Global, regional, and national causes of child mortality in 2000–13, with projections to inform post-2015 priorities: an updated systematic analysis

Li Liu, Shefali Oza, Daniel Hogan, Jamie Perin, Igor Rudan, Joy E Lawn, Simon Cousens, Colin Mathers, Robert E Black

Summary

Background Trend data for causes of child death are crucial to inform priorities for improving child survival by and beyond 2015. We report child mortality by cause estimates in 2000–13, and cause-specific mortality scenarios to 2030 and 2035.

Methods We estimated the distributions of causes of child mortality separately for neonates and children aged 1–59 months. To generate cause-specific mortality fractions, we included new vital registration and verbal autopsy data. We used vital registration data in countries with adequate registration systems. We applied vital registration-based multicause models for countries with low under-5 mortality but inadequate vital registration, and updated verbal autopsy-based multicause models for high mortality countries. We used updated numbers of child deaths to derive numbers of deaths by causes. We applied two scenarios to derive cause-specific mortality in 2030 and 2035.

Findings Of the 6·3 million children who died before age 5 years in 2013, 51·8% (3·257 million) died of infectious causes and 44% (2·761 million) died in the neonatal period. The three leading causes are preterm birth complications (0·965 million [15·4%, uncertainty range (UR) 9·8–24·5]; UR 0·615–1·537 million), pneumonia (0·935 million [14·9%, 13·0–16·8]; 0·817–1·057 million), and intrapartum-related complications (0·662 million [10·5%, 6·7–16·8]; 0·421–1·054 million). Reductions in pneumonia, diarrhoea, and measles collectively were responsible for half of the 3·6 million fewer deaths recorded in 2013 versus 2000. Causes with the slowest progress were congenital, preterm, neonatal sepsis, injury, and other causes. If present trends continue, 4·4 million children younger than 5 years will still die in 2030. Furthermore, sub-Saharan Africa will have 33% of the births and 60% of the deaths in 2030, compared with 25% and 50% in 2013, respectively.

Interpretation Our projection results provide concrete examples of how the distribution of child causes of deaths could look in 15–20 years to inform priority setting in the post-2015 era. More evidence is needed about shifts in timing, causes, and places of under-5 deaths to inform child survival agendas by and beyond 2015, to end preventable child deaths in a generation, and to count and account for every newborn and every child.

Introduction

In 2013, an estimated 6·3 million liveborn children worldwide died before age 5 years.[1] This number decreased from 9·9 million in 2000, despite an increase in the number of livebirths, showing that countries have made great progress in improving child survival since the turn of the millennium. Nevertheless, Millennium Development Goal (MDG) 4—to reduce child mortality by two-thirds between 1990 and 2015—will probably only be achieved by a few countries.[2–4]

As we approach the post-2015 era, a new set of country targets to reduce child deaths are being formulated. These targets include A Promise Renewed target of 20 or fewer under-5 deaths per 1000 livebirths by 2035 (or 25 or fewer deaths by 2030),[5,6] and the Every Newborn Action Plan target of ten or fewer neonatal deaths per 1000 livebirths by 2035 (or 12 or fewer neonatal deaths by 2030).[7] These targets have either already been set or are being discussed within the framework of the *Lancet* Commission on Investing in Health and the Sustainable

Development Goals (SDGs), to be met by 2035 and 2030, respectively.[8,9] To achieve these targets and end preventable child deaths, substantial effort is needed. The global effect will be dependent on high coverage of the most effective interventions, on the biggest causes of death, in the places with the most deaths.[10–12] As such, national, regional, and global trend data for causes of child death are crucial to inform what countries and interventions to prioritise and should be routinely updated. We report child mortality by cause estimates in 2000–13, and cause-specific mortality scenarios to 2030 and 2035.

Methods

Estimation of the causes of child mortality

Detailed descriptions of the input data and statistical methods have been published elsewhere.[13] In brief, we estimated the distributions of causes of child mortality separately for neonates and children aged 1–59 months. Dependent on data availability and quality, we estimated

the distribution of child mortality by cause with application of one of various methods. First, we used vital registration data reported to WHO for countries with an adequate vital registration system (>80% coverage of vital events with high-quality data).[13] Second, for countries with low rates of under-5 mortality (rate at or lower than 35 deaths per 1000 livebirths in 2000–13), but inadequate vital registration data, we used a vital registration data-based multicause model, applying a multinomial logistic regression framework, to derive estimates. Third, for countries with high under-5 mortality (more than 35 per 1000 livebirths in 2000–13), we applied a mainly verbal autopsy data-based multicause model, applying a multinomial logistic regression framework similar to that used for countries with low mortality and inadequate vital registration data. For India, we developed a state-level verbal autopsy data-based multicause model with only Indian subnational verbal autopsy data for children aged 1–59 months, and used the global verbal autopsy model described above for neonates. For China, we extracted data for child mortality by cause from Chinese literature and used them to develop single-cause model-based estimates.[14] For HIV/AIDS, measles, pertussis, and malaria outside of Africa, we used UNAIDS and WHO estimates. Once the proportional distribution of child mortality by cause was estimated for each country-year, we applied these estimates to the annual numbers of deaths in children aged 1–59 months and neonates as estimated by the UN Inter-Agency Group for Child Mortality Estimation (UN-IGME). We then aggregated these results to obtain estimates for the overall under-5 age group.[1]

For countries applying the verbal autopsy data-based multicause model, we updated the previous systematic review. We added 15 new studies and roughly 4000 deaths in neonates and 47 new and updated study datapoints representing almost 45 000 deaths in children aged 1–59 months (appendix p 3). Overall, 112 study datapoints representing more than 98 000 neonatal deaths and 128 study datapoints representing more than 320 000 deaths in children aged 1–59 months were included in this round of analysis (figure 1). Furthermore, adequate vital registration data became available for neonates in Kuwait, Macedonia, Montenegro, South Korea, St Lucia, and South Africa.

