.563–0.997)
Sepsis	0.521 (0.356–0.735)
Other	0.409 (0.318–0.883)
Pneumonia*	0.386 (0.264–0.545)
Congenital abnormalities†	0.272 (0.205–0.384)
Diarrhoea‡	0.079 (0.057–0.211)
Tetanus	0.059 (0.032–0.083)
Children aged 1–59 months	
Diarrhoea‡	1.257 (0.774–1.886)
Pneumonia*	1.189 (0.789–1.415)
Other infections	0.753 (0.479–2.830)
Malaria	0.732 (0.601–0.851)
Other non-communicable diseases	0.228 (0.143–0.606)
Injury	0.279 (0.174–0.738)
AIDS§	0.201 (0.186–0.215)
Pertussis¶	0.195 (—)
Meningitis	0.164 (0.110–0.728)
Measles	0.118 (0.075–0.180)
Congenital abnormalities†	0.104 (0.078–0.160)

Uncertainty range (UR) is defined as the 2.5–97.5 centile. --=data unavailable.
 *Estimated number of deaths in children younger than 5 years overall is 1.575 million (UR 1.046 million–1.874 million). †Estimated number of deaths in children younger than 5 years overall is 0.376 million (UR 0.283 million–0.580 million). ‡Estimated number of deaths in children younger than 5 years overall is 1.336 million (UR 0.822 million–2.004 million).
 §Uncertainty range is based on UNAIDS' estimated lower and upper bounds for deaths in children younger than 15 years. ¶Crowcroft and colleagues²⁰ sensitivity analysis presents extreme upper and lower values for various inputs.

Table 1: Estimated numbers of deaths by cause in 2008

published reports and unpublished sources; studies were included if they were done after 1979, had a duration of 12 months or a multiple of 12 months, and recorded at least 25 deaths in children younger than 5 years, with each death represented once, and less than 25% of deaths due to unknown causes. Deaths were grouped into one of seven categories: pneumonia, diarrhoea, malaria, injury, meningitis or encephalitis, measles, or other known causes. Deaths attributed to neonatal causes, AIDS, or undetermined causes were excluded. Since we used only deaths due to known causes in the estimation, we assumed that the proportional distribution of deaths with undetermined causes was the same as that for deaths with known causes. Deaths attributed to more than one of the seven causes were reallocated on the basis of the relative importance of single causes in the same studies. Deaths attributed to malnutrition were reallocated to one of the five infection categories on the basis of the relative importance of each of these causes.

Similar to the high-mortality model for neonatal deaths,¹⁶ a study-based multinomial logistic regression model was applied to country-level data to estimate causes of child death.¹⁷ We used ordinary least squares regression

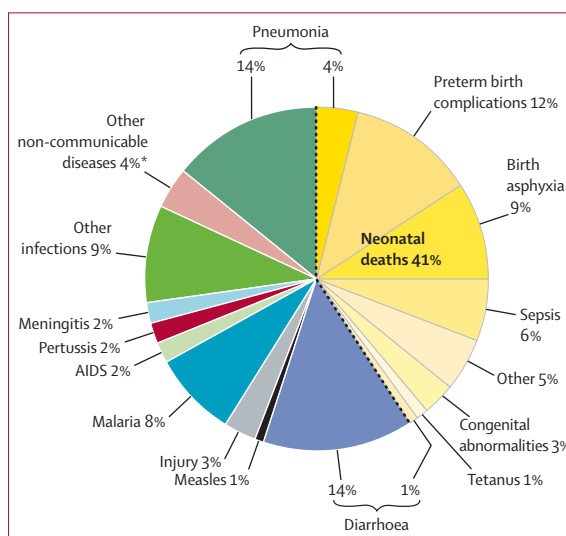


Figure 4: Global causes of child deaths
 Data are separated into deaths of neonates aged 0–27 days and children aged 1–59 months. Causes that led to less than 1% of deaths are not presented.
 *Includes data for congenital abnormalities.

to identify possible explanatory variables for the log-ratio models of the proportion of each of the six causes of death relative to the proportion of the reference cause. After selection of pneumonia as the reference cause and final covariates for the six log-ratio models, studies were given a weight proportional to the inverse of the square root of the total number of deaths. These studies were then included in the study-level multinomial logistic regression model with robust standard errors to obtain parameter estimates. We applied country-level covariate data from public databases (eg, WHO, UNICEF, World Bank) for 2008 to the study-based multinomial logistic regression model to estimate country-level cause-specific fractions. These fractions were then multiplied by the total number of non-AIDS deaths in children aged 1–59 months for each country. The country-level estimates of deaths by cause were adjusted for estimated effects of recently scaled up interventions: pneumonia and meningitis estimates were adjusted for use of the *Haemophilus influenzae* type b vaccine, and malaria estimates were adjusted for use of insecticide-treated bednets. Country-level estimates of causes of death were then combined with cause-specific data from WHO technical programmes and deaths due to AIDS from UNAIDS, and were adjusted to the estimated total number of deaths in children aged 1–59 months, as described below.

Estimation of deaths due to malaria, pertussis, measles, tetanus, meningitis, and AIDS

For countries without complete vital registration data, cause fractions from the neonatal and child multicausal models were replaced by cause-specific inputs from WHO technical programmes for malaria, pertussis, measles, and tetanus. The resulting cause fractions were adjusted

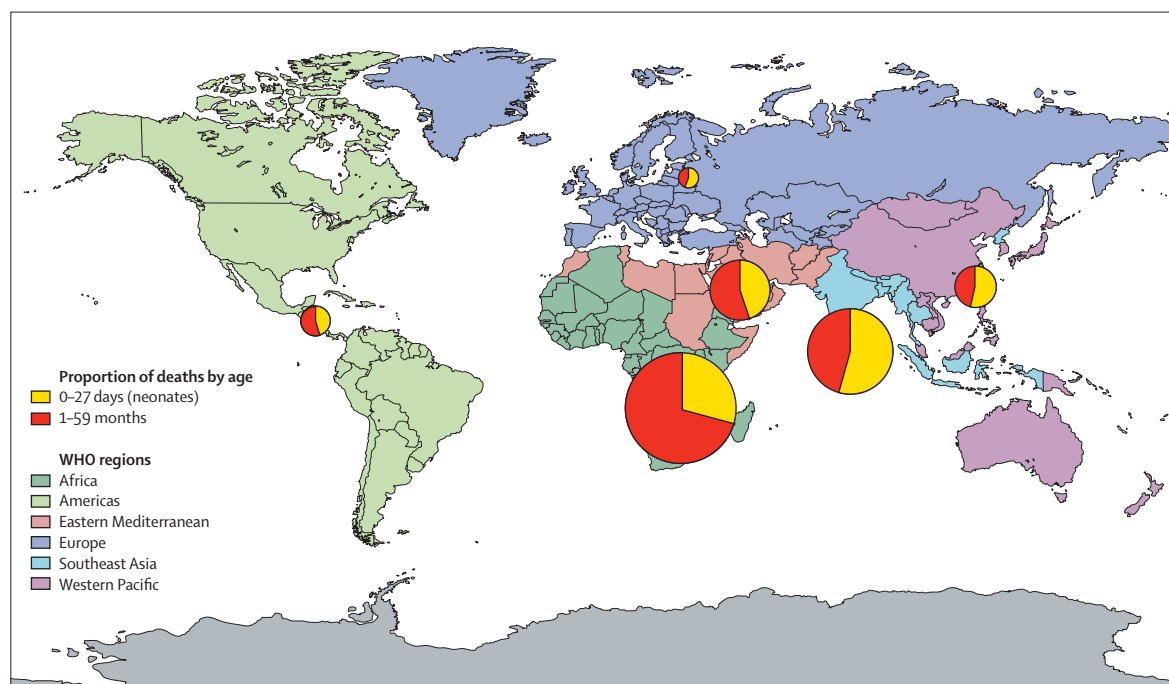


Figure 5: Distribution of 8.795 million child deaths in 2008 by WHO region and by age

to sum to one. WHO has prepared revised and updated malaria mortality estimates for children younger than 5 years for 2008 by use of the data sources and methods described in the World Malaria Report 2009.¹⁸ Updated estimates of pertussis cases were prepared by the WHO Department of Immunization, Vaccines and Biologicals (IVB) by use of WHO and UNICEF estimates for vaccination coverage in 2008, interpolated for missing data.¹⁹ For countries without complete data for death registration, deaths from pertussis were based on a natural history model of vaccine coverage and age-specific case-fatality rates from community-based studies.²⁰ Measles incidence and mortality for 2008 were estimated from a revised natural history model of routine vaccination coverage,¹⁹ supplementary immunisation activities, reported measles cases, estimates of notification efficiency, and estimates of age-specific case-fatality rates.²¹ Estimation of deaths from measles in India is described below.

