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Newborn survival: a multi-country analysis of a decade of change

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Neonatal deaths account for 40% of global under-five mortality and are ever more important if we are to achieve the Millennium Development Goal 4 (MDG 4) on child survival. We applied a results framework to evaluate global and national changes for neonatal mortality rates (NMR), healthy behaviours, intervention coverage, health system change, and inputs including funding, while considering contextual changes. The average annual rate of reduction of NMR globally accelerated between 2000 and 2010 (2.1% per year) compared with the 1990s, but was slower than the reduction in mortality of children aged 1–59 months (2.9% per year) and maternal mortality (4.2% per year). Regional variation of NMR change ranged from 3.0% per year in developed countries to 1.5% per year in sub-Saharan Africa. Some countries have made remarkable progress despite major challenges. Our statistical analysis identifies inter-country predictors of NMR reduction including high baseline NMR, and changes in income or fertility. Changes in intervention or package coverage did not appear to be important predictors in any region, but coverage data are lacking for several neonatal-specific interventions. Mortality due to neonatal infection deaths, notably tetanus, decreased, and deaths from complications of preterm birth are increasingly important. Official development assistance for maternal, newborn and child health doubled from 2003 to 2008, yet by 2008 only 6% of this aid mentioned newborns, and a mere 0.1% (US$4.56m) exclusively targeted newborn care. The amount of newborn survival data and the evidence based increased, as did recognition in donor funding. Over this decade, NMR reduction seems more related to change in context, such as socio-economic factors, than to increasing intervention coverage. High impact cost-effective interventions hold great potential to save newborn lives especially in the highest burden countries. Accelerating progress requires data-driven investments and addressing context-specific implementation realities.

Keywords Neonatal, newborn, survival, mortality trends, multi-country evaluation, evaluation framework, cause of death, preterm birth, scale up, donor funding

KEY MESSAGES

- In 2010, 3.1 million newborns died in the first month of life, 17% fewer than in 2000. The annual rate of reduction of the neonatal mortality rate (NMR) globally (2.1%) has accelerated since 2000, but remains slower than the rate of reduction for maternal mortality (4.2%) and mortality amongst children aged 1–59 months (2.9%). Variation between regions and countries is considerable and not previously analysed.
- There has been progress in reducing most causes of death since 2000, especially tetanus as well as neonatal infections addressable through child health programmes - pneumonia and diarrhoea. Deaths due to preterm birth complications are decreasing more slowly, and these are now the second leading cause of child deaths, requiring innovation for prevention solutions and urgent scale up of care solutions.
- Our statistical analysis of inter-country NMR reduction suggests that in the last decade contextual factors, such as changes in income and fertility, are associated with more rapid NMR reduction, with measureable coverage change of newborn-related interventions contributing little. Lack of coverage data for some key interventions is a critical gap. In Africa, NMR change has been so limited that statistical modelling was not helpful in identifying predictors.
- Official development assistance (ODA) for maternal, newborn and child health nearly doubled from 2003 to 2008, yet even by 2008 only 6.1% of this funding mentioned newborn-related activities. Per live birth in 2009, this equates to US$3.51 in ODA mentioning newborns or US$0.13 in ODA exclusively targeting newborns. Currently, government funding is not systematically tracked for reproductive, maternal, newborn and child health.
- Over the last decade, and especially since 2005, there have been major advances in the evidence base for newborn survival—particularly more data and greater frequency of burden of disease estimation—and in consensus for implementation, as well as some increases in funding. In order to accelerate progress, greater emphasis is required on scaling up care, especially in the highest burden countries, and addressing context-specific implementation challenges regarding personnel, supplies and monitoring.

Introduction

Over the last decade newborn deaths have decreased by 17%, yet in the year 2010, an estimated 3.1 million neonates (0–28 days) died, mainly in low-income countries (UNICEF *et al*. 2011). Newborn deaths were rarely mentioned in global policy and programmes prior to the year 2000, but more recently global organizations and country governments have increased attention for newborn survival (G8 2009; Shiffman 2010).

Much of the focus on neonatal survival has been driven by the Millennium Development Goal (MDG) 4 for child survival, which targets a two-thirds reduction in under-five mortality between 1990 and 2015. The proportion of under-five deaths that occur in the first month of life has increased over the last decade, and today is more than 40% (Oestergaard *et al*. 2011; UNICEF *et al*. 2011). Hence, progress towards MDG 4 will be increasingly determined by success in reducing newborn deaths. *The Lancet*'s Newborn Survival Series in 2005 catalysed increased attention and influenced global and national health agendas (Lawn *et al*. 2006c), with new data on national numbers and causes of newborn death (Lawn *et al*. 2005), solutions and costs (Darmstadt *et al*. 2005), especially for implementation in low-income countries (Knippenberg *et al*. 2005).

An analysis of the neonatal mortality rate (NMR) found that while the rate of reduction is slower than for maternal and under-five deaths, the pace has accelerated since 2000 (Hill *et al*. 2012). However, huge variability between regions and even between neighbouring countries exists (Oestergaard *et al*. 2011). Some countries, including those with low average incomes and relatively few health workers, have made remarkable progress in reducing neonatal deaths or in increasing coverage particularly of skilled attendance, compared with their neighbours. More analysis is now possible given recent improvements in trend data for neonatal mortality and cause-specific mortality estimates globally, regionally and nationally (Black *et al*. 2010; Lozano *et al*. 2011; Oestergaard *et al*. 2011; Liu *et al*. 2012).

To date, there has been no systematic multi-country evaluation of the changes in newborn survival, or of the processes and pathways that may influence scale up of effective interventions. This paper, the first in a supplement of seven papers, applies a results framework to examine global and regional changes for newborn survival between 2000 and 2010 in terms of mortality, coverage and health system indicators as well as national and donor funding, using primarily quantitative data. The overall supplement of seven papers, including five detailed country case studies, examines neonatal mortality reduction from 2000 to 2010, considering associated changes in coverage of care and funding, as well as qualitative markers of health system and policy change, in order to identify common pathways to scale and potential accelerators and constraints (Box 1). What has changed globally since 2000 and how has it manifested in different regions, country contexts and health systems? Has increased attention translated into programmatic action and fewer deaths? Or is global progress in neonatal mortality reduction simply due to socio-economic change or other contextual factors? What may have influenced more rapid policy and programmatic change? Such analyses and insights will help inform priorities for accelerating progress for newborn survival and also increase understanding of other large-scale system change. They may also contribute to

Box 1 A decade of change for newborn survival: supplement objectives and overview

Overall supplement objectives:

(1) Describe changes in *national neonatal mortality and causes of neonatal deaths* at global and regional level with more detail for selected countries (goal level of the results framework).
(2) Evaluate factors that may have contributed to mortality change including *coverage of key health interventions* and also considering *contextual factors* (strategic objective level).
(3) Undertake analysis of *funding flows* including government and out-of-pocket funding (from National Health Accounts) and a novel multi-country analysis of official development assistance (ODA) delineating newborn-specific funding where possible.
(4) For selected countries, through a consultation with national stakeholder and other experts, examine national policy and programme changes and inputs to identify pivotal events that may have contributed to scale up of newborn care, using comparable tools as follows (see Box 3):
   – *Policy and Programme Timeline*
   – *Scale-up Readiness Benchmarks*
   – *Geographic reach assessment*
(5) Compile quantitative and qualitative data on changes across multiple countries and consider implications for reducing neonatal mortality, and scaling up of coverage of care, identifying potential accelerators and constraints, to inform future priorities for newborn care, and for use in public health more broadly.

Overview of the supplement:

The lead editorial highlights common themes and challenges, cross-cutting learning about the process of change, as well as potential opportunities for saving newborn lives (Darmstadt *et al*. 2012).

This first paper applies the results framework to examine broad and mainly quantitative global and regional changes for newborn survival between 2000 and 2010.

The second paper describes a novel methodology for measuring national readiness to implement newborn care interventions at scale in the form of quantifiable benchmarks and presents results for nine countries (Moran *et al*. 2012).