Centralised imputation of national covariate time series ensured consistent application of covariate values across estimation methods. Additional methodological updates included modelling of early and late neonatal deaths separately in the vital registration and verbal autopsy data-based multicause models; consideration of pneumonia and sepsis as two causes instead of one in the neonatal verbal autopsy data-based multicause model and then modelling of their proportions separately; estimation of tetanus as a cause in the neonatal verbal autopsy data-based multicause model instead of with a single-cause model; inclusion of injury as a separate cause in the neonatal vital registration multicause model; and the separate reporting of updated estimates of pertussis in children aged 1–59 months.

See **Online** for appendix

Model selection and uncertainty estimation

We used cross validation for model selection. We used model input data to estimate uncertainty in estimates of cause of death. For countries with an adequate system of vital registration, we assumed a marginal error rate with a Poisson distribution. For vital registration and verbal
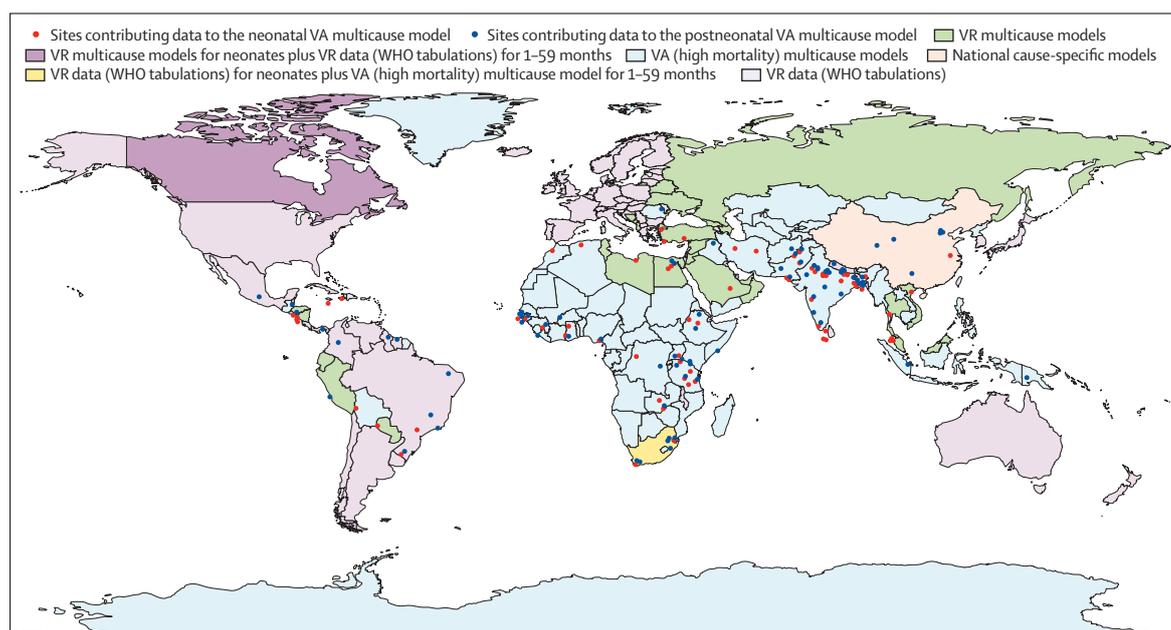

Figure 1: **Study datapoints and methods used to estimate causes of death in children younger than 5 years in 2000–13**
VA=verbal autopsy. VR=vital registration.

autopsy data-based multicause models, we resampled input data used to estimate causes of death to build a distribution of estimates with the bootstrap.[15] Furthermore, we simultaneously sampled from modelled distributions of deaths due to HIV, measles, malaria, and pertussis, and from the expected number of deaths in each country as estimated by the UN IGME. We compiled these inputs with cause-of-death estimates from the multicause model for a complete distribution for countries, which we then aggregated for regional and global distributions by year. We estimated uncertainty ranges (URs) with the 2·5th and 97·5th percentile of the simulated distribution of the number of child deaths for each cause. Appendix p 4 describes additional details of methods.

Methods of projection

Projections were done in accordance with two post-2015 targets: under-5 mortality at or less than 25 deaths per 1000 livebirths in 2030, and at or less than 20 deaths per 1000 livebirths in 2035. Methods for the projection to the 2030 target were the same as those used for the projection to 2035.

We considered two scenarios for 2030: the projection scenario and the achievement scenario. The projection scenario verifies what happens if recent country trends continue, and which countries will and will not meet the targets. The achievement scenario speculates what needs to happen for all countries, particularly those failing within the context of the projection scenario, to meet the targets. For the projection scenario, we assumed that trends in cause-specific mortality between 2000 and 2013 would continue until 2030. We used national cause-specific average annual rates of reduction (ARRs) estimated from Poisson regression of cause-specific mortality in 2000–13 to project cause-specific mortality from 2013 to 2030. We obtained all-cause under-5 mortality in 2030 by summing across all projected cause-specific mortality rates. Appendix p 5 provides additional details of this projection method.

For the achievement scenario, cause-specific targets in 2030 for countries with high mortality were derived from the cause composition of countries with under-5 mortality between 20 and 30 deaths per 1000 livebirths in 2000–13. We calculated the weighted average cause-specific mortality fractions of these countries. Because these countries rarely had a substantial malaria burden, we forced the projected malaria to pneumonia ratio to equal the country-specific ratio of malaria to pneumonia deaths estimated in 2013. We then rescaled projected cause-specific fractions when necessary to sum to one. We obtained the target cause-specific mortality by multiplying the adjusted cause-specific mortality fractions by the target all-cause mortality of 25 deaths per 1000 livebirths. For countries in which the 2013 cause-specific mortality was lower than the target rate, we assumed that the rate in 2013 would be maintained. Required ARRs were calculated on the basis of cause-specific mortality in 2013 and 2030. 166 WHO member states with livebirths projected by the UN,[16] and with at least 50 neonatal and 50 postneonatal deaths in 2013, were included in the projections.