IVB and CHERG have developed a revised statistical model that predicts the odds of neonatal death due to tetanus in high-burden countries. This model is based on WHO estimates of literacy in women, and the proportions of births that are protected from tetanus and are delivered by skilled birth attendants.^{9,22} We used the neonatal tetanus model for high-burden countries for 2008 estimates. For low-burden countries without complete death registration data or estimates from the neonatal tetanus model, we used the CHERG neonatal multinomial logistic regression model^{15,16} to estimate neonatal deaths due to tetanus. For high-mortality countries, we used results from the multicausal model for children aged

1–59 months to estimate deaths due to meningitis or encephalitis, apart from in a few countries with low meningitis mortality, for which previously published estimates were used.^{23,24} Estimates for deaths due to AIDS were done by UNAIDS.¹⁰

Estimation of causes of deaths in India and China

The Registrar General of India has introduced substantially revised verbal autopsy methods into the sample registration system as part of India's continuing Million Death Study.^{25,26} To estimate child deaths by cause for India, CHERG collaborated with the Million Death Study team to use data from a nationally representative sample of more than 123 000 deaths (23 000 child deaths) in 2001–03. Causes of deaths in neonates and children aged 1–59 months were assigned to categories (webappendix pp 1–3), and weighted by rural and urban subdivisions of each state to provide nationally representative cause fractions.

Estimates of deaths due to measles in children younger than 5 years from India's Million Death Study were substantially smaller than were those derived from the natural history model.¹⁹ In the Million Death Study, verbal autopsy rules included deaths due to measles for which either an underlying or an intermediate cause of death had been assigned, but some deaths from measles might have been misclassified. The natural history model estimates might have been too high, mainly because they are heavily affected by an estimated case-fatality rate. We calculated the mean of estimates from the Million Death Study and the natural history model to provide a

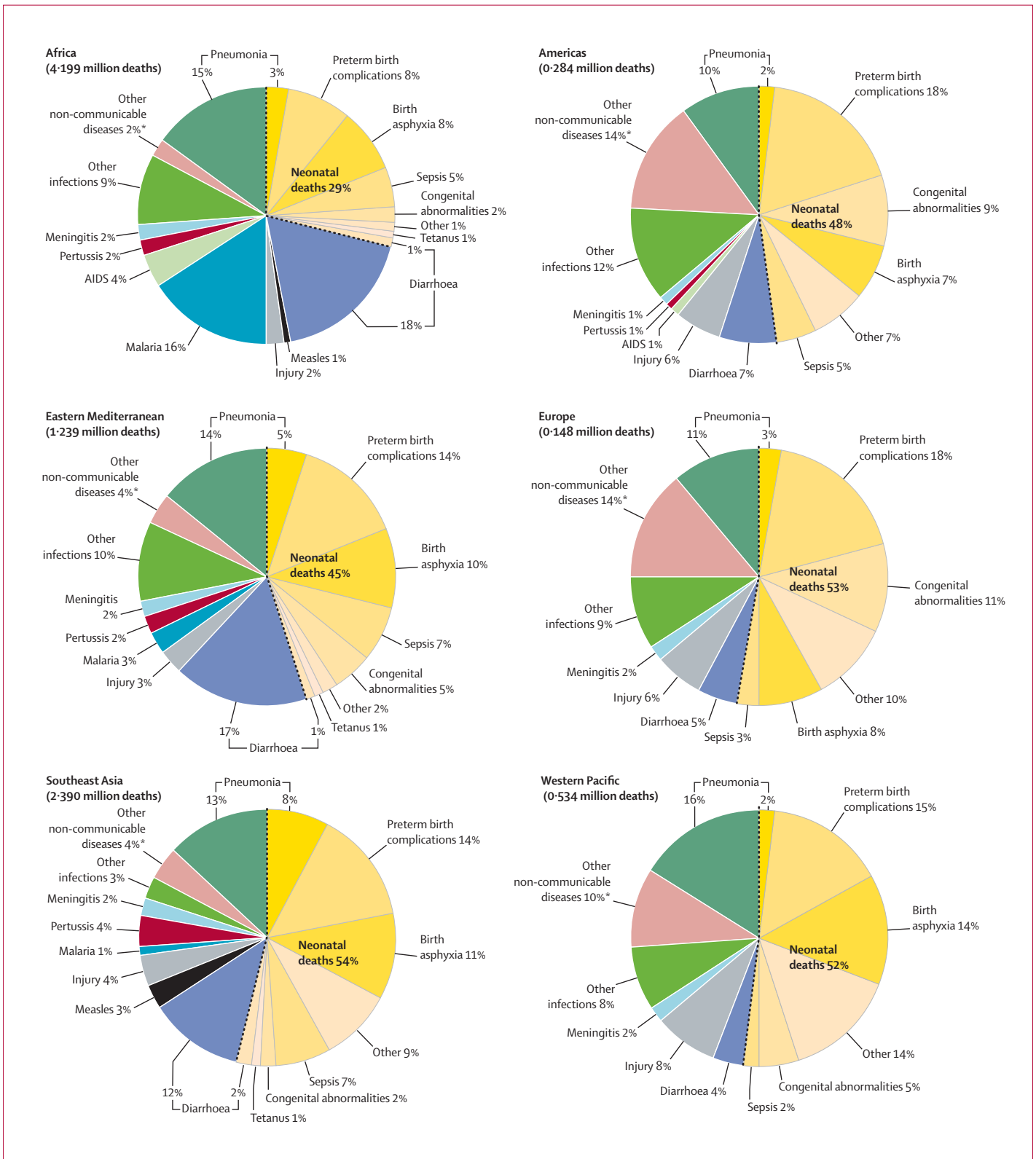


Figure 6: Regional causes of child deaths

Data are separated into deaths of neonates aged 0–27 days and children aged 1–59 months. Causes that led to less than 1% of deaths are not presented. *Includes data for congenital abnormalities.