Papers three through seven examine in detail the changes for newborn survival in selected countries, including Bangladesh, Nepal, Pakistan, Malawi and Uganda (Khan *et al*. 2012; Mbonye *et al*. 2012; Pradhan *et al*. 2012; Rubayet *et al*. 2012; Zimba *et al*. 2012). To avoid duplication, methods for the country case studies are detailed in this paper. Each country analysis is structured around the same results framework, applying standard analyses and qualitative assessment tools, with critical input from a wide team of country experts and stakeholders.

debates about mixed-method assessments of health system change (Bennett *et al*. 2011).

Frameworks for integration of newborn care at scale

Highly cost-effective interventions exist to reduce neonatal deaths (Darmstadt *et al*. 2005). However, there is no single 'magic bullet' intervention or 'one size fits all' programmatic approach (Knippenberg *et al*. 2005). There are some interventions that may be effectively delivered vertically, such as tetanus immunization, but most high impact newborn care interventions are intended to be integrated within packages across the continuum of care from pregnancy, birth and the postnatal period and through all levels of the health system (Marsh *et al*. 2002; Lawn and Kerber 2006; Lawn *et al*. 2006b; Kerber *et al*. 2007). Nine health service delivery packages that impact newborn health exist in most health systems, and involve links with reproductive, maternal and child health as well as immunization, malaria, HIV/AIDS, nutrition and other programmes (Figure 1) (Kerber *et al*. 2007). There is increasing global consensus around these interventions, underscored by the recent publication of essential maternal, newborn and child health (MNCH) packages and interventions agreed to by multiple organizations (PMNCH 2011). Implementation at scale of evidence-based care would prevent around two-thirds of newborn deaths (Darmstadt *et al*. 2008).

Local context is important when considering the potential reach and performance of health systems for addressing MNCH. In contexts with high NMR and weaker formal health systems, there may be opportunities to strengthen entry points closer to home, such as community preventive care packages of pregnancy and postnatal visits (WHO *et al*. 2009), and community case management of neonatal sepsis (Bang *et al*. 1999), while engaging in broader health facility and health system strengthening. Effective care at birth to reduce neonatal deaths, stillbirths and maternal deaths requires strengthening human resource capacity, though there is scope to improve care at birth even in settings with low rates of skilled attendance at delivery (Lawn *et al*. 2009b). Scaling up of newborn survival interventions involves interactions with many policies, programmes, cadres of worker and supply systems while considering local context and is therefore a useful example for examining the process towards change at scale.

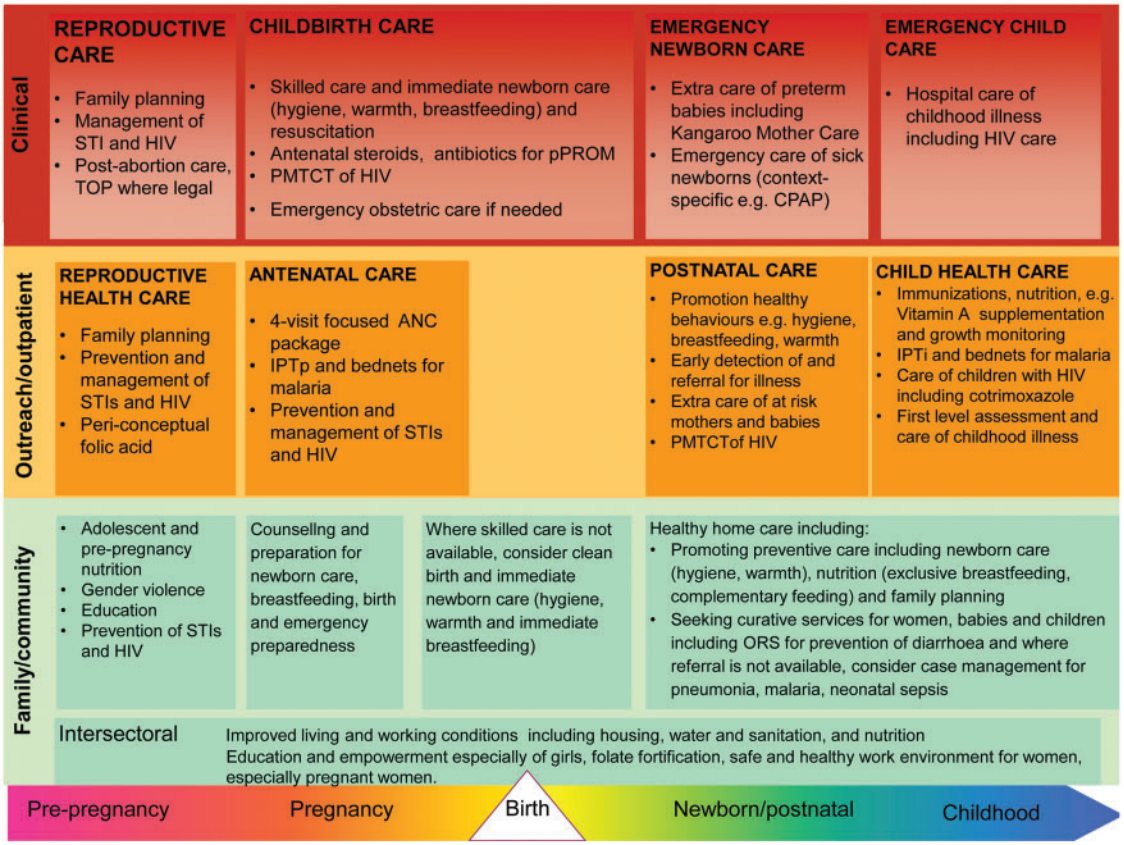


Figure 1 Integrated service delivery packages for maternal, newborn and child health
Source: Kerber *et al*. (2007). *Note*: First published in *Disease Control Priorities in Developing Countries* chapter (Lawn *et al*. 2006b), then revised with inputs from consensus group for Women Deliver in 2008, and then specific adaption for Africa (Kinney *et al*. 2010). This figure has been updated here with newborn health interventions from a review of essential interventions by PMNCH (PMNCH 2011) and *Born Too Soon: The Global Action Report on Preterm Birth* (March of Dimes *et al*. 2012). Abbreviations used: ANC = antenatal care; CPAP = continuous positive airway pressure; HIV = human immunodeficiency virus; IPTi = intermittent preventive treatment in infants; IPTp = intermittent preventive treatment during pregnancy for malaria; ORS = oral rehydration solution; PMTCT = prevention of mother-to-child transmission of HIV; pPROM = prelabor premature rupture of membranes; STI = sexually transmitted infection; TOP = termination of pregnancy.

Frameworks for evaluation of newborn survival

Conceptual frameworks for health can be used for problem characterization, implementation or evaluation (Marsh *et al*. 2008; Ergo *et al*. 2011). Some frameworks focus on principles, such as DFID's four pillars (women's empowerment, removal of barriers preventing access, quality, and accountability) (DFID 2010). The International Health Partnership proposed a common framework for evaluating MNCH programmes, and stressed the importance of standardized process documentation, as well as comparable designs for country-level evaluations (Bryce *et al*. 2011).

Global public health experts are grappling with appropriate evaluation designs to assess complex programmes especially with concurrent changes in context (Bryce and Victora 2005). Randomized trials are not always possible or appropriate but are of particular value in evaluations which try to understand the relationship between different interventions and outcomes and to control for contextual factors (English *et al*. 2011). Where randomized trials are not possible or feasible, data are needed to capture changes in programme results and changes in context over time (Victora *et al*. 2011).