In this round of estimation, we strove to achieve full transparency. Additional details of the input data and estimation methodology, including statistical codes, are online and publicly available through WHO's Global Health Observatory and the Maternal and Child Epidemiology Estimations website.

Role of the funding source

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

Results

Of the 6·3 million children who died in their first 5 years of life in 2013, 51·8% (3·257 million) died of infectious causes. Pneumonia, diarrhoea, and malaria were the leading infectious causes: pneumonia caused 0·935 million deaths (UR 0·817–1·057 million; 14·9% of total deaths, UR 13·0–16·8) deaths, diarrhoea caused 0·578 million deaths (0·448–0·750 million; 9·2%, 7·1–11·9), malaria caused 0·456 million deaths (0·351–0·546 million; 7·3%, 5·6–8·7) in children younger than 5 years (table, figure 2). 2·761 million

	Number of deaths (UR; millions)
Neonates aged 0–27 days	
Preterm birth complications	0·965 (0·615–1·537)
Intrapartum-related complications	0·662 (0·421–1·054)
Sepsis	0·421 (0·269–0·688)
Congenital abnormalities	0·276 (0·175–0·438)
Other disorders	0·232 (0·145–0·373)
Neonatal pneumonia*	0·136 (0·084–0·219)
Tetanus	0·049 (0·032–0·079)
Neonatal diarrhoea†	0·020 (0·012–0·033)
Children aged 1–59 months	
Other disorders	0·967 (0·781–1·134)
Pneumonia*	0·800 (0·681–0·923)
Diarrhoea†	0·558 (0·429–0·731)
Malaria	0·456 (0·351–0·546)
Injury	0·324 (0·258–0·391)
Meningitis	0·151 (0·125–0·185)
AIDS	0·103 (0·076–0·142)
Measles	0·102 (0·074–0·166)
Pertussis	0·060 (0·043–0·094)

UR=uncertainty range. *Estimated number of pneumonia deaths in children younger than 5 years overall including the neonatal period is 0·935 million (UR 0·817–1·057 million; 14·9%, UR 13·0–16·8). †Estimated number of diarrhoea deaths in children younger than 5 years overall including the neonatal period is 0·578 million (0·448–0·750 million; 9·2%, 7·1–11·9).

Table: Estimated numbers of deaths by cause in 2013

(44%) under-5 deaths were in the neonatal period. The most common causes of neonatal deaths were preterm birth complications (0·965 million [15·4%, UR 9·8–24·5]; UR 0·615–1·537 million), intrapartum-related complications (birth asphyxia 0·662 million [10·5%, 6·7–16·8]; UR 0·421–1·054 million), and neonatal sepsis (0·421 million [6·7%, 4·3–11·0]; UR 0·269–0·688 million). Other important causes were injury (in children aged 1–59 months), which contributed 0·324 million deaths (5·2%, UR 4·1–6·2; UR 0·258–0·391 million), and congenital abnormalities (in the neonatal period), which contributed 0·276 million deaths (4·4%, UR 2·7–7·0; 0·175–0·438 million).

Among the ten MDG regions, sub-Saharan Africa contributed roughly half (49·6%, 3·113 million) of under-5 deaths worldwide in 2013, and southern Asia almost a third (32·1%, 2·015 million). Cause distributions varied across MDG regions (appendix pp 6–10). 61·5% (1·914 million) deaths in children younger than 5 years were due to infectious causes in sub-Saharan Africa, including nearly all global child deaths due to malaria (97·0%, UR 95·1–98·9) and HIV/AIDS (90·4%, 88·1–91·0). In addition to malaria, the leading causes of under-5 deaths in sub-Saharan Africa were pneumonia (0·493 million [15·8%, UR 13·1–18·7]; UR 0·407–0·581 million) and preterm birth complications (0·326 million [10·5%, 6·2–17·9]; 0·194–0·557 million). Southern Asia had the highest number of neonatal deaths (1·086 million). The leading causes in this region were preterm birth complications (0·440 million [21·8%, UR 15·9–30·8]; UR 0·320–0·621 million), pneumonia (0·290 million [14·4%, 13·3–15·6]; 0·269–0·315), and intrapartum-related complications (0·222 million, UR 0·161–0·313 million; 11·0%, 8·0–15·5). Appendix pp 11–82 provide additional details of the 2013 estimates by region.

The five countries with the highest number of under-5 death in 2013 were India, Nigeria, Pakistan, Democratic Republic of the Congo, and China (appendix pp 11–82). Together these countries accounted for half the world's under-5 (49·3%, 3·094 million) and neonatal (52·5%, 1·451 million) deaths in 2013. The three leading causes of under-5 deaths in India and Pakistan were preterm birth complications, pneumonia, and intrapartum-related complications (appendix pp 11–82). Nigeria and Democratic Republic of the Congo both had high fractions of malaria and pneumonia deaths (appendix pp 11–82). In China, intrapartum-related complications, preterm birth complications, and pneumonia were the leading causes of under-5 deaths; more than three-fifths of deaths were in the first 28 days (appendix pp 11–82). Appendix pp 11–82 provide country-level estimates.