	All cause by age			AIDS	Diarrhoea	Pertussis	Tetanus	Measles
	<5 years	0-27 days	1-59 months					
Africa								
Algeria	30184	17258	12925	39	3876	421	187	220
Angola	165344	36299	129045	2951	41403	2073	657	1129
Benin	39267	11150	28117	530	5114	1389	190	98
Botswana	1448	741	706	0	101	0	5	0
Burkina Faso	117069	25694	91374	995	22071	817	1251	35
Burundi	44786	11661	33124	1095	10568	157	256	494
Cameroon	89461	21939	67523	4362	14484	672	187	719
Cape Verde	342	193	149	0	28	4	3	20
Central African Republic	25936	7255	18682	1758	4484	817	87	1
Chad	98624	22084	76540	2850	21552	4273	1901	5
Comoros	2274	898	1377	0	457	26	6	0
Congo (Brazzaville)	15537	4303	11234	727	2222	108	20	0
Côte d'Ivoire	79165	29267	49899	3247	10424	927	320	1
Democratic Republic of the Congo	553529	162690	390839	6281	102679	10866	1029	4095
Equatorial Guinea	3478	996	2482	107	326	150	7	327
Eritrea	10237	3032	7205	449	2188	68	102	168
Ethiopia	321432	121594	199839	9080	73341	3535	4898	187
Gabon	3029	1099	1930	294	180	99	10	27
Ghana	54723	22672	32052	1437	5193	605	244	1115
Guinea	54326	17039	37288	1014	7524	1611	328	1827
Guinea-Bissau	12164	2910	9254	231	2321	283	31	290
Kenya	188928	50033	138896	8855	38802	1432	440	1568
Lesotho	4567	2210	2358	774	451	57	9	0
Liberia	20328	6425	13904	568	3493	651	77	385
Madagascar	71086	23964	47122	81	15964	747	268	0
Malawi	56348	17193	39155	7693	6169	353	191	0
Mali	100403	28463	71940	1116	19261	2114	568	9
Mauritania	12344	4830	7514	67	1936	148	84	0
Mauritius	289	166	123	2	5	0	0	0
Mozambique	110420	37565	72855	15504	13105	1229	779	0
Namibia	2425	1034	1391	441	153	60	7	158
Niger	120938	26874	94064	577	24575	3429	1897	106
Nigeria	1076613	298154	778459	29457	201368	32353	8619	707
Rwanda	41234	14197	27037	281	9305	142	160	468
São Tomé and Príncipe	493	167	326	0	72	1	2	3
Senegal	48933	16035	32898	710	7240	350	338	1458
Seychelles	13	9	4	0	0	0	0	0
Sierra Leone	42671	9959	32712	638	8904	1050	169	2027
South Africa	72553	21316	51237	33149	6293	1	139	1
Swaziland	2873	638	2235	1407	240	17	5	0
Tanzania	174959	59243	115717	14889	20211	1507	565	0
The Gambia	6239	2067	4172	84	867	26	36	59
Togo	19985	7020	12965	1152	2324	164	122	20
Uganda	189990	45007	144983	9542	30391	6472	510	4060
Zambia	76812	19557	57255	9179	11222	568	117	400
Zimbabwe	35583	10758	24825	7541	3291	1808	60	2680
Americas								
Antigua and Barbuda	19	14	6	0	0	0	0	0
Argentina	10451	6104	4347	16	94	50	0	0
Barbados	33	21	12	1	0	0	0	0

Meningitis	Malaria	Pneumonia	Other infections*	Preterm birth complications	Birth asphyxia	Neonatal sepsis	Congenital abnormalities	Other non-communicable diseases	Injury
317	0	5862	3452	6620	3824	1708	2279	678	700
2685	13911	33078	26858	10427	9531	7628	2945	5182	4886
1007	9165	7616	4125	3981	2470	964	1171	560	888
139	15	177	133	329	153	59	149	116	72
1407	23875	24374	17827	7586	5874	3109	1958	2869	3020
1025	4142	7459	6796	3072	3354	2726	836	1074	1732
2405	17038	16115	11248	7523	5782	3511	2204	1509	1703
13	1	49	30	83	39	16	32	15	11
482	3715	5254	2856	2234	1861	1113	613	352	309
1532	18338	19010	10238	5699	6340	2879	1281	1274	1452
89	0	499	319	368	216	129	64	59	43
306	3705	2489	1685	1726	1000	581	499	230	238
1922	16704	13222	7073	9532	6975	4591	2406	778	1042
10612	94196	112655	61928	54669	36045	23497	15055	9158	10764
61	969	410	171	356	257	153	118	17	47
190	29	1977	1739	1097	684	413	336	321	477
6797	21786	48892	34791	28439	36295	28681	6645	9637	8429
73	888	329	110	456	249	128	130	23	32
594	14365	5712	4159	6625	6207	4923	2028	435	1081
1016	12832	9245	4229	4327	4410	3433	1126	643	762
355	2147	2191	1352	942	744	617	202	208	249
3674	20666	30406	27630	14417	14581	11479	4226	4225	6529
125	0	585	420	736	599	475	202	39	95
347	3163	3449	2120	2063	1656	1238	457	367	293
2004	2494	15130	10202	8062	6344	4646	1655	2055	1435
1590	9376	7376	5936	5649	4556	3321	1590	1166	1381
1062	20918	18802	10647	8416	6838	3944	2074	2238	2398
274	1645	2413	1307	1565	1169	789	376	263	308
7	0	21	36	66	42	15	63	22	12
2590	13789	19447	10568	11067	9405	6176	2994	1746	2020
50	124	334	160	439	203	94	137	26	39
2835	21714	26319	15243	8543	6823	3062	1467	2276	2072
17637	217357	177212	108805	84164	85417	62221	22210	13300	15786
1155	2436	6272	5753	3746	4260	3471	1055	1032	1697
18	4	127	57	61	40	26	19	48	15
461	9167	8735	6200	5047	3768	2395	1451	768	845
0	0	1	3	5	1	0	2	1	0
621	5520	8444	5337	3269	2459	1562	537	1065	1071
607	51	6250	4212	8973	5113	1720	2378	2288	1377
63	1	337	198	243	130	73	83	48	28
5414	28745	25005	17135	17058	17043	13138	5407	2912	5930
67	1447	1002	736	707	486	291	171	82	177
375	5130	2949	1605	2257	1720	950	672	216	331
4101	42549	25751	17513	13734	12806	9713	3769	2338	6742
1528	11709	11323	9793	5699	5467	4486	1664	1352	2306
796	1222	4728	2514	4094	2926	1546	1235	498	643
0	0	1	1	9	1	0	4	1	1
94	0	743	1049	3090	574	593	2572	879	696
0	0	1	4	12	5	2	4	1	2

(Continues on next page)

	All cause by age			AIDS	Diarrhoea	Pertussis	Tetanus	Measles
	<5 years	0-27 days	1-59 months					
(Continued from previous page)								
Belize	144	62	82	6	11	0	0	0
Bolivia	14169	6506	7663	28	2158	262	52	0
Brazil	66624	33112	33513	151	3543	36	213	0
Canada	2210	1319	892	0	1	0	0	0
Chile	2231	1168	1063	3	6	15	0	0
Colombia	18103	11046	7057	51	750	21	83	0
Costa Rica	775	494	281	0	11	7	0	0
Cuba	750	383	366	1	10	0	0	0
Dominica	13	10	3	0	0	0	0	0
Dominican Republic	7346	4156	3190	96	677	9	18	0
Ecuador	7022	3190	3832	64	388	0	31	0
El Salvador	2259	940	1319	88	82	0	12	0
Grenada	30	25	4	0	0	0	0	0
Guatemala	15401	4754	10647	427	2937	312	228	0
Guyana	827	316	511	48	126	0	1	0
Haiti	19168	6736	12432	873	3887	1541	439	0
Honduras	6144	3114	3030	84	605	4	21	0
Jamaica	1651	454	1197	61	231	1	10	0
Mexico	36367	14733	21634	83	2002	6	79	0
Nicaragua	3845	1762	2084	25	343	22	25	0
Panama	1626	707	919	11	98	27	0	0
Paraguay	4315	2335	1979	43	378	3	19	0
Peru	14768	7647	7121	191	658	0	131	0
Saint Kitts and Nevis	14	11	4	0	0	0	0	0
Saint Lucia	48	36	12	0	0	0	0	0
Saint Vincent and the Grenadines	25	19	7	0	1	0	0	0
Suriname	257	115	143	6	15	0	0	0
The Bahamas	75	31	44	1	1	0	0	0
Trinidad and Tobago	697	484	213	43	4	0	0	0
Uruguay	798	401	396	1	16	0	0	0
USA	35238	19260	15978	6	33	40	0	1
Venezuela	10805	5922	4883	32	777	10	65	0
Eastern Mediterranean								
Afghanistan	310739	63124	247615	17	89709	1093	2766	1822
Bahrain	171	81	89	0	1	0	0	0
Djibouti	2241	861	1380	136	418	21	9	5
Egypt	44806	27175	17631	33	2146	155	518	155
Iran	45571	26147	19424	242	4480	11	173	0
Iraq	42159	23687	18472	0	4871	2325	348	98
Jordan	3070	1993	1077	0	119	0	11	0
Kuwait	557	295	262	0	3	0	0	0
Lebanon	860	499	361	6	21	4	0	4
Libya	2435	1364	1071	0	89	0	0	0
Morocco	23591	15086	8505	22	2917	201	279	3
Oman	699	431	268	0	13	0	7	0
Pakistan	464886	284149	180736	425	74209	7180	5604	275
Qatar	122	56	65	0	2	0	0	0
Saudi Arabia	12473	6946	5527	0	597	0	0	0
Somalia	75933	23978	51955	165	16576	2991	2068	3848
Sudan	138357	52532	85825	3350	14726	1184	546	7
Syria	9625	4693	4932	0	449	1	60	1