Multi-country evaluations of MNCH packages using a standard evaluation framework and a rigorous design remain rare. When these have been done, success has largely depended on choosing the right interventions and delivery package, increasing coverage of the selected interventions, and effective measurement, especially in the context of rapid change. Two valuable examples of evaluations of packages with curative and promotive care are the Integrated Management of Childhood Illness (IMCI) multi-country evaluation in five countries (Bangladesh, Brazil, Peru, Tanzania and Uganda) (Bryce *et al*. 2005) and the Accelerated Child Survival and Development (ACSD) programme in three African countries (Benin, Ghana and Mali) (Bryce *et al*. 2010). Both evaluations found that services did not achieve desired coverage and quality and that child mortality did not decrease compared with control groups. The ACSD evaluation found increased coverage in preventive interventions delivered by outreach and campaign strategies (e.g. immunizations and vitamin A supplementation), but it noted that these were the lower impact interventions (Jones *et al*. 2003). Neither the IMCI nor the ACSD evaluation included the highest impact interventions to reduce neonatal deaths.

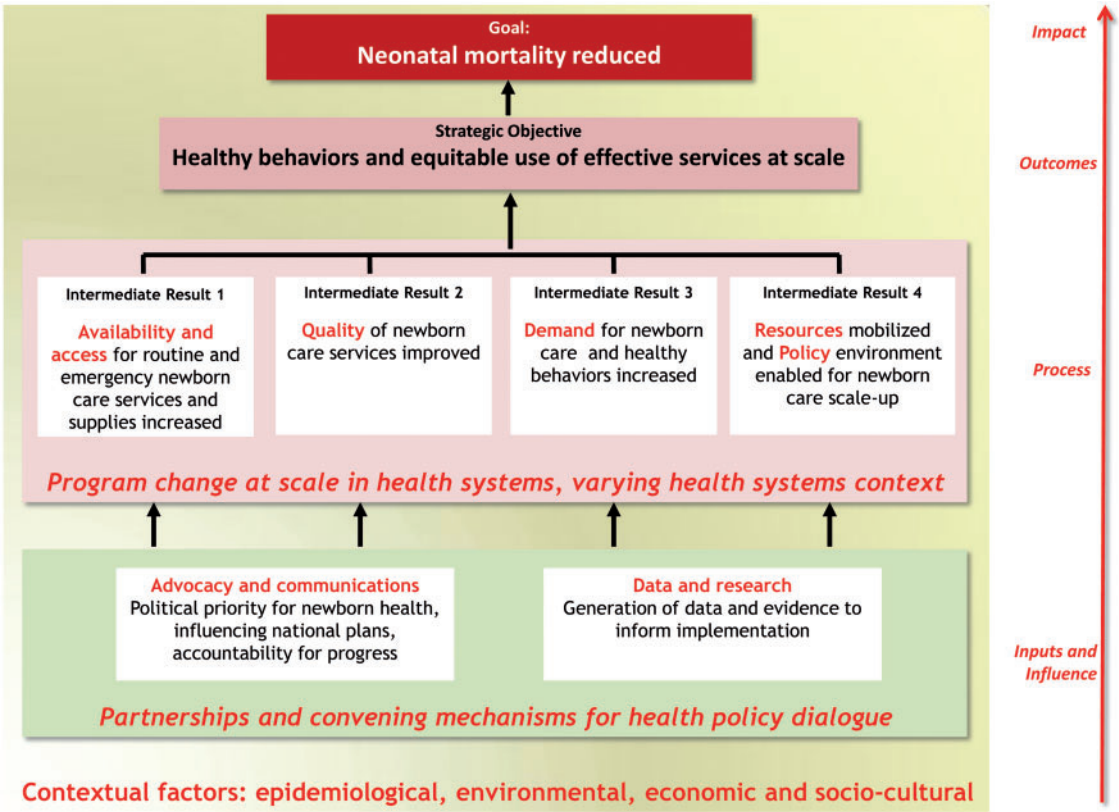


Figure 2 Saving Newborn Lives results framework

Saving Newborn Lives programme and results framework

Most frameworks with the goal of improved health outcomes focus on intervention coverage and have variable constructs related to intermediate results and inputs (Marsh *et al*. 2008; Victora *et al*. 2011). The conceptual framework used in this supplement is consistent with the components in the International Health Partnership framework (Bryce *et al*. 2011). Save the Children's Saving Newborn Lives (SNL) programme adapted a standard logical framework in 2006 in order to guide programming and evaluation of national newborn survival programmes at scale. The main adaptations were an emphasis on context, health system change and an explicit inclusion of equity at the strategic objective level (Figure 2). The SNL results framework considers the *goal* (saving newborn lives, measured by reduced NMR) to be a result of the *strategic objective* of increased equitable coverage of evidence-based newborn services and healthy behaviours. Increased coverage is a result of programme change at scale within the health system through the achievement of short-term outcomes or *intermediate results*. These results include improving availability and access of newborn care services through: developing human resource capacity and availability of essential equipment and medicines; ensuring quality of care; increasing demand for services by families and communities; and, achieving a supportive policy environment including availability of adequate financial resources. The processes (inputs and influence) listed interact to promote systems change: evidence generation, advocacy and use of data for planning, consensus-building mechanisms and partnerships. In addition, the socio-political, economic, environmental, biologic and legal context affects all levels of the change.

Objectives

This first paper in the supplement on a decade of change for newborn survival (Box 1) applies the SNL results framework to a multi-county evaluation examining global and regional changes for newborn survival between 2000 and 2010 in terms of variation in neonatal mortality reduction, data from a 10-year trend analysis for neonatal cause of death, coverage and health system indicators as well as new analyses of national and donor funding, using mainly quantitative data. A novel statistical analysis of intervention coverage and contextual factors for neonatal mortality globally and regionally is undertaken.

Methods

Overview

The analyses used in this supplement, including this paper, were structured according to the SNL results framework (Figure 2) considering mortality, intervention coverage and intermediate results and inputs, especially funding flows. We applied standard tools for the intermediate results level to examine policy change and events over time, as well as specific benchmarks for newborn survival (Moran *et al*. 2012). We linked quantitative data with standardized policy and

programme assessments to unpack the process of moving to scale for newborn survival. An overview of the input data by level of the framework is shown in Table 1, with more details in Supplementary Data Web Annex A.

Country selection

Different groups of countries were used for the various analyses in this supplement and paper (Figure 3). We assessed 193 countries, all United Nations (UN) member states, for NMR and neonatal cause of death change. The multi-country model examining covariates of NMR reduction was developed using 144 countries, excluding those with <10 000 births per year (32 countries) or inadequate data (17 countries). Our analysis of donor funding was restricted to Countdown to 2015 priority countries, which account for over 90% of newborn deaths globally (75 countries). Then we undertook a more detailed analysis of 18 countries in Africa, Asia and Latin America. These countries, where SNL worked, were selected based on criteria of burden size (number of neonatal deaths) or risk (level of NMR), and opportunity for programmatic change at scale. Together they accounted for 62% of neonatal deaths in 2010 and their average annual reductions in average maternal mortality ratio (MMR), under-five mortality rate (U5MR) and NMR were similar to the global averages.

Finally, in-depth country case studies were conducted. These countries were selected from the 18 SNL countries by scoring with pre-set criteria including: availability of national mortality and coverage data; changes in NMR; changes in coverage of key indicators, in particular skilled birth attendance; changes in newborn health policy, programmes and research; and country mechanism for convening national stakeholders. The five top countries were selected (Bangladesh, Pakistan, Nepal, Malawi and Uganda). In each of these countries, a team of national experts was convened, including members from the Ministry of Health, UN agencies, professional associations, academics and non-governmental organizations (NGOs) and ranged in size from 11 to 40 members. These teams met several times during a two-year process, and also communicated by conference calls and email in order to provide input data, complete standard policy change assessments, and review and interpret changes for newborn survival in their country.

Data sources and analysis

Neonatal mortality reduction (goal)

To analyse neonatal mortality trends, we used data from national and sub-national household surveys, as well as from the UN and the Institute for Health Metrics and Evaluation (IHME) (Table 1). Descriptions of mortality estimates and the different methods employed are given in Supplementary Data Web Annex A. For this paper, we used UN estimates of mortality since these provide a consistent time series, and have been through a country review process. To assess change over time, the average annual rate of reduction for NMR is compared with regional rates and with changes of U5MR, mortality of children after the neonatal period (1–59 months) and MMR (WHO *et al*. 2012; UNICEF *et al*. 2011).