From 2000 to 2013, despite an increase in the number of livebirths from 127·703 million to 137·688 million globally, the total number of deaths in children younger than 5 years decreased from 9·887 million to 6·282 million. Under-5 mortality reduced from 77·4 to 45·6 per 1000 livebirths during the same period.
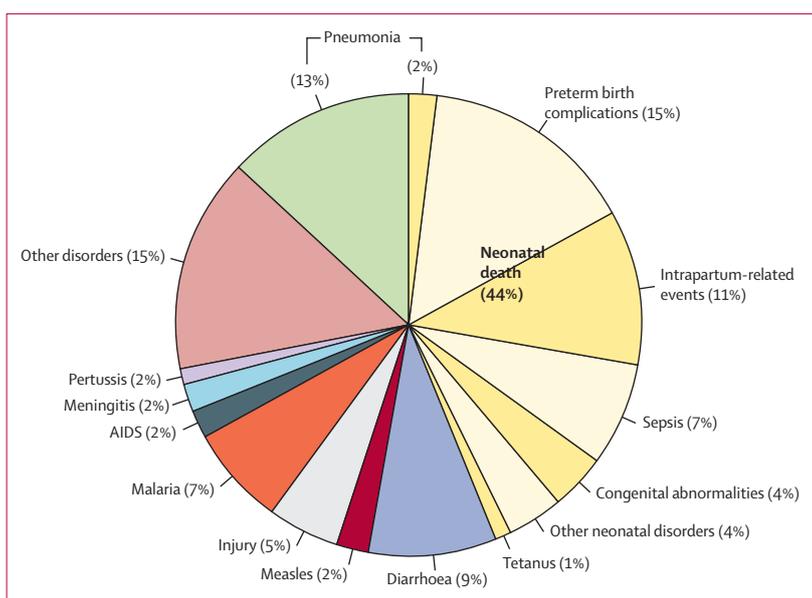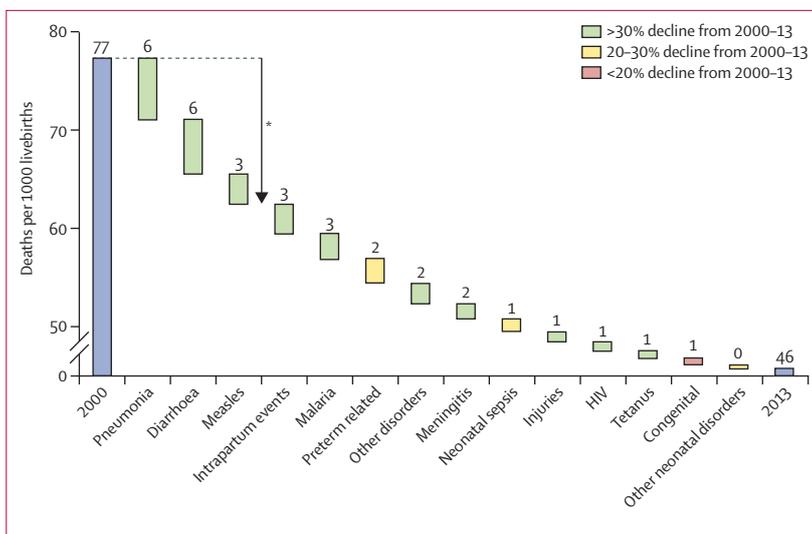

Figure 2: Global causes of child deaths in 2013

Figure 3: Global trends in cause-specific mortality rates in neonates and children aged 1–59 months, 2000–13
*About 47% of the reduction comes from pneumonia, diarrhoea, and measles.

Pneumonia, diarrhoea, and measles deaths showed the largest reductions in absolute terms (figure 3). Together, their reductions accounted for nearly half (47·3%, UR 32·8–95·0) of the gain in survival in children younger than 5 years in 2000–13 (figure 3).

During the same period, globally, under-5 mortality reduced at an average ARR of 4·1% per year, less than the 4·4% needed to reach MDG 4 by 2015.[17] Mortality declined more quickly in children aged 1–59 months than in neonates (ARR 4·9% *vs* 2·9% per year); as such, the proportion of under-5 deaths in the neonatal period increased from 37·6% to 43·9% in 2000–13. In children aged 1–59 months, measles-specific mortality varied
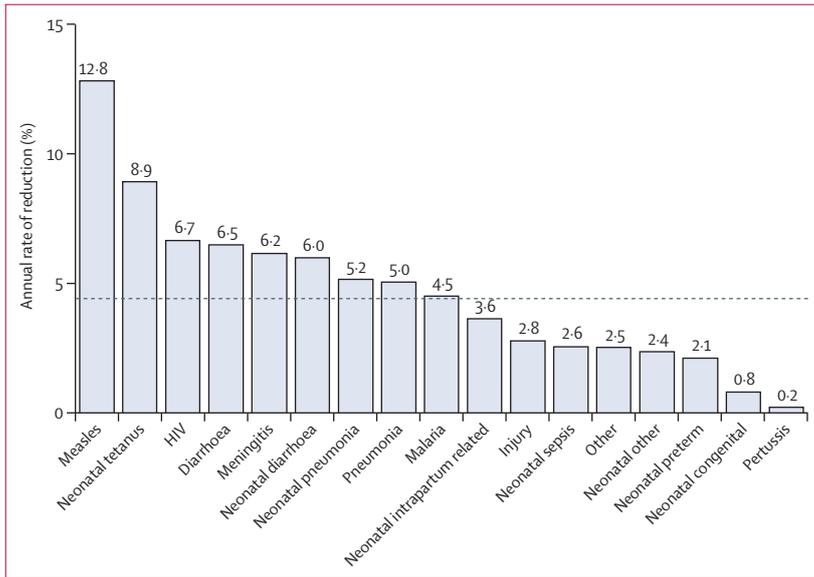
Figure 4: Estimated annual rate of reduction at the global level in 2000–13, by cause
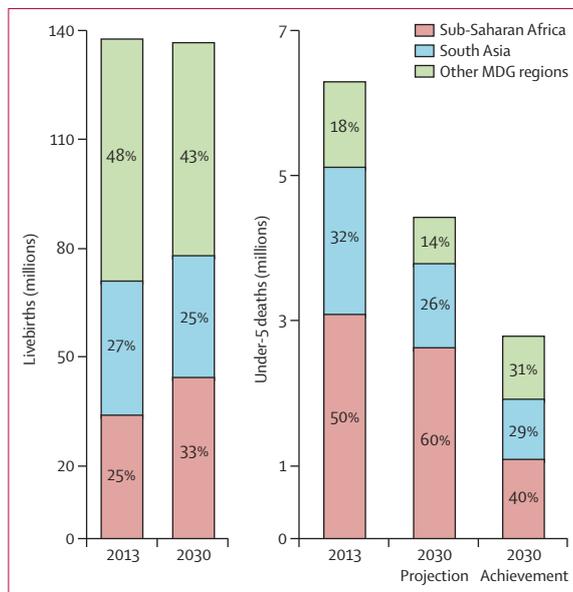Dashed horizontal line shows an annual rate of reduction of 4·4%.