Meningitis	Malaria	Pneumonia	Other infections*	Preterm birth complications	Birth asphyxia	Neonatal sepsis	Congenital abnormalities	Other non-communicable diseases	Injury
1	0	16	19	26	13	5	21	9	15
359	3	2582	1740	2247	1784	1169	650	700	436
977	38	5846	10985	15369	6719	4379	9754	5210	3403
15	0	30	328	604	267	41	541	255	128
26	0	125	205	547	106	63	785	217	133
272	12	2215	3042	3490	1283	1252	3136	1196	1300
5	0	39	77	178	72	43	236	80	26
12	0	81	115	72	51	65	183	102	57
0	0	1	1	4	1	1	3	0	0
77	4	1353	851	1884	831	322	683	338	204
154	0	1198	842	1529	618	116	1095	545	443
100	0	309	224	475	200	26	420	171	149
0	0	4	3	11	4	1	6	1	1
502	0	3114	1622	2861	714	145	797	973	769
11	7	142	83	131	78	54	67	43	37
490	166	3862	1342	2108	1908	1126	459	503	462
141	2	1084	678	1323	720	325	570	348	241
25	0	374	249	221	87	15	156	140	81
131	0	4551	3459	6346	2481	1771	7989	4269	3200
103	0	757	438	841	323	62	495	237	173
21	0	217	237	257	105	85	390	73	105
74	0	725	467	1039	546	197	442	215	166
461	17	2290	1413	3650	1457	273	2319	988	920
0	0	0	2	5	4	0	1	1	1
0	0	0	4	25	11	1	5	1	1
0	0	0	5	9	3	3	2	1	2
8	2	26	27	57	26	15	31	26	20
1	0	7	9	9	11	7	14	9	8
3	0	40	79	151	46	50	144	75	63
9	0	57	112	160	34	45	220	57	86
175	0	890	5119	10590	1687	911	8001	3770	4013
119	1	1118	888	2511	935	869	2035	425	1019
7557	46	80694	50853	14240	16165	12977	5792	14882	12126
0	0	2	13	40	11	2	73	12	17
35	4	417	306	252	202	141	162	81	52
1843	0	4748	3855	14803	2520	597	8146	3253	2037
449	1	7313	4189	12097	4004	1760	6422	2576	1852
973	0	8570	2341	9533	4933	1951	3461	616	2141
45	0	329	263	1082	190	48	598	244	140
0	0	21	28	157	18	9	265	31	25
25	0	66	62	260	51	9	202	84	65
10	0	214	211	727	147	27	533	297	179
319	0	4063	2191	4853	3440	1912	2356	411	624
4	0	47	41	225	44	8	178	83	49
6218	539	84210	34420	77392	67613	56337	31690	10795	7976
0	0	7	7	30	6	1	32	23	14
47	0	1227	907	3925	735	161	2355	1461	1058
1317	4440	14418	7681	6169	6414	4139	2159	1651	1896
2481	34434	21533	11744	24994	9576	2510	4976	2466	3830
128	0	1053	886	2524	524	90	2075	1137	699

(Continues on next page)

	All cause by age			AIDS	Diarrhoea	Pertussis	Tetanus	Measles
	<5 years	0-27 days	1-59 months					
(Continued from previous page)								
Tunisia	3490	1964	1527	0	167	0	17	0
United Arab Emirates	461	295	166	0	4	0	0	0
Yemen	56 834	27 280	29 554	0	11 480	3 407	1 374	4 46
Europe								
Albania	650	165	485	0	12	0	2	0
Andorra	3	1	2	0	0	0	0	0
Armenia	1 114	649	465	4	18	0	0	0
Austria	350	203	147	0	1	0	0	0
Azerbaijan	6 175	3 114	3 060	10	708	36	8	4
Belarus	1 245	627	618	0	6	0	0	0
Belgium	584	289	295	0	9	2	0	0
Bosnia and Herzegovina	482	255	227	0	6	0	0	0
Bulgaria	795	332	463	0	14	0	0	0
Croatia	233	146	88	0	1	0	0	0
Cyprus	41	20	21	0	0	0	0	0
Czech Republic	408	198	210	0	5	0	0	0
Denmark	283	172	111	0	2	0	0	0
Estonia	97	51	46	1	0	0	0	0
Finland	204	115	89	0	0	0	0	0
France	3 090	1 680	1 410	0	24	2	0	0
Georgia	1 638	1 018	620	4	90	0	2	0
Germany	2 943	1 686	1 257	2	7	0	0	0
Greece	374	191	183	0	0	0	0	0
Hungary	675	371	304	0	2	0	0	0
Iceland	14	6	8	0	0	0	0	0
Ireland	345	189	156	0	0	1	0	0
Israel	655	318	337	0	0	5	0	0
Italy	2 350	1 266	1 084	0	1	0	0	0
Kazakhstan	9 661	5 066	4 595	16	227	0	0	1
Kyrgyzstan	4 675	2 138	2 538	12	652	2	5	0
Latvia	210	116	94	0	2	0	0	0
Lithuania	209	89	120	0	0	0	0	0
Luxembourg	14	5	9	0	0	0	0	0
Macedonia	250	149	101	0	9	0	0	0
Malta	27	9	18	0	0	0	0	0
Moldova	805	360	445	0	18	0	0	0
Monaco	2	1	1	0	0	0	0	0
Montenegro	65	39	26	0	0	0	0	0
Netherlands	851	522	329	0	0	0	0	0
Norway	209	99	110	0	6	0	0	0
Poland	2 644	1 560	1 084	0	6	0	0	0
Portugal	378	187	190	4	0	0	0	0
Romania	2 721	1 322	1 399	0	37	0	0	0
Russia	16 689	9 119	7 570	15	196	2	0	0
San Marino	1	0	1	0	0	0	0	0
Serbia	889	565	324	0	3	0	0	0
Slovakia	407	176	231	0	1	0	0	0
Slovenia	59	39	20	0	0	0	0	0
Spain	2 150	1 054	1 097	4	0	1	0	0
Sweden	340	175	165	1	3	0	0	0
Switzerland	342	222	120	0	0	0	0	0