Our assessment of trends in causes of neonatal deaths benefits from recently available time series for the years 2000–2010, using these previously published methods with multinomial modelling to predict proportionate mortality for 193 countries (Lawn *et al*. 2006a; Liu *et al*. 2012).

Contextual factors

Political, social, economic, environmental and structural factors are essential to consider as they may account for mortality reduction complicating the association between direct health interventions and observed impact (Victora *et al*. 2005). *The Lancet* Neonatal Survival Series proposed that the level of neonatal mortality was a tracer of health system context, including health systems, and split countries into categories by level of NMR for prioritizing and phasing newborn care (Knippenberg *et al*. 2005). This method has also been used in other assessments of variation across countries (Lawn *et al*. 2009a). We updated this analysis to examine if these NMR groupings are useful for defining various settings and how the situation has changed for the countries with highest and lowest mortality over this decade.

Healthy behaviours and equitable use of effective health services (strategic objective)

To examine change in newborn-related health interventions, coverage data from national and sub-national household surveys was compared over time and with regional data (Table 1). National coverage data are primarily available for the service delivery packages in Figure 1 (e.g. antenatal care, skilled attendance) and for a few specific interventions that have been a focus for longer, such as tetanus toxoid immunization or breastfeeding promotion. Other high impact neonatal interventions with recent attention, such as Kangaroo Mother Care (Lawn *et al*. 2010b), have no national data available. In order to estimate the potential impact of MNCH intervention coverage on mortality for the five country case studies, the Lives Saved Tool (LiST) was used (Figure 3), applying the most recent available rates and causes of maternal, neonatal and child deaths, by country (Box 2) (Khan *et al*. 2012; Mbonye *et al*. 2012; Pradhan *et al*. 2012; Rubayet *et al*. 2012; Zimba *et al*. 2012). Supplementary Data Web Annex B provides more details on the LiST analysis.

Evaluation of covariates of national variation in neonatal mortality trends

To understand national variation in the annual rate of change (ARC) of NMR, we developed a multiple linear regression model, with national ARC of NMR between 2000 and 2010 as the dependent variable and 13 potential covariates relating to context and coverage. *Contextual* factors include gross national income (GNI) per capita, political stability, government effectiveness, female literacy rate, general and adolescent fertility rates, HIV prevalence in women aged 15–49, total health expenditure per capita. *Coverage* of a range of interventions along the continuum of care include proportion of births attended by skilled health personnel, proportion of births protected from tetanus (tetanus PAB), and coverage of the third dose of diphtheria/pertussis/tetanus vaccine (DTP3) (WHO 2010). We derived annual time series, 1990–2010, of each covariate (Supplementary Data Web Annex C1). We also included the NMR level in year 2000 as a covariate.

For this analysis, the subsets of the covariates are highly correlated (see Supplementary Data Web Annex C4).

Table 1 Data sources related to newborn survival: changes since 2000 and priorities for future advances

Framework	Metric	Data sources	Changes since 2000	Priorities for future advances
Goal				
	• Neonatal mortality rate • Causes of neonatal death	• Vital Registration system (gold standard) • Household surveys (notably DHS and MICS) • Facility surveillance records/audit • Verbal autopsy • Modelled estimates (UN, IHME)	• Timing and visibility – Erratic frequency of NMR estimation now done annually by UN with more subnational data (causes and mortality) and country review. Also frequent country, regional and global estimates from IHME. • Transparency – inputs and methods, now well described, mainly peer reviewed and in public domain • Trends – now possible given consistent methods and modelling • Programmatic relevance – neonatal causes grouped by programmatic categories instead of some in 'perinatal causes' and some in 'other'	• Stillbirth rate estimates and time series produced by *The Lancet* Stillbirth Series team but no routine system • Improved neonatal death data especially verbal autopsy consistency • Wide-scale comparable mortality audits tracking avoidable causes of death • Acute morbidity and long-term impairment, estimates and improved data inputs
Strategic objective				
	• Equitable coverage of services and behaviours, e.g. antenatal care, skilled attendance, postnatal care, tetanus toxoid immunization, breastfeeding	• Household surveys (DHS, MICS) • Special surveys, e.g. immunization coverage • UN databases and estimates • Lives Saved Tool (LiST)	• Some newborn care indicators included by Countdown to 2015 • Postnatal care in 2 days indicator included as one of six key indicators by COIA • Postnatal care indicator measurement improved in household surveys but still only available for ~30 countries	Critical need for improved coverage data on: • Interventions provided at a given contact point, e.g. birth, postnatal care • High impact interventions without population level data that could be collected in household surveys, e.g. kangaroo mother care • Effect of health promotion on change in coverage
Context				
	• Gross National Income • Governance scores • Female literacy • Fertility, adolescent birth rate	• World Bank • UN estimates, e.g. UNICEF, UNFPA, UNDP	• More awareness of the importance of context, and in many countries rapid change in context, which may also reverse, e.g. with financial crisis	• More consistent measure of context in studies and complex programme evaluations
Intermediary results				
Demand				
	• Care seeking for newborn illness • Demand for maternal services, e.g. family planning, facility birth	• Household surveys but low statistical power and limitations of quantitative methods to measure demand	• Increased attention to demand promotion, including financial incentives.	• Critical need for more measures, influencers of demand that can be qualitatively and/or quantitatively tracked

(continued)

Table 1 Continued

Framework	Metric	Data sources	Changes since 2000	Priorities for future advances
Availability	• Average distance to facility or % population within km of facility • Human resource density • Equipment availability	• Health Facility Assessments, e.g. SPA and special surveys	• Newborn indicators added to SPA • Essential medicines for children and newborns • Standard equipment list established	• Develop newborn-specific rapid health facility assessment as a standalone assessment or incorporated into other surveys
Quality	• Evidence-based and safe: avoiding preventable injuries, reducing medical errors • Effective: providing services based on scientific knowledge (clinical guidelines) • Efficient: avoiding wasting time and other resources • Family centred: care that is respectful and responsive to individuals and timely	• Health Facility Assessments, e.g. SPA and special surveys • Mortality audits • Criterion-based audit • Competency assessment of providers, e.g. for neonatal resuscitation • Client interviews	• Advances in mortality audit tools and understanding of scale up of mortality audits • Quality improvement initiatives incorporate newborn care • Increasing uptake of perinatal audit; pater and electronic adaptation	• Standard assessment of provider competency for newborn care at facility and community level • Consensus on standards for care and routine measurement against those standards
Policy, enabling, resources	• Policy change • Achievement of benchmarks for scale-up readiness	• Policy documents • Scale-up Readiness Benchmarks	• User fees and other financial barriers • Incentives • Method to track policy change	• More rigorous assessment of the relationship of benchmarks to coverage and mortality change
Funding flows for health	• Total health expenditure (US$), including government, private and other out-of-pocket expenditure • Per capita total health expenditure (US$), including government, private and other out-of-pocket expenditure • ODA per target population (US$)	• National health accounts (NHA) data • OECD/CRS database • Countdown to 2015 for MNCH	• Annualized NHA data available • ODA for MNCH Indicator tracked by Countdown to 2015 using comparable methods	• Sub-account analysis of NHA data • COIA recommendation to track national RMNCH funding but currently not available
Inputs to advance scale up of relevance to newborn survival	• Research, advocacy, partnerships	• Policy and Programme Timeline for newborn survival • Scale-up Readiness Benchmarks	• IHP and others proposed approaches to define and measure inputs for complex programmes, and the concept of contribution as opposed to attribution	• Need consensus on standard approaches to documenting inputs other than financial tracking

Note: Abbreviations used: COIA = Commission on information and accountability for Women's and Children's Health; DHS = Demographic and Health Survey; IHME = Institute for Health Metrics and Evaluation; IHP = International Health Partnership; LiST = Lives Saved Tool; MICS = Multiple Indicator Cluster Surveys; NHA = National Health Accounts; NMR = Neonatal Mortality Rate; ODA = Official Development Assistance; OECD/CRS = Organisation for Economic Co-operation and Development's Creditor Reporting System; RMNCH = Reproductive, maternal, newborn and child health; SPA = Service Provision Assessments; UN = United Nations; WHO = World Health Organization.