Figure 5: Distribution of livebirths and under-5 deaths in 2013 and 2030, by MDG region
MDG=Millennium Development Goal.

because of outbreaks, but decreased at an ARR of 12·8% (UR 10·2–13·2; figure 4, appendix pp 83–160). Mortality rates from diarrhoea, HIV/AIDS, meningitis, pneumonia, and malaria in children aged 1–59 months all reduced by 4·4% per year or more; however, injury-specific mortality reduced much more slowly at a rate of 2·8% (UR 2·0–3·6) per year (figure 4). In neonates, the ARR for tetanus-specific mortality was 8·9% (UR 5·0–13·4; figure 4). Other causes with ARRs exceeding 4·4% in the neonatal period included diarrhoea and

pneumonia; the remaining neonatal causes had slower annual reductions (figure 4).

In 2000–13, southern Asia and sub-Saharan Africa had the largest absolute reductions in under-5 deaths (1·484 million and 1·138 million, respectively; appendix pp 11–82). The three causes contributing most to these reductions were pneumonia (24·3%, UR 20·9–28·6), diarrhoea (20·8%, 17·4–27·5), and intrapartum-related complications (13·4%, 5·4–17·0) in southern Asia, and malaria (21·7%, 12·2–43·9), measles (17·2%, 16·8–29·2), and diarrhoea (16·8%, 8·2–33·8) in sub-Saharan Africa (appendix pp 11–82). Measles, neonatal tetanus, and HIV/AIDS achieved rapid ARRs of 17·6% (UR 12·2–17·8), 8·5% (2·3–10·7), and 7·5% (4·6–7·5), respectively, in sub-Saharan Africa, but many other causes reduced slowly (appendix pp 155–60). In southern Asia, more causes achieved an ARR of 4·4% or more, but preterm birth complications—the leading cause of death—only decreased at an annual rate of 0·6% (UR –2·0 to 3·5; appendix pp 155–60). Appendix pp 83–60 provide additional details of global, regional, and country-level cause-specific mortality and ARR.

Projecting forward, the distribution of livebirths and under-5 deaths will shift across MDG regions by 2030 (figure 5). Although the number of livebirths is projected to remain at about 137 million at the global level in 2030, the share of global livebirths in sub-Saharan Africa will increase from 24·9% to 32·6%, and will remain at about a quarter in southern Asia (figure 5).[16] Within the context of the projection scenario, worldwide, 4·4 million children will still die before age 5 years in 2030, whereas this number would reduce to 2·8 million with the achievement scenario (figure 5). The proportion of under-5 deaths in sub-Saharan Africa will increase from 49·6% to 59·8% in the projection scenario, but will reduce to 39·7% in the achievement scenario (figure 5).

Within the projection scenario, more than a third of countries (57 of 166) examined will not achieve the 2030 target (appendix pp 161–62). Almost three-quarters (42 of 57) countries failing to achieve the target would be in sub-Saharan Africa (appendix pp 161–62). Not surprisingly, these countries are mostly those with high mortality in 2013 (appendix pp 161–62). No countries with under-5 mortality rates of more than 67·9 per 1000 livebirths in 2013 will achieve the target within this scenario. Global under-5 mortality will be 32·3 per 1000 livebirths, almost half (48·0%) of which will be attributable to neonatal causes (neonatal mortality rate of 15·5 deaths per 1000 livebirths). The global cause composition will be somewhat different, with most neonatal causes increasing in their shares (appendix pp 163–64)—eg, the proportion of deaths due to neonatal preterm birth complications would increase from 15% to 18%. In older children (aged 1–59 months), most cause fractions will decrease, except for injury and other causes which will increase from 5% to 6% and 15% to 18%, respectively (appendix pp 163–64). The regional picture is largely similar to the global

picture, with some exceptions. For example, the proportion of malaria will decrease noticeably from 14% to 8% in sub-Saharan Africa and the proportion of preterm birth complications will increase substantially from 22% to 34% in southern Asia (appendix pp 163–64).

Figure 6 shows global cause-specific mortality in 2013 and 2030 within the context of the achievement scenario. Most cause-specific mortality rates need to be reduced substantially to meet the target. Preterm birth complications, post-neonatal pneumonia, and intrapartum related complications will remain the leading causes of under-5 mortality in 2030, with their cause-specific mortality rates projected to be 3·4, 2·4, and 2·2, respectively, per 1000 livebirths (figure 6), compared with 7·0, 5·8, and 4·8, respectively, per 1000 livebirths in 2013. By design, all 166 countries will reach the 2030 target within this scenario. Although many countries do not need much acceleration in their ARR, some countries with high mortality will need more rapid reductions to reach the target (appendix p 165). In fact, 26 countries would have to more than double their ARR for under-5 mortality, and 29 countries for neonatal mortality, to reach the targets (data not shown). At the aggregate level, appendix p 166 shows the difference between the ARR achieved in 2000–13 and that needed to achieve the cause-specific targets in 2030. All causes of high mortality would need some level of acceleration, with preterm birth complications needing an absolute increase of 2·2% in ARR and malaria needing an increase of 2·4% (appendix p 166). If the targets are to be achieved, global under-5 mortality will reduce to 20·3 per 1000 livebirths and neonatal mortality to 10·2 per 1000 livebirths. Projections to 2035 with the under-5 mortality target of 20 per 1000 livebirths yielded largely similar results (appendix pp 167–74).