Meningitis	Malaria	Pneumonia	Other infections*	Preterm birth complications	Birth asphyxia	Neonatal sepsis	Congenital abnormalities	Other non-communicable diseases	Injury
152	0	363	263	1062	205	43	714	298	206
4	0	23	26	145	26	5	134	61	34
1124	263	10251	3881	9529	6631	3001	2787	1218	1442
7	0	117	54	93	43	4	145	104	68
0	0	0	0	1	0	0	1	1	0
65	0	187	95	292	114	22	186	82	49
7	0	3	43	88	32	1	112	38	25
172	0	1349	798	1329	609	281	441	279	152
25	0	55	187	120	76	25	378	161	211
20	0	8	91	83	46	13	189	68	57
3	0	67	37	117	48	6	114	52	32
15	0	170	94	137	73	16	145	87	44
1	0	10	31	47	17	11	85	15	15
0	0	2	1	10	2	0	14	8	4
11	0	22	60	56	52	10	93	48	50
3	0	4	18	95	26	0	88	34	12
2	0	2	11	9	10	4	26	10	20
2	0	8	22	40	12	6	75	26	13
42	0	50	660	408	361	84	810	442	208
26	0	304	160	438	210	89	188	71	55
50	0	44	310	965	199	47	819	320	181
3	0	28	6	130	16	0	135	23	32
16	0	46	125	165	31	4	172	76	37
1	0	0	3	1	1	1	3	3	0
10	0	0	27	53	16	5	167	47	18
8	0	10	86	122	38	10	259	88	28
20	0	35	347	552	165	62	721	340	108
203	0	1672	4434	101	67	0	1412	865	663
162	0	1039	643	859	544	186	311	130	132
1	0	15	22	14	52	3	63	20	17
4	0	13	17	24	15	9	74	18	36
0	0	0	1	4	2	0	3	2	2
0	0	14	4	111	25	6	63	11	8
1	0	2	1	6	2	0	8	3	4
13	0	182	40	35	54	46	248	57	113
0	0	0	0	0	0	0	1	0	0
0	0	6	2	17	7	1	18	9	4
14	0	14	116	150	99	53	242	111	53
4	0	1	26	30	35	6	59	24	18
20	0	119	158	800	186	108	914	183	148
5	0	23	16	84	39	5	122	51	31
23	0	895	366	329	98	11	574	160	229
279	0	1184	2935	2130	1352	448	3980	1937	2231
0	0	0	1	0	0	0	0	0	0
9	0	53	65	351	111	11	196	61	30
5	0	45	16	113	18	3	118	56	31
0	0	1	11	14	5	7	12	6	3
50	0	37	392	373	145	90	641	284	133
5	0	8	43	40	34	11	113	68	12
1	0	3	68	80	33	10	94	35	18

(Continues on next page)

	All cause by age			AIDS	Diarrhoea	Pertussis	Tetanus	Measles
	<5 years	0-27 days	1-59 months					
(Continued from previous page)								
Tajikistan	12 000	4 286	7 714	27	2 304	9	23	5
Turkey	29 698	19 147	10 551	0	389	32	234	45
Turkmenistan	5 352	2 339	3 014	0	691	2	11	1
UK	4 324	2 399	1 925	1	4	6	0	0
Ukraine	7 259	3 794	3 465	64	59	3	0	0
Uzbekistan	21 200	10 892	10 308	47	2 549	9	27	0
Southeast Asia								
Bangladesh	182 936	113 884	69 053	60	20 155	1 731	2 674	1 622
Bhutan	1 199	523	676	0	169	7	9	0
Burma	123 562	49 119	74 443	663	15 841	948	121	409
India	1 829 826	1 003 767	826 060	8 585	237 482	86 182	13 248	81 275
Indonesia	173 036	80 140	92 895	635	26 120	284	662	545
Maldives	163	90	73	0	14	0	0	0
Nepal	36 822	22 578	14 244	279	5 416	764	408	74
North Korea	18 246	9 373	8 873	14	2 202	232	18	0
Sri Lanka	6 239	3 165	3 073	6	202	6	21	33
Thailand	14 035	9 971	4 064	273	266	15	53	15
Timor-Leste	3 924	1 901	2 023	0	529	7	46	214
Western Pacific								
Australia	1 407	801	606	0	5	0	0	0
Brunei	51	26	25	0	1	0	0	0
Cambodia	32 349	11 260	21 089	107	2 306	12	124	172
China	369 289	205 710	163 578	1 191	11 420	401	50	467
Cook Islands	7	3	3	0	0	0	0	0
Federated States of Micronesia	109	42	67	0	5	0	0	0
Fiji	313	149	164	2	17	0	1	0
Japan	3 620	1 261	2 359	0	46	0	0	0
Kiribati	100	35	65	0	17	0	0	0
Laos	10 209	3 441	6 768	10	758	45	265	316
Malaysia	3 519	1 748	1 771	131	35	9	42	9
Marshall Islands	47	19	28	0	4	0	0	0
Mongolia	2 037	685	1 352	2	92	1	0	0
Nauru	10	7	3	0	0	0	0	0
New Zealand	360	245	116	0	1	1	0	0
Niue	1	1	0	0	0	0	0	0
Palau	6	3	3	0	0	0	0	0
Papua New Guinea	13 971	5 306	8 665	362	728	63	154	286
Philippines	72 760	32 788	39 972	32	4 852	77	588	216
Samoa	108	47	61	0	8	0	0	0
Singapore	111	48	63	0	0	0	0	0
Solomon Islands	548	221	327	0	21	1	2	3
South Korea	2 409	987	1 422	0	5	0	0	0
Tonga	56	25	31	0	4	0	0	0
Tuvalu	8	3	5	0	0	0	0	0
Vanuatu	228	94	134	0	15	0	1	3
Vietnam	20 836	12 982	7 854	682	471	44	134	376
Total								
Worldwide	8 795 349	3 575 053	5 220 296	201 236	1 336 289	195 465	61 023	117 623

The sum of data for individual causes, different age-groups, or individual countries does not match the total values in some cases because of rounding. The totals for individual causes differ from those in table 1 life (eg, congenital abnormalities, tetanus, sepsis). *Includes some deaths due to preterm birth complications, birth asphyxia, and other perinatal causes.

Table 2: Estimated numbers of deaths by cause in children younger than 5 years by WHO region and country

Meningitis	Malaria	Pneumonia	Other infections*	Preterm birth complications	Birth asphyxia	Neonatal sepsis	Congenital abnormalities	Other non-communicable diseases	Injury
374	0	2493	2034	1788	1101	612	429	440	361
706	0	4152	2113	9014	3316	552	5326	2366	1452
127	0	1219	859	950	538	311	334	156	153
76	0	147	265	1549	306	39	1109	646	175
152	0	315	1147	823	521	173	2047	990	963
630	0	4554	2971	4660	2142	956	1600	519	536
3912	3244	25978	17719	30547	32375	29464	6788	2374	4293
44	0	291	146	167	129	87	45	56	49
1971	2168	16293	11298	17288	13175	10803	2757	2145	27682
31607	6292	371605	267011	248993	191607	121395	54823	56360	53362
3031	1389	38331	25617	33258	17516	8633	9612	3857	3545
4	0	26	18	42	18	8	15	10	7
785	8	5299	3011	6168	6591	5304	1440	467	808
634	0	3649	2021	3854	2129	1277	1154	612	447
33	0	647	605	1382	511	92	1155	541	1005
37	70	1468	1215	4175	1575	330	2897	1003	643
71	449	409	316	485	629	452	122	105	90
13	0	32	240	316	131	20	333	208	109
1	0	1	7	7	4	1	18	4	7
1153	251	9097	5976	3556	3236	2443	744	2058	1113
7443	2	62229	60113	56074	62117	7128	36989	24198	39466
0	0	1	1	1	0	0	1	1	1
5	0	32	14	19	8	3	6	13	4
2	0	41	31	71	27	4	55	40	22
15	0	225	407	321	178	66	1400	577	387
2	0	24	16	15	8	3	7	4	4
436	19	2735	1923	879	1082	563	371	515	292
13	6	215	275	766	299	39	911	471	300
1	0	11	7	8	3	1	4	5	2
74	0	581	422	280	104	30	134	217	102
0	0	2	1	3	2	1	1	0	0
7	0	17	42	93	38	12	89	26	35
0	0	0	0	0	0	0	0	0	0
0	0	1	1	1	1	0	1	1	1
658	1018	3135	1819	1588	1593	869	471	802	424
2481	40	17351	12370	13883	5014	1269	6122	5348	3118
3	0	21	14	22	9	2	12	12	6
2	0	14	3	28	1	3	39	16	6
26	34	141	79	98	34	9	35	50	16
12	0	86	247	630	121	85	505	424	293
0	0	9	7	11	5	1	9	7	4
0	0	1	1	1	1	0	1	1	1
9	5	53	21	45	17	3	19	27	9
715	28	2079	1893	5618	2142	366	4025	1296	966
166100	732049	1575257	1062071	1072544	828800	522576	375897	254529	293890