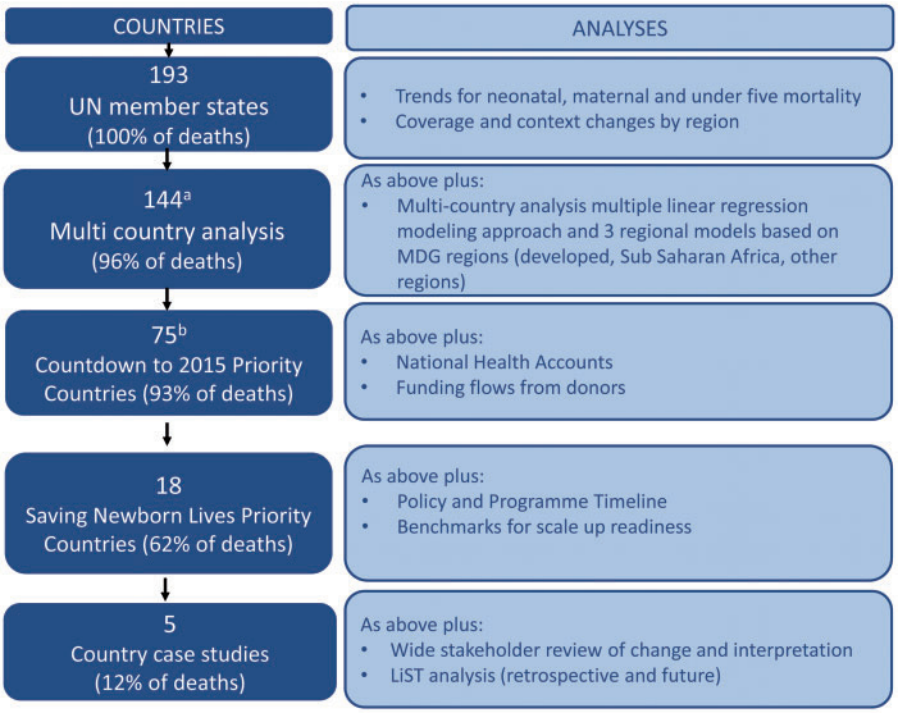


Figure 3 Flowchart for country selection and analysis
Notes: [a] Excluding 32 countries with <10 000 annual live births and 17 countries with insufficient time series data.
[b] Countdown to 2015 has 75 countries. The ODA analysis excluded the Countdown to 2015 priority countries added in 2011: Comoros, Kyrgyzstan, Solomon Islands, Sao Tome and Principe, Uzbekistan, and Vietnam. South Sudan has limited national data so was analysed with the Republic of Sudan. The previous Countdown to 2015 MNCH funding analysis was for the 68 countries included in Countdown to 2015 at that time.

We therefore applied the elastic net algorithm to fit the parameters in the model—this algorithm enables simultaneous assessment of a range of covariates despite co-linearity between contextual and coverage variables (Tibshirani 1996; Zou and Hastie 2005). We employed the R-package 'Glmnet' (Friedman *et al*. 2010) to use this algorithm and identify the best-performing statistical model through 10-fold cross-validation, a type of out-of-sample prediction error measurement (Hastie *et al*. 2001). More information about the elastic net algorithm is available in Supplementary Data Web Annex C2.

While the time period from 1990 is the MDG baseline, the focus of this paper and supplement is the period 2000–2010 since there was minimal attention to global newborn survival before the year 2000. In addition, 2000 was an inflection point for rate of change for under-five mortality and to a lesser extent neonatal mortality.

Given major regional differences in changes for mortality and covariates, especially for sub-Saharan Africa, to minimize possible bias and to increase the predictive validity of the statistical modelling, we fitted three separate regional multiple linear regression models to the following MDG regional groupings: (1) Developed region (38 countries); (2) Sub-Saharan Africa (40 countries); and (3) Other regions (66 countries).

Programme change at scale in health systems (intermediate level)

To assess changes in national newborn policy and programmes, a combination of qualitative and quantitative methods were developed and applied in the country case studies (Box 3). Progress on newborn policy and programmes was evaluated using two standard tools: the Policy and Programme Timeline (details available in Supplementary Data Web Annex D) and the Scale-up Readiness Benchmarks (Moran *et al*. 2012). Availability and access to newborn health services considered health worker density, equipment and supplies for newborn survival as well as the geographic reach of implementation (Box 3). Quality of newborn care was examined through assessments of health facilities, such as Service Provision Assessments, and through specific programmes related to quality improvement. Increased demand for newborn care was also considered and explored though review of literature as well as data provided in national surveys.

Financial resources for newborn health

To assess changes in funding for newborn health across countries and in selected countries, national expenditure and donor funding were analysed. National health funding data were obtained from the World Health Organization's National Health Accounts and analysed to examine total expenditure on health, including government, out-of-pocket and other private expenditure (more details in Supplementary Data Web Annex E) (WHO 2011b). Comparable data for national spending are not systematically tracked across countries for MNCH.

Donor health funding data were examined by reviewing existing published estimates and by conducting an additional

Box 2 Description of Lives Saved analyses used in country case studies

Background to LiST

The Lives Saved Tool (LiST) is a module in Spectrum, which is a free and widely used demographic software package developed and refined in the past 20 years for projecting population trends by age and sex, based on UN estimates. Embedded software models the effects of scaling up HIV interventions on HIV prevalence and mortality. The LiST models effects on stillbirths and maternal, neonatal and child mortality as well as stunting and wasting are based on *The Lancet*'s Series on Child Survival, Neonatal Survival, Maternal and Child Undernutrition and Stillbirths. LiST includes national time series data for mortality, health status and intervention coverage. Coverage data for many interventions in low- and middle-income countries are available through Demographic and Health Surveys (DHS), but coverage data are lacking for many high impact neonatal interventions (e.g. rates of neonatal resuscitation), and LiST uses estimated levels for coverage indicators based on other data, such as Service Provision Assessments (Measure DHS 2011) or national HMIS data as described elsewhere (Johns Hopkins Bloomberg School of Public Health 2010). The detailed review process to estimate effect sizes of cause-specific mortality, and the modelling assumptions in LiST have been published elsewhere (Boschi-Pinto *et al*. 2010; Stover *et al*. 2010; Boschi-Pinto and Black 2011).

LiST can be used to conduct both *retrospective* analyses and *future* analyses by changing coverage for selected interventions by year and from a given baseline year. The programme links the user's input coverage data by year to cause-specific mortality estimates using standard effect sizes, resulting in estimates of lives saved per year by intervention and cause for a specific country (Johns Hopkins Bloomberg School of Public Health 2010).

Country case studies

For the country case studies, a LiST *retrospective* analysis was used to assess mortality change from 2000 to 2010 using coverage data from national household surveys. Since countries varied in their availability of national survey data, the purpose of the retrospective analysis varied across country papers. For countries with nationally available data for around the years 2000 and 2010, e.g. Bangladesh, Malawi and Nepal (Pradhan *et al*. 2012; Rubayet *et al*. 2012; Zimba *et al*. 2012), those survey data points were used to determine if the mortality change predicted in LiST is consistent (within a confidence range) with what was reported by national surveys. In the cases where national household survey mortality estimates suggest greater mortality reduction than predicted by LiST, it may be assumed that contextual progress contributed more than coverage increases.