Discussion

Of the 6·3 million children who died before age 5 years in 2013, roughly half died of infectious causes and just over two-fifths died in the neonatal period. The three leading causes of death were preterm birth complications, pneumonia, and intrapartum-related complications. Reductions in pneumonia, diarrhoea, and measles collectively were responsible for half the 3·6 million fewer deaths that took place in 2013 versus 2000. Causes with the slowest progress included congenital, preterm, neonatal sepsis, injury, and other causes. If present trends continue, 4·4 million children younger than 5 years will still die in 2030.

Progress in child survival worldwide has been described as one of the greatest success stories of international development, with child deaths being reduced by half in the past two decades since the MDG baseline. More than half this change has happened in the past decade. Improved understanding of cause-specific trends is essential to accelerate further change. Despite remarkable progress at the level of global averages, at national level, MDG 4 will not be achieved
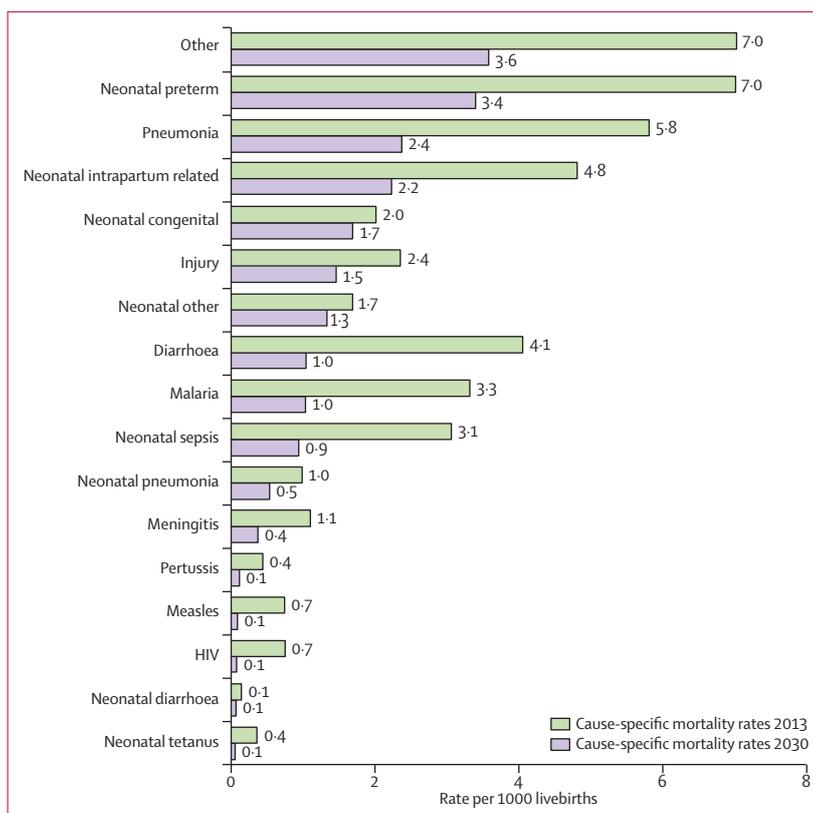

Figure 6: Global cause-specific mortality in 2030 within the achievement scenario by comparison with cause-specific mortality in 2013

in most countries in 2015. As we enter the final 500 days of the MDG era, our analysis underlines a major transition for child survival symbolised by the fact that preterm birth complications are now the leading cause of under-5 deaths globally, not just of deaths in the neonatal period. Pneumonia is the second leading cause of under-5 deaths. Intrapartum-related complications were the third leading cause, replacing diarrhoea, which was the third leading cause in 2010.[13] Understanding of this and other shifts that affect where, when, and how children die is crucial to inform investments for completion of the unfinished agenda for child deaths and ensure that the present reality is addressed, not the situation based on a cause-of-death pie chart from the past decade. Our data show various shifts in terms of the timing, causes, and geography of child deaths, and the move beyond child survival. These analyses also emphasise associated shifts in the data that should be anticipated and addressed so that by 2030, investigators have moved beyond uncertain estimates and obtain real data for every birth and every death.[18]

A well-recognised shift is apparent in the timing of child deaths closer and closer to the time of birth.[19,20] This shift is now happening all over the world, with 44% of child deaths in the neonatal period. Africa is the region with the lowest proportion of death in the neonatal

period, partly because of specific postnatal and child causes, notably malaria and HIV. This shift is indicative of progress in reductions of infection deaths for children, and slow progress for neonatal mortality reduction and particularly preterm birth, for which prevalence is rising in many countries; even simple care is often scarce.[21] Furthermore, deaths due to infectious diseases, such as pneumonia, diarrhoea, and malaria, are concentrated in the first 2 years of life, which should direct programmes towards these very young ill children.[22]

Although reductions in pneumonia, diarrhoea, and measles were responsible for half the decrease in deaths from 2000 to 2013, there is still a major uncompleted agenda for child infections, with a total burden of 3·3 million, just more than half of under-5 mortality. Reductions in deaths due to malaria in sub-Saharan Africa and intrapartum-related complications in southern Asia also contributed greatly to the improvement of child survival in these regions. Rate of reductions varied widely by cause and we noted a marked variation in the rate of reduction at country level. High levels of acceleration in mortality reduction have been achieved in the past in some countries for measles and malaria for example. If countries were to match their better performing neighbours for large causes of death, acceleration could be achieved in fewer than the 500 days left until the MDG deadline of 2015.

Deaths in the neonatal period will continue to increase proportionately, but the level of increase will vary by cause. Preterm birth complications will probably remain the leading cause of neonatal and under-5 deaths. Congenital abnormalities were also projected to increase in importance, both in the neonatal period and beyond, especially as care is improved. In older children, the category of other causes will increase and will likely contribute about a fifth of the under-5 deaths in 2030. This category includes deaths due to childhood cancers, congenital abnormalities, and from preterm birth complications, but death after 28 days, and all these conditions will need complex hospital care. The burden of sickle-cell disease is also projected to increase in the next few decades.[23] Injury is projected to increase in importance, especially in older children (aged 1–59 months). As most countries worldwide shift from low-income to middle-income status, planning for improved paediatric services, which is neglected even in high-income countries, will become increasingly important.[24] Major acceleration in progress would be needed at the global level for various high-burden causes to reach the target in 2030, including neonatal sepsis, malaria, preterm complications, and post-neonatal diarrhoea.