because some of the other neonatal causes were split into individual causes in table 2. Additionally, some deaths from causes that are mainly associated with the neonatal period occurred after the first month of

provisional total of 81 000 deaths due to measles, pending further consideration of both approaches. The Million Death Study also assigned a substantially greater proportion of child deaths to malaria than did WHO estimates of total malaria cases and case fatality.¹⁸ Pending further analysis of data from the Million Death Study, we used WHO estimates of deaths from malaria in children younger than 5 years for 2008. We used the same method as for other countries to estimate deaths due to pertussis because of the difficulties associated with use of verbal autopsy to differentiate pertussis from other respiratory infections. Together with cause-specific inputs from WHO technical programmes and UNAIDS, the resulting cause-specific inputs for India were adjusted to fit the estimated total deaths in neonates and children aged 1–59 months. Neonatal deaths in India were estimated to account for 54% of deaths in children younger than 5 years in 2008; this percentage was calculated by use of the method described above for estimation of the neonatal mortality rate with data from the Million Death Study for 2004–05, and three nationally representative surveys for 1998–99, 2002–03, and 2005–06.

For China, causes of child deaths were based on estimates of cause fractions for deaths in neonates and children aged 1–59 months as previously described,²⁷ adjusted to our estimates for total number of deaths in neonates and children aged 1–59 months in China in 2008. WHO technical programme estimates for deaths caused by malaria, tetanus, pertussis, and measles were used because these causes accounted for small proportions of child deaths and were not generally included as specific causes in published data from China.

Estimation of uncertainty

Methods used to obtain uncertainty estimates for the multicausal models are described elsewhere.^{16,17} Briefly, we used a jackknife analysis to estimate the standard error of the model's out-of-sample predictions. Monte Carlo simulations (1000 iterations) were used to perturb country-level estimates based on these standard errors. Uncertainty ranges (URs) for the simulations, defined as the 2.5–97.5 centile, provide an indication of the uncertainty in the estimates. This approach to uncertainty estimation captures, to some extent, the misclassification of deaths by verbal autopsy and the variability across studies. However, it does not capture uncertainty related to the estimation of mortality in children younger than 5 years that is presented elsewhere,^{7,8} or that related to the analysis of vital registration data that comprises a very small proportion of the total deaths. The uncertainty for the estimation of deaths due to AIDS,¹⁰ malaria,¹⁸ measles,²¹ pertussis,²⁰ and tetanus (Cousens S, personal communication) were derived from single-cause disease models.

Figures 2 and 3, and webappendix pp 7–12 show the methods used for each country. The preliminary estimates were sent by WHO to all countries, and after

receipt of feedback, or in some cases more recent data, the estimates were finalised.

Role of the funding source

The sponsor of the study had no role in the study design, data collection, data analysis, data interpretation, or the decision to submit for publication. All authors had complete access to data, and the corresponding author had final responsibility for the decision to submit for publication.

Results

Of 8.795 million child deaths that occurred in 2008,¹ 68% (5.970 million) were caused by infectious diseases. The total numbers of deaths by cause are listed in tables 1 and 2 and in webappendix pp 13–25, and the distribution of deaths by cause is shown in figure 4. The most important infectious diseases were pneumonia in neonates and older children, diarrhoea, and malaria. Deaths occurring in the neonatal period (aged 0–27 days) accounted for 41% (3.575 million) of all deaths in children younger than 5 years. In this age-group, the greatest single causes of death were preterm birth complications and birth asphyxia, but collectively infectious causes were also important, especially sepsis and pneumonia.

Distribution of deaths (figure 5) and their causes (figure 6) varied widely across the WHO regions. The largest numbers of deaths were in the African region (4.199 million) and in the southeast Asian region (2.390 million). These two regions had differing patterns of causes of death: a lower proportion of neonatal deaths occurred in the African region than in the southeast Asian region (29%, 1.224 million vs 54%, 1.295 million); and a higher proportion of deaths in Africa were due to malaria (16%, 0.677 million) and AIDS (4%, 0.181 million) than in southeast Asia, in which about 1% (0.024 million) were due to these two causes combined. In the Americas, Europe, Asia, a high proportion of child deaths occurred during the neonatal period, ranging from 48% (0.137 million/0.284 million) in the Americas to 54% (1.295 million/2.390 million) in southeast Asia, with preterm birth complications and birth asphyxia as leading causes (figure 6). In countries with low neonatal mortality rates, congenital causes became proportionately more important.

In all children younger than 5 years, the most important single causes of death were pneumonia, diarrhoea, and preterm birth complications (table 2, figure 4). Other important causes were birth asphyxia and malaria. 92% (0.677 million) of deaths due to malaria, and 90% (0.181 million) of deaths due to AIDS occurred in the African region. Successful vaccination programmes have reduced the worldwide total for deaths caused by measles and tetanus, but each of these diseases was still responsible for about 1% of deaths worldwide in 2008 (table 2).

Numbers of deaths by cause in neonates, children aged 1–59 months, and all children younger than 5 years are

provided for 193 countries in table 2 and webappendix pp 13–25. 43% (274·392 million/634·176 million) of all children younger than 5 years worldwide reside in five countries—India, Nigeria, Democratic Republic of the Congo, Pakistan, and China—and these countries accounted for 49% (4·294 million) of all deaths in this age-group in 2008. These countries were responsible for high proportions of global totals for neonatal causes of death: birth asphyxia (53%, 0·443 million), sepsis (52%, 0·271 million), preterm birth complications (49%, 0·521 million), and congenital abnormalities (43%, 0·161 million). The highest proportions of deaths due to pneumonia occurred in India, Nigeria, Democratic Republic of the Congo, Pakistan, and Afghanistan, which collectively accounted for 52% (0·826 million). 51% (0·676 million) of deaths caused by diarrhoea occurred in India, Nigeria, Afghanistan, Pakistan, and Ethiopia. Deaths caused by malaria were concentrated in sub-Saharan Africa, with Nigeria, Democratic Republic of the Congo, Uganda, Sudan, and Tanzania accounting for 57% (0·417 million) of deaths. Similarly, 51% (0·103 million) of deaths due to AIDS occurred in South Africa, Nigeria, Mozambique, Tanzania, and Uganda. Injuries were shown to be important preventable causes of death in nearly all countries, with 32% (0·093 million) of such deaths in India and China.