LiST was also used to predict *future* scenarios for addressing missed opportunities in facilities for facility births, for increasing outreach services by 20%, and for assessing potential maximum impact (90% coverage of all essential care). These analyses used the same methods and selected interventions for scale up as Friberg *et al*. (2010). More details on these analyses and input data can be found in Supplementary Data Web Annex B.

analysis of aid benefitting newborns in the same countries and time period. We considered data from the Organisation for Economic Co-operation and Development (OECD)'s Creditor Reporting System database of official development assistance (ODA) for health 2002–2009 as well as previously published data on ODA for MNCH between 2003 and 2008 as tracked for Countdown to 2015 (Pitt *et al*. 2010), for which the methods and limitations are detailed elsewhere (Pitt *et al*. 2012). In brief, a search of the Creditor Reporting System database was undertaken for any mention of the word 'newborn' or a derivative, and also for 23 terms referring to newborn-specific interventions. All projects identified were manually reviewed and classified according to whether the project: (1) *mentions newborns,* but may also benefit other populations, or (2) *exclusively benefits newborns*. We present results as total and as per capita values of ODA for health, ODA for maternal and newborn health, and ODA for child health (US$). All government and donor funding values are in constant 2008 USD.

Results and discussion

Neonatal mortality reduction

Neonatal mortality declined at a slower pace than under-five deaths in the last decade (Figure 4). Between 2000 and 2010, the average annual rate of reduction for under-five mortality was 2.5% (including neonatal deaths) (UNICEF *et al*. 2011; Hill *et al*. 2012). When splitting out mortality by age of death, the mortality for children aged 1–59 months decreased at an average of 2.9% per year, while NMR decreased at 2.1% per year (UNICEF *et al*. 2011; Hill *et al*. 2012). As a result, the proportion of under-five deaths during the neonatal period rose from 36% to more than 40%, an 11% relative increase (Table 2a). In order to reach MDG 4, the annual rate of reduction of under-five mortality must increase to 13.5% per year between 2011 and 2015 globally (Figure 4); thus accelerated reduction in neonatal mortality is increasingly critical for progress towards MDG 4. Maternal mortality decreased at an average annual rate of 4.2% over the decade (WHO *et al*. 2012).

Box 3 Methods to assess changes in national newborn policies, programmes and processes

To assess changes in national newborn survival policy and programmes, mixed qualitative and quantitative methods were developed and applied. Data were collected through review of national reports, assessments, guidelines, newborn situation analyses and programme documents, and were then reviewed by key national stakeholders. The standard tools applied include the following:

Policy and Programme Timeline

Tool: A standardized format and protocol for historical review of critical events and changes for policies, programmes, advocacy and research at country level to identify pivotal events that may have influenced the national newborn health landscape positively or negatively (Supplementary Data Web Annex D).

Protocol: For each country, events relating to newborn survival were recorded from 2000 to 2010 at three levels: the national context; national level health policies, strategies and plans showing incorporation of MNCH; and newborn-specific programmes and activities, e.g. activities to reduce deaths due to preterm complications, intrapartum-related deaths and infections. National expert groups completed the timeline, which was then critically reviewed by other stakeholders in-country (8–40 experts), including an exercise to select the most influential events for newborn survival in the last decade.

Scale-up Readiness Benchmarks

Tool: A scoring of 27 selected markers for scale up readiness for newborn health that address themes around agenda-setting, policy formulation and implementation (Moran *et al*. 2012).

Protocol: Experts in each of the selected countries completed a checklist of benchmarks each categorized as achieved, partially achieved, or not achieved for three time points (2000, 2005, 2010). The results from the benchmark tool were compared with the policy and programme timeline and supporting policy and programme documents for consistency (Moran *et al*. 2012).

Geographic reach of implementation

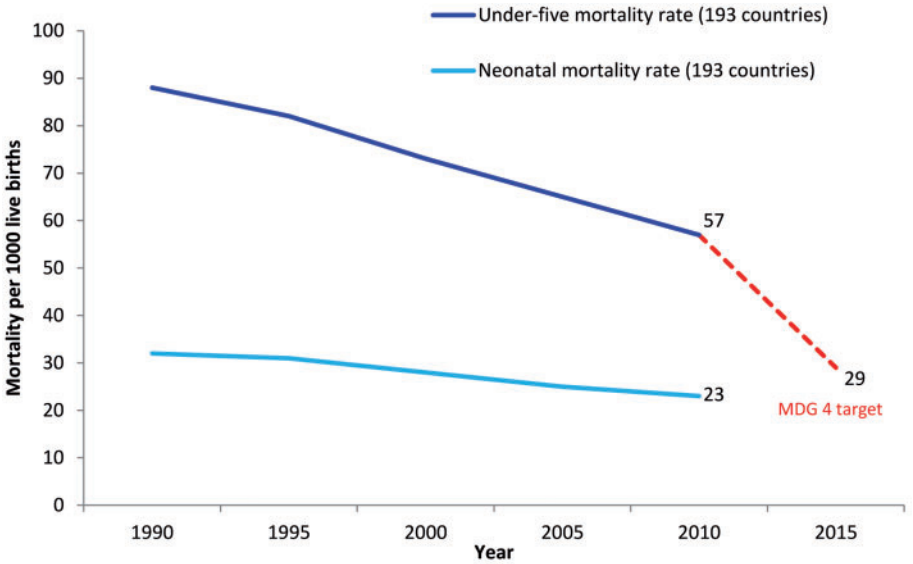
We worked with in-country teams to assess and document the geographic reach of selected packages of care relevant to newborn survival using information collected from Ministries of Health, UN agencies, Save the Children and other implementing partners. The reach was shown by district on national maps, where possible giving the ratio of trained staff per capita of total population.

Since 2000, China, India, Nigeria and Pakistan are among the world's most populous countries with the most annual births and have consistently experienced the greatest number of neonatal deaths (Table 2b). It is notable that Nigeria and Pakistan now have more neonatal deaths than China, due to China's decreasing NMR *and* fertility rate. The 10 countries with the highest numbers of neonatal deaths in 2000 (India, China, Nigeria, Pakistan, Bangladesh, the Democratic Republic of the Congo, Ethiopia, Indonesia, Brazil and Afghanistan) together decreased neonatal deaths by 347 000 deaths between 2000 and 2010, contributing to 59% of the global reduction from 3.7 million to 3.1 million.

Somalia, Sierra Leone, Mali and the Democratic Republic of the Congo have remained in the list of top five countries with the highest neonatal mortality rates in both 2000 and 2010 (Table 2b). Two-thirds of neonatal deaths now take place in countries with mortality above 30 deaths per 1000 live births. All five countries in the highest mortality band (NMR $\geq$45) in 2010—Afghanistan, the Democratic Republic of the Congo, Mali, Pakistan and Somalia—have experienced recent instability and conflict, highlighting the gap for newborn survival strategies in emergencies and humanitarian crises. Countries with the least change in the risk of neonatal deaths are primarily in sub-Saharan Africa, but some high-income countries such as Canada, Switzerland and the United States have also made little progress since 2000. This slower progress may be reflective of wide availability of intensive care before the decade started, and increasing preterm birth prevalence in these countries during this decade (March of Dimes *et al*. 2012).

However, some countries have achieved remarkable progress, with five countries more than halving neonatal mortality rates over the decade (Turkey, Oman, Greece, Belarus and Estonia) (Table 2c). Between 2000 and 2010, the countries in sub-Saharan Africa with the greatest overall reduction of NMR were Botswana and Namibia; for Southern Asia, they were Iran, Bangladesh and Nepal. NMR was higher among the 18 SNL countries than the global average throughout this time period, yet varied greatly from 12 deaths per 1000 live births in Vietnam to 48 in Mali in 2010, and the average annual rate of NMR reduction ranged from 0.1% in Afghanistan to 4% in Bangladesh.