The share of global livebirths in sub-Saharan Africa has steadily increased between 2000 and 2013, and is predicted to rise to a third of all births in 2030. If trends in fertility and cause-specific child mortality are continued, families in sub-Saharan Africa would be predicted to suffer more than 60% of the world's deaths for children younger than 5 years. The share of global births and under-5 deaths in middle-income countries versus low-income countries is also predicted to increase. This shift has important implications for service delivery, such as neonatal intensive care and hospital-based paediatric care that will be more affordable in these countries.

Looking ahead to 2030, scale up of proven interventions to prevent and treat childhood diseases is the key to acceleration of progress towards improved child survival and achievement of the post-2015 targets.[25] Maternal and child nutrition need to be further improved. Maternal micronutrient supplementation reduces fetal growth restriction, preterm births, and neonatal mortality.[26-29] Improved breastfeeding practices and nutrition interventions in early childhood would reduce deaths from infections and severe acute malnutrition to improve child survival.[28,30]

Coverage of interventions to address leading neonatal disorders and infectious diseases are the highest impact priorities. Quality care at birth is key for improvement of neonatal survival, but is only effective if specific interventions are implemented, such as neonatal resuscitation and antenatal corticosteroids for preterm labour.[31] More than 80% of neonatal deaths are in babies born small, of whom two-thirds are preterm,[7] and targeting of interventions for improved care to this population, starting with simple care, such as kangaroo mother care, and then adding more complexity over time, is a key strategy used in all countries that have made progress in reducing neonatal mortality.[31] Scale-up of new and low-cost advances in neonatal infection, such as umbilical-cord care with chlorhexidine[32-34] and simplified antibiotic treatment (Baqui A, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA; personal communication), could accelerate progress in neonatal infectious causes.

Major progress has been made for measles and neonatal tetanus, and the post-2015 focus would be on accelerating progress and the addition of new vaccines, such as *Haemophilus influenzae* type B, and pneumococcus and rotavirus vaccines hold potential for reducing deaths from pneumonia and diarrhoea.[22,35] Additionally, vaccines are actively developed and evaluated for malaria.[36-38] But substantial reductions in malaria deaths can already be achieved by scale-up of insecticide-treated bednets and improved treatment. Aggressive scale up of prevention of mother-to-child transmission for HIV/AIDS has been instrumental in aiding progress in some countries, notably South Africa.[39] Case management of pneumonia and diarrhoea has received little attention and wide-scale implementation is needed, especially since integrated management of childhood illness has dropped off the global agenda. Additional implementation research to understand how to scale-up coverage and quality of established cost-effective interventions is urgently needed.[40] More discovery and intervention research is needed to identify

ways to prevent preterm birth complications or better ameliorate their effects in sub-Saharan Africa, southern Asia, and other settings that will still have resource constraints and limitations in facility care in 2030. Additional exercises, such as *The Lancet* Series on Childhood Pneumonia and Diarrhoea, the Every Newborn Series, and the new Series on Maternal and Child Nutrition, all provided information about how the scale-up of cause-specific interventions can improve child survival in 2030 and 2035, and how such scale-up can possibly be achieved.

One important shift in the post-2015 era is to move to beyond child survival to reduce child morbidity and ensure healthy development. As child mortality decreases and care improves, that survivors are not impaired is crucial. Furthermore, many of the risk factors for mortality, such as preterm birth,[7] small for gestational age,[41] and stunting are also risk factors for loss of development and economic potential.[42] This shift means that programmes should focus on quality—eg, safe oxygen use to avoid retinopathy of prematurity[43] or dexamethsone to reduce deafness after meningitis. The shift also has implications for systematic follow up of survivors and for attention to nutrition and provision of stimulating environments for young children.[44,45]

Disease-specific interventions are only part of the solution. Effective socioeconomic interventions, including family planning, should also be considered. Improved access to family planning could also be a primary prevention measure to reduce under-5 deaths, particularly in regions such as sub-Saharan Africa where high fertility is still prevalent. Initiatives such as Family Planning 2020 to enable 120 million more women and girls to use contraceptives by 2020, could have an important effect on child survival, reducing the number of deaths because of decreases in numbers of births and reducing the rate of child death mainly through healthy birth spacing.[46] Scale-up of family planning improves maternal health and empowerment, and benefits child survival.[46,47] Other important strategies include improvement of women's education and of socioeconomic development.[48,49]

Time trends, including annual estimates in 2000–13, updated in this analysis are largely consistent with those from the last analysis at the global level (appendix p 175, panel 1).[13] Estimated reductions in deaths were faster in this analysis than in the previous analysis for several causes, including malaria and pneumonia in children aged 1–59 months. These changes were partly driven by faster declines in total numbers of child deaths and under-5 mortality,[1] but also resulted from the updated cause-specific mortality fractions based on newly included and updated vital registration and verbal autopsy data, and the methodological changes. For under-5 mortality, we applied estimates produced by the UN IGME,[1] whereby the global rate reduced from 77·4 (UR 76·4–78·7) to 45·6 (44·1–48·4) per 1000 livebirths in 2000–13. These estimates are slightly higher than the most recent

estimates produced by the Institute of Health Metrics and Evaluation (IHME), whereby under-5 mortality reduced from 69·4 (UR 68·5–70·4) to 44·0 (41·9–46·3) per 1000 livebirths in 2000–13.[50] The estimated proportion of neonatal deaths was also noticeably different: 43·9% by UN IGME and 41·6% by IHME in 2013.