Discussion

Collectively, the most important causes of death in children younger than 5 years were infectious diseases, especially pneumonia, diarrhoea, and malaria. The most important single causes of death were pneumonia, diarrhoea, and preterm birth complications. Two-fifths of deaths occurred in the neonatal period, during which the greatest single causes of death were preterm birth complications and birth asphyxia, but collectively, infectious diseases were also important. Numbers of deaths varied widely across WHO regions, with most deaths recorded in Africa and southeast Asia.

Despite a continuing increase in the population of children younger than 5 years, the mortality rate is declining: 8·795 million deaths occurred in 2008 versus 10·6 million per year during 2000–03.¹⁵ With greater declines in mortality in children aged 1–59 months than in neonates, the proportion of deaths in neonates has increased from 37% in 2000–03,³ to 41% (3·575 million) of 8·795 million deaths in children younger than 5 years in 2008. Thus, the main causes of death in the neonatal period—preterm birth complications, birth asphyxia, and sepsis and pneumonia—have become even more important. In children aged 1–59 months, the two most important causes of death remain the same as in previous estimates, diarrhoea and pneumonia, but the percentage of deaths in children younger than 5 years attributable to each cause has reduced by 20–25%.⁵ This reduction is partly due to the smaller proportion of deaths occurring in children aged 1–59 months, but also to new data

showing that the previous estimate of deaths due to diarrhoea in China was probably too high (12% vs new estimate of 3·1% [0·011 million/0·369 million]).^{27,28} Caution is essential with any comparison between previous and 2008 estimates of causes of death because additional data and changes in analytical methods could result in increased accuracy of estimates, but not a true indication of a time trend for certain diseases.

The concentration of all-cause child deaths and deaths due to some specific causes, such as diarrhoea, pneumonia, malaria, and AIDS, in a small set of countries is striking. This result is partly related to the large populations of children younger than 5 years in these countries, but also some diseases are concentrated because of epidemiological and social conditions. Success in disease control efforts in these countries is essential if MDG 4 goals are to be achieved. However, nearly all countries still face the challenge to reduce child deaths from preventable conditions, irrespective of their number or cause. These national estimates of the causes of child death in 2008 should help to identify priority interventions for child survival, and how to allocate national and international resources.

Undernutrition, including stunting, severe wasting, deficiencies of vitamin A and zinc, and suboptimum breastfeeding, is not presented as a direct cause of death in these statistics, but has been found to be an underlying cause in a third of deaths in children younger than 5 years.²⁹ In countries with adequate vital registration data, malnutrition was rarely listed as a cause of death, and verbal autopsy classification systems greatly underestimate the role of these nutritional deficiencies. Thus, we chose to allocate the few deaths reported to be caused by malnutrition to major infectious diseases that often precipitate severe wasting. Successful implementation of interventions to prevent the development of undernutrition and micronutrient deficiencies and to treat severe acute malnutrition would substantially reduce child mortality and improve the health and development of surviving children.^{4,30}

These estimates are based on some advances in both data and methodology (panel). Vital registration data are available for additional countries and further verbal autopsy data could be included because new studies have been done, and a change to the methods could allow analysis of studies that were previously excluded. The use of national data for the world's two largest countries (India and China) has been a major advance, but additional work is needed with data from these countries to fully represent the present state of major causes. The multinomial logistic regression model that is now used to estimate the causes of deaths in children aged 1–59 months, as was done previously for neonatal deaths,¹⁶ is a substantial improvement on the use of single-cause models. Single-cause models predicted collective death estimates that exceeded the yearly total number of deaths, so that adjustments needed to be made to fit these estimates

Panel: Major changes in estimation methods in 2008 compared with 2000–03⁵

- New estimates of national mortality rate in children younger than 5 years and in neonates
- Multicausal models led to increased datapoints from 102 to 148
- National data used for India and China
- Multicausal model used instead of single-cause models for age-group of 1–59 months (similar to previous multicausal neonatal model)
- Adjustments in modelled estimates to account for recent scale-up of vaccination with *Haemophilus influenzae* type b vaccine and distribution of insecticide-treated bednets
- Estimates of AIDS, neonatal pneumonia and sepsis, meningitis, pertussis, and non-communicable diseases added to previously presented causes
- Provision of uncertainty bounds for global numbers of child deaths from major causes

within the total. Of the seven causes of death (including the group of other known causes) in the multinomial logistic regression model of deaths in children aged 1–59 months, five were used directly for the estimates of 80% of the deaths. Malaria estimates were taken from other sources for 2008,¹⁸ but the high correlation (data not shown) between these estimates and the results of the multinomial logistic regression model provide encouragement that the multicausal model can be used for malaria mortality in the future. The multinomial logistic regression model was used for estimation of 98% of neonatal deaths, the exception being tetanus.

The major limitation for these estimates continues to be the scarcity of data on the causes of child death in the countries with the highest mortality. Ideally, recent data would be available for all countries through medically certified vital registration, but figures 2 and 3 show how few countries have adequate vital registration. Unfortunately data of sufficient completeness from this source is available for only 76 countries, covering 4% (0.344 million/8.795 million) of deaths in children younger than 5 years in 2008. For other countries, various statistical models have to be used to estimate the cause distribution of deaths. The gap in evidence is most acute for sub-Saharan Africa, in which data based on verbal autopsy methods are available from few countries. The countries with high mortality and the least resources are those that most need the information to target disease control programmes and primary health-care services. Yet these countries are least likely to have adequate data of their own—eg, only one country in sub-Saharan Africa has a vital registration system with reasonable completeness and a few others have nationally representative survey-based estimates of the causes of child mortality. Therefore, our estimates for many countries are derived from statistical modelling

with study-specific and national covariates. These estimates include substantial uncertainty, but we believe that they are still useful for planning national health and nutrition efforts.

CHERG will continue to work with WHO and UNICEF to identify data, improve estimation methods, and encourage use of resulting cause-specific child mortality numbers and rates in national and global health planning and priority setting. We anticipate updating these estimates every year to complement yearly updates in total deaths in children younger than 5 years. We challenge countries and programmes to advance the quality and consistency of data on causes of death, and, most importantly to use such data in the design of programmes to achieve maximum progress in the crucial few years before 2015.

Contributors

REB coordinated the analyses and prepared all drafts of the report, incorporating comments by coauthors. All authors contributed to the conceptualisation, analysis, and completion of the estimates, and to editing of the report. CHERG provided assistance with new methods and critique of provisional estimates of the causes of child mortality.

Child Health Epidemiology Reference Group of WHO and UNICEF

Robert E Black (Chair), Jennifer Bryce, Laura Caulfield, Christa Fischer Walker, Hope Johnson, Henry Kalter, Joanne Katz, Li Liu, and Neff Walker (Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA); Diego Bassani and Prabhat Jha (University of Toronto, ON, Canada); Zulfiqar Bhutta (Aga Khan University, Karachi, Pakistan); Thomas Eisele (Tulane University School of Public Health, New Orleans, LA, USA); Harry Campbell, Igor Rudan, and Evropi Theodoratou (University of Edinburgh, Edinburgh, UK); Simon Cousens and Veronique Filippi (London School of Hygiene and Tropical Medicine, London, UK); Majid Ezzati (Harvard University, Boston, MA, USA); Claudio Lanata (Nutrition Research Institute, Lima, Peru); Joy Lawn (Saving Newborn Lives/Save the Children, Cape Town, South Africa); Herbert Peterson (University of North Carolina, Chapel Hill, NC, USA); and Richard Steketee (PATH Malaria Vaccine Initiative, Ferney Voltaire, France).

Conflicts of interest

We declare that we have no conflicts of interest.