Over the last decade, changes in neonatal cause of death data and estimation methods have led to improved guidance for policy and programmes. Until *The Lancet* Neonatal Series in 2005, there were no global or nationally comparable estimates for causes of neonatal deaths. An important advance over the past decade was the shift from 'perinatal causes', which include all deaths coded in a particular chapter of the International Classification of Diseases, to considering causes of death in the neonatal period and using programmatically relevant grouping (Lawn *et al*. 2008) (Figure 5). The previous approach hid the high proportion of deaths in the neonatal period and also masked the most easily preventable causes of neonatal deaths—tetanus and infections—by including them in the 'Other' grouping. Co-ordinated by the Child Health Epidemiology



Average annual rate of reduction	1990-2010	2000-2010
Under-five mortality rate	2.2%	2.5%
Children 1-59 months mortality rate	2.5%	2.9%
Neonatal mortality rate	1.8%	2.1%

Figure 4 Progress towards Millennium Development Goal 4 for child survival showing progress globally (193 countries)
Data sources: UN Interagency Group for Child Mortality Estimates (UNICEF *et al*. 2011) with new analysis of mortality trend by age at death.

Reference Group (CHERG), consensus was reached on a short list of programmatically-relevant causes of neonatal death that could be distinguished in verbal autopsy data and mapped onto the International Classification of Disease codes (Lawn *et al*. 2006a). Using data inputs from vital registration and various studies, a multinomial model was developed to estimate proportionate mortality within the neonatal period for 193 countries (Lawn *et al*. 2005; Lawn *et al*. 2006a). This method is now used for annual updates by CHERG and the World Health Organization (WHO) (Liu *et al*. 2012).

Three causes of death account for more than 85% of the world's 3.1 million neonatal deaths: complications of preterm birth, infections and intrapartum-related causes ('birth asphyxia'). Across regions, the NMR level and rate of reduction varies, but cause-specific mortality changes are less marked (Figure 6). When arranged by NMR level, countries in the two highest mortality bands have higher proportions of infections and deaths from intrapartum-related causes than countries with the lowest overall mortality (Lawn *et al*. 2009a).

There has been impressive progress in reducing deaths from neonatal tetanus with a 92% decrease since the late 1980s (Roper *et al*. 2007; Blencowe *et al*. 2010). Despite two global elimination target dates in the past decade, maternal and neonatal tetanus has not yet been eliminated, with approximately 60 000 newborns dying each year from tetanus (Liu *et al*. 2012), primarily in a limited number of large countries with insufficient rates of tetanus toxoid immunization and low coverage of facility births, such as Nigeria and India (Blencowe *et al*. 2010). Some progress has been made in reducing deaths from other neonatal infections, especially pneumonia and diarrhoea, and some progress for intrapartum-related neonatal causes (Lawn *et al*. 2010a; Liu *et al*. 2012). Neonatal deaths globally are dominated by complications of preterm birth as a direct (35%) and also indirect cause of deaths, such as death from infection in complications of moderately preterm babies (March of Dimes *et al*. 2012). Historical trends in high-income countries also show an increasing proportion of neonatal deaths due to preterm complications, but the gestation-specific risk has been dramatically changed by neonatal intensive care (March of Dimes *et al*. 2012).

Changes in context

Table 3 shows 193 countries organized into five categories according to their level of NMR in 2010 and the associated variation of contextual factors and health system markers (Knippenberg *et al*. 2005; Lawn *et al*. 2009a). The median GNI per capita in the 50 countries with NMR $\leq$5 is 40 times more than the five countries with NMR $\geq$45 (US$33 990 and US$847, respectively. Rate change of GNI between 2000 and 2010 had minimal variation across the categories. Female literacy was considerably lower for high mortality settings (49% in Category 4 and 29% in Category 5), compared with 96% in Category 1 with NMR $<$5. Other contextual variables such as urbanization, cell phone use and food security may have important associations with health outcomes but are not shown here.

Progress for coverage of newborn survival interventions and health system performance

These NMR categories also help delineate the variation of health system settings, especially at the time of birth. Skilled birth attendant coverage is universal in the low mortality countries but less than 50% in high mortality settings (Table 3).

Table 2 Changes for maternal, newborn and child survival 2000–2010 (193 countries)

a. Births and deaths

	2000	2010
Live births	131 140 000	134 683 000
Maternal deaths	451 000	359 000
Stillbirths	2 850 000	2 650 000*
Under-five deaths	10 169 000	7 614 000
Neonatal deaths	3 681 000	3 072 000
Neonatal deaths as % of under-five deaths	36%	40%

b. Country ranking by neonatal mortality rates and by numbers of neonatal deaths

Highest neonatal mortality		Highest number of newborn deaths	
2000	2010	2000	2010
Sierra Leone (53)	Somalia (52)	India	India
Mali (52)	Mali (48)	China	Nigeria
Somalia (52)	DR Congo (46)	Nigeria	Pakistan
DR Congo (48)	Sierra Leone (46)	Pakistan	China
Angola (47)	Afghanistan (45)	Bangladesh	DR Congo
Nigeria (46)	Central African Republic (43)	DR Congo	Ethiopia
Burundi (46)	Burundi (42)	Ethiopia	Bangladesh
Mozambique (45)	Angola (41)	Indonesia	Indonesia
Liberia (45)	Pakistan (41)	Brazil	Afghanistan
Pakistan (45)	Chad (41)	Afghanistan	Sudan

c. Countries with the largest neonatal mortality rate reduction from 2000 to 2010 (% change)

Developed region	Sub-Saharan Africa	Other regions (Asia, North Africa and Latin America)
Estonia (58%)	Botswana (38%)	Oman (53%)
Belarus (55%)	Namibia (35%)	Turkey (51%)
Greece (55%)	Rwanda (32%)	El Salvador (46%)
Slovenia (48%)	Malawi (29%)	Peru (45%)
Ireland (47%)	Tanzania (28%)	Egypt (45%)

* For 2009.

Data sources: Neonatal deaths, under-five deaths and live births from UN (UNICEF *et al*. 2011). Trends in maternal mortality from WHO *et al*. 2012. Stillbirth from Cousens *et al*. (2011). *Note*: Excluding countries with <10 000 annual live births.

The median caesarean delivery rate ranges from 24% in Category 1 to 2.6% in Category 4 and 5 countries. Though high caesarean section rates are not desired, rates less than 5% are a marker of lack of availability of emergency and neonatal intensive care, especially in rural areas. Health worker density varies markedly across NMR categories. The density of midwives and nurses is over 30-fold higher in Category 1 (664 per 10 000 population) compared with Category 4 (57 per 10 000 population) and Category 5 (30 per 10 000), and the density of doctors is 50 times higher.

Changes in coverage levels of newborn-related interventions differ by region and indicator. In the past two decades, there has been little change in the coverage of skilled birth attendance (an indicator for MDG 5) in sub-Saharan Africa and South Asia, where more than two-thirds of maternal and neonatal deaths occur (Lawn *et al*. 2009b). Yet recent data from several sub-Saharan African and South Asian countries show a rapid change in coverage. In some cases, incentives may have played a key role (Lim *et al*. 2010; Basinga *et al*. 2011), but in others, such as Malawi, there were many changes at the same time, with community mobilization and redefining roles for traditional birth attendants, as well as facility refurbishment (Zimba *et al*. 2012).

Additionally, exclusive breastfeeding has increased in most regions (UNICEF 2011). Challenges remain in definition variation of 'exclusive' between various survey tools. Descriptive data analyses suggest that immediate breastfeeding is associated with reduced neonatal mortality, while attempting control for reverse causality (Edmond *et al*. 2006). Globally, less than half of newborns are breastfed within 1 hour of birth (UNICEF 2011).