The validity of our estimates is largely determined by the availability and quality of cause-of-death data. The proportion of under-5 deaths that happened in countries with adequate vital registration data remained below 3% in this analysis, whereas 90·2% of deaths in this age group were in countries estimated by the verbal autopsy data-based multicause model. Despite much active research in methodology in the past two decades, verbal autopsy still has several inherent limitations.[51–53] Further standardisation of verbal autopsy methods is needed, and more research into improving the quality of cause-of-death information, such as with application of minimally invasive autopsy, should be considered.[54,55] When quantifying uncertainty, we accounted for some sources of uncertainty, essentially random sampling error, but did not account for other important sources, including model uncertainty, uncertainty around covariate values, and uncertainty associated with misclassification of causes of deaths, particularly when verbal autopsy was used. Our future scenarios also have several limitations. For causes with potential outbreaks, such as measles and meningitis, an assumption of Poisson distribution is a crude approximation. In the achievement scenario, we adjusted the cause-specific targets for malaria. However, the targets could be artificially low for some other infectious

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Panel 1: Research in context

Systematic review
WHO and UNICEF's Child Health Epidemiology Reference Group (CHERG) has systematically estimated and published a series of child mortality by cause estimates since 2003, with the last publication containing time trends.[13,57–61] We used newly available vital registration and verbal autopsy data and improved estimation methods to systematically estimate the distribution of child mortality by cause in 2013 with time trends since 2000. Other investigators have estimated distribution of mortality by cause among all age groups.[62]

Interpretation
In addition to inclusion of 62 new and updated verbal autopsy studies adding close to 50 000 deaths as model inputs to the verbal autopsy multicause model, and six new countries now contributing neonatal deaths from vital registraion instead of verbal autopsy data, our estimation methods were also further refined with changes such as estimation of early and late neonatal deaths by cause separately. These additions and refinements are important to further improve validity of our estimates. Furthermore, we provided cause-specific mortality projections to 2030 and 2035 in the projection scenario and achievement scenario, with the projection scenario assuming that present cause-specific trends continue and the achievement scenario assuming that all countries were to achieve the post-2015 child survival target by achieving their own cause-specific targets. The projection results provide concrete examples of how the distribution of child causes of deaths could look in 15–20 years to inform priority setting in the post-2015 era. Ultimately, the momentum on strengthening civil registration and vital statistics should be capitalised to count and account for every newborn and every child.

Panel 2: Strengthening of national civil registration and vital statistics systems to improve child survival

The increasing momentum towards strengthening of national civil registration and vital statistics systems in developing countries holds great promise for improvement of the accuracy and precision of child cause-of-death estimates. Expansion of these systems into countries with restricted institutional health monitoring will probably focus on the initial registration of all births and deaths, thus producing more accurate estimations of age-specific and sex-specific mortality rates. This process then provides a platform from which systems for recording causes of death can evolve, including the development of more detailed data collection with the International Classification of Diseases in routine health facility settings, with more detail than the broad cause categories that can be determined with verbal autopsy techniques.

Using a country's own civil registration and vital statistics systems data has at least two important consequences for child cause-of-death estimates. First, a fully functioning, high coverage civil registration and vital statistics system improves the accuracy, and reduces the uncertainty, of estimates, enabling decision makers to better prioritise scarce resources towards reducing specific causes of death. Second, this system is more frequent and timely than a 5-yearly survey, so response to change can be more rapid, and also more targeted, for example, to subnational populations. Hence collection of these data allow for assessment of policies and programmes because changes in the cause of death distribution can be directly observed over time, rather than projected with models.

Targets are being proposed to monitor the development of sustainable civil registration and vital statistics systems, some of which are related directly towards understanding child cause of death statistics.[18] Achievement of such targets should be a priority, because strengthening of national civil registration and vital statistics systems offers the opportunity to improve priority setting through more accurate estimates and better policy assessment, ultimately leading to improved population health.

Although great progress has been made in child survival in the past two decades, with most of this progress in the past decade, it has not been enough. Millions of children are still dying of preventable causes at a time when we have the means to deliver cost-effective interventions. Through the MDG effort, we have learned that substantial progress can be achieved but is not guaranteed, that good-quality data are crucial for tracking of progress, and that long-term targets are useful not only for planning and coordination, but also for rallying countries and the global health community. There is already substantial momentum and interest in the further improvement of child survival, reducing of child morbidity, and promotion of child development in the post-2015 era. Almost 200 countries have signed on to the new goals and targets set out by A Promise Renewed and the Every Newborn Action Plan, guided by the *Lancet* Commission on Investing in Health framework and the Sustainable Development Goals. For many countries, most of which are in sub-Saharan Africa, achievement of these targets will require progress substantially beyond what has already been achieved. As the global health and development community moves into the new set of development goals, more resources should be allocated to child survival programmes. We now have the evidence to develop this momentum to achieve not only the unfinished child health agenda of the MDGs, but to further accelerate progress to end preventable child deaths in a generation, and count and account for every newborn and every child.

causes, such as HIV/AIDS, because only a few countries included in the determination of the targets had substantial burdens of these disorders. The scenario probably also assumed more homogeneity in cause composition than in reality. Despite these limitations, the cause-specific projection adds insights into cause-specific changes and identified potential acceleration needed to achieve the post-2015 targets.

Ongoing and future efforts in local and national data collection to generate context-specific child cause-of-death information will be key to improvement in estimation validity in the future. Additional investment in improvement of child health statistics and strengthening of health information systems is imperative. Development of sample registration of births and deaths, and eventually universal national civil registration systems would contribute to better health statistics and improved child survival (panel 2). We have strived to improve transparency of the estimation process, whereby primary estimation steps are available online and can be publicly accessed. Evidence-based policy making and programme planning can only be optimised if full openness and transparency can be achieved in the process of evidence generation.[56] No model, however transparent, can compensate for an absence of input data and there is urgent need to improve this especially for civil registration (panel 2).

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