Acknowledgments

The study was supported by WHO and UNICEF funding for meetings, and by a grant from the Bill & Melinda Gates Foundation to the US Fund for UNICEF for CHERG; the neonatal estimates were also supported by a grant from the Bill & Melinda Gates Foundation to Saving Newborn Lives/Save the Children; and the Global Fund to Fight AIDS, Tuberculosis and Malaria provided funding for validation of WHO estimates of country burdens. Throughout the development of the estimates, technical input was provided by WHO staff, including Rajiv Bahl, Ties Boerma, Thomas Cherian, Olivier Fontaine, Fiona Gore, Raymond Hutubessy, Jose Martines, Lulu Muhe, and Shamim Qazi, and by UNICEF staff, including David Brown, Mark Young, and Mickey Chopra. We thank Mikkel Oestergaard and Mie Inoue of WHO for collaboration on estimates of the total number of deaths in neonates and children younger than 5 years; Doris Ma Fat and Veronique Joseph of WHO for analysis of WHO death registration data; Cynthia Boschi Pinto of WHO and Nancy Binkin of UNICEF for coordinating the participation of their respective institutions; Carolyn Weidemann for coordinating the grant in support of CHERG from the Bill & Melinda Gates Foundation; Kit Chan and Yan Guo for collaboration on the estimates from China; Rajesh Kumar and Shally Awasthi for collaboration on the estimates from India; Alma Adler and Shefali Oza for their contributions to updating of the neonatal databases and early versions of the neonatal models; Martin Aryee for assistance with the diarrhoea mortality analyses; and Laura Lamberti for preparation of the figures.

References

- 1 You D, Wardlaw T, Salama P, Jones G. Levels and trends in under-5 mortality, 1990–2008. *Lancet* 2010; **375**: 100–03.
- 2 Jones G, Steketee RW, Black RE, Bhutta ZA, Morris SS, The Bellagio Child Survival Study Group. How many child deaths can we prevent this year? *Lancet* 2003; **362**: 65–71.
- 3 Darmstadt GL, Bhutta ZA, Cousens S, Adam T, Walker N, de Bernis L, for the Lancet Neonatal Survival Steering Team. Evidence-based, cost-effective interventions: how many newborn babies can we save? *Lancet* 2005; **365**: 977–88.
- 4 Bhutta ZA, Ahmed T, Black RE, et al, for the Maternal and Child Undernutrition Study Group. What works? Interventions for maternal and child undernutrition and survival. *Lancet* 2008; **371**: 417–40.
- 5 Bryce J, Boschi-Pinto C, Shibuya K, Black RE, the WHO Child Health Epidemiology Reference Group. WHO estimates of the causes of death in children. *Lancet* 2005; **365**: 1147–52.
- 6 Countdown Coverage Writing Group, on behalf of the Countdown to 2015 Core Group. Countdown to 2015 for maternal, newborn, and child survival: the 2008 report on tracking coverage of interventions. *Lancet* 2008; **371**: 1247–58.
- 7 UNICEF, WHO, World Bank, UN Population Division. Levels and trends of child mortality in 2006: estimates developed by the Inter-agency Group for Child Mortality Estimation. http://www.childinfo.org/files/infant_child_mortality_2006.pdf (accessed Feb 10, 2010).
- 8 WHO. WHO mortality database: tables. <http://www.who.int/healthinfo/morttables/en/index.html> (accessed Feb 10, 2010).
- 9 UNICEF. The state of the world's children 2009. New York, NY: UNICEF, 2009. <http://www.unicef.org/sowc> (accessed Nov 4, 2009).
- 10 UN. 2008 report on the global AIDS epidemic. http://www.unaids.org/en/KnowledgeCentre/HIVData/GlobalReport/2008/2008_Global_report.asp (accessed Dec 29, 2009).
- 11 UN Population Division. World population prospects: the 2008 revision. New York, NY: United Nations, 2009.
- 12 WHO. Neonatal and perinatal mortality: country, regional and global estimates. Geneva: World Health Organization, 2006. http://www.who.int/entity/making_pregnancy_safer/publications/neonatal.pdf (accessed March 3, 2010).
- 13 WHO. Input dataset for neonatal mortality estimates. http://www.who.int/healthinfo/statistics/MORT_2008_neonatal_empirical.xls (accessed May 5, 2010).
- 14 Committee on Obstetric Practice, American College of Obstetricians and Gynecologists. Inappropriate use of the terms fetal distress and birth asphyxia. *Int J Gynaecol Obstet* 1998; **61**: 309–10.
- 15 Lawn JE, Cousens S, Zupan J, for the Lancet Neonatal Survival Steering Team. 4 million neonatal deaths: When? Where? Why? *Lancet* 2005; **365**: 891–900.
- 16 Lawn JE, Wilczynska-Ketende K, Cousens SN. Estimating the causes of 4 million neonatal deaths in the year 2000. *Int J Epidemiol* 2006; **35**: 706–18.
- 17 Johnson HL, Liu L, Fischer-Walker C, Black RE. Estimating the distribution of causes of death among children age 1–59 months in high mortality countries with incomplete death certification. *Int J Epidemiol* (in press).
- 18 WHO. World Malaria Report 2009. Geneva: World Health Organization, 2009.
- 19 WHO. WHO/UNICEF estimates of national immunization coverage. http://www.who.int/immunization_monitoring/routine/immunization_coverage/en/index4.html (accessed April 25, 2010).
- 20 Crowcroft NS, Stein C, Duclos P, Birmingham M. How to best estimate the global burden of pertussis? *Lancet Infect Dis* 2003; **3**: 413–18.
- 21 Wolfson LJ, Strebel PM, Gacic-Dobo M, Hoekstra EJ, McFarland JW, Hersh BS, for the Measles Initiative. Has the 2005 measles mortality reduction goal been achieved? A natural history modelling study. *Lancet* 2007; **369**: 191–200.
- 22 WHO. WHO/UNICEF review of national immunization coverage, 1980–2008. Geneva: World Health Organization, 2009. http://www.who.int/immunization_monitoring/en/globalsummary/wucoveragecountrylist.cfm (accessed April 25, 2010).
- 23 O'Brien KL, Wolfson LJ, Watt JP, et al, for the Hib and Pneumococcal Global Burden of Disease Study Team. Burden of disease caused by *Streptococcus pneumoniae* in children younger than 5 years: global estimates. *Lancet* 2009; **374**: 893–902.
- 24 Watt JP, Wolfson LJ, O'Brien KL, et al, for the Hib and Pneumococcal Global Burden of Disease Study Team. Burden of disease caused by *Haemophilus influenzae* type b in children younger than 5 years: global estimates. *Lancet* 2009; **374**: 903–11.
- 25 Jha P, Gajalakshmi V, Gupta PC, et al, RGI-CGHR Prospective Study Collaborators. Prospective study of one million deaths in India: rationale, design, and validation results. *PLoS Med* 2006; **3**: e18.
- 26 Jha P, Jacob B, Gajalakshmi V, et al, RGI-CGHR Investigators. A nationally representative case-control study of smoking and death in India. *N Engl J Med* 2008; **358**: 1137–47.
- 27 Rudan I, Chan KY, Zhang JSF, et al, on behalf of WHO/UNICEF's Child Health Epidemiology Reference Group (CHERG). Causes of deaths in children younger than 5 years in China in 2008. *Lancet* 2010; **375**: 1083–89.
- 28 WHO. World health statistics 2008. Geneva: World Health Organization, 2008.
- 29 Black RE, Allen LH, Bhutta ZA, et al, for the Maternal and Child Undernutrition Study Group. Maternal and child undernutrition: global and regional exposures and health consequences. *Lancet* 2008; **371**: 243–60.
- 30 Victora CG, Adair L, Fall C, et al, for the Maternal and Child Undernutrition Study Group. Maternal and child undernutrition: consequences for adult health and human capital. *Lancet* 2008; **371**: 340–57.