Predictors of neonatal mortality reduction

The three regional multiple linear regression models—for Developed Region, Sub-Saharan Africa and Other Regions—identify the relative importance of covariates of NMR reduction from 2000 to 2010 (Figure 7). Between 2000 and 2010, the

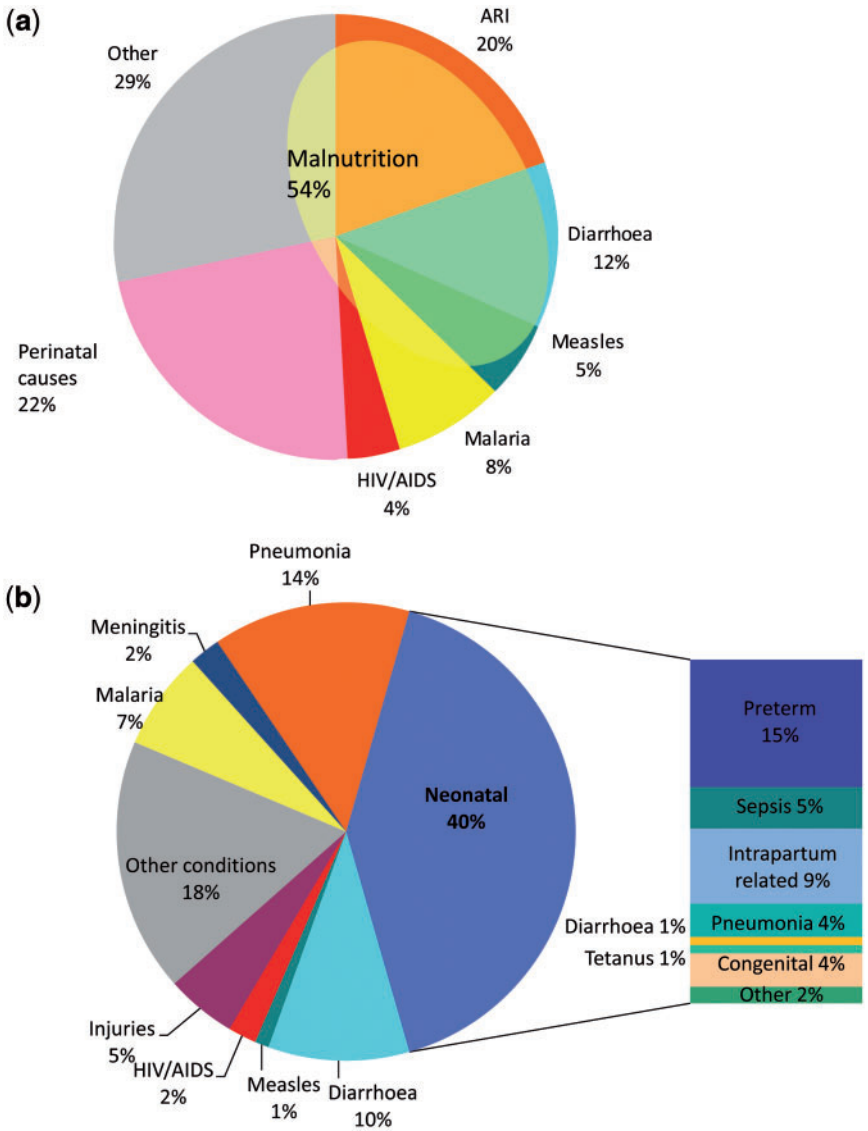


Figure 5 Global estimates for causes of death for neonates and children 2000 and 2010. *Note*: The purpose of these figures is to show change in methodology of cause of death in 2000 and 2010; therefore the data in these figures cannot be compared since data collection methods varied. (**a**) Child and neonatal causes of death globally in 2000: neonatal deaths comprised 36% of under-five deaths but were not visible, being split across 'perinatal causes' and other categories. *Source*: United Nations estimates (Lawn 2009). *Note*: Estimates were used until early 2005, including by WHO and UNICEF and as the basis for integrated management of childhood illnesses (IMCI). (**b**) Child and neonatal causes of death global estimates for 193 countries for the year 2010: increased visibility for deaths in the neonatal period as well as increased programme relevance and increased quality of all the input data and national estimation methods. *Source*: CHERG and WHO (Liu *et al*. 2012).

NMR decreased in each of the 144 countries included (Figure 3), meaning that the ARC of NMR was negative for these countries over this period. Supplementary Data Web Annex C3 shows the high co-linearity between covariates and the association between ARC of NMR and each of the covariates for each of the models in the form of two-way Pearson correlation matrices (see Supplementary Data Web Annex C for more details).

For developed countries, NMR reduction occurred more rapidly than for other regions, at over 3.0% per year. Many covariates showed an association with NMR reduction, but the two covariates explaining the most variation in ARC of NMR (2000–2010) were ARC of GNI per capita and of the general fertility rate. ARC of GNI per capita is strongly correlated with ARC of total health expenditure across these countries (see Supplementary Data Web Annex C3), which suggests that for most of these countries economic development has translated into relative increases in national health expenditure (see Supplementary Data Web Annex C4). In this group of countries, Balkan and Eastern European countries have seen the largest proportionate reduction in NMR and have made rapid recent improvements in neonatal intensive care. A critical agenda in these countries is more focus on impairment outcomes (Mwaniki *et al*. 2012).

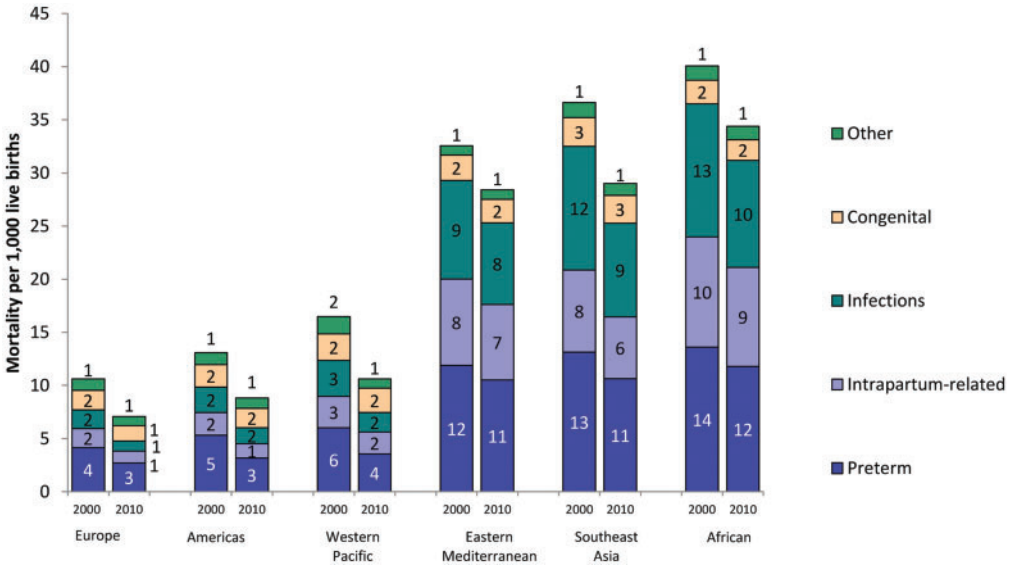


Figure 6 Cause-specific neonatal mortality rates by WHO regions from 2000 to 2010. *Data sources*: Analysis from CHERG/WHO neonatal cause of death time series (Liu *et al*. 2012). *Note*: Infections include sepsis, pneumonia, diarrhoea and tetanus.

For sub-Saharan African countries, the average rate of reduction of NMR has been very low at around 1% per year, and thus statistical covariates of change are more difficult to detect (Figure 7). High NMRs in the year 2000 were associated with slower progress, presumably since most of the countries that had not previously managed to reduce NMR continued to make little progress. The single strongest covariate of ARC of NMR, after baseline NMR, is ARC of tetanus protected at birth (tetanus PAB). An increase in tetanus PAB was weakly associated with slower NMR reduction, but this may be because countries with very low baseline tetanus PAB coverage and rapid increases in coverage were those with the weakest health systems, which often faced other challenges, for example Nigeria and Ethiopia. Since 2000, 14 countries achieved maternal neonatal tetanus elimination and most of these were countries with stronger health systems (WHO 2012). While neonatal tetanus reduction is feasible and important, tetanus accounts for fewer than 2% of neonatal deaths globally and this intervention alone will not result in dramatic NMR reduction going forward.

For other countries included in the model, mainly in Asia and Latin America, there has been variable NMR change, with outlying countries experiencing rapid progress (e.g. Bangladesh) or slower progress (e.g. Pakistan). The three covariates explaining most of the variation in ARC of NMR for these countries were ARC of general fertility rate, ARC of skilled birth attendance and baseline NMR in 2000. Oman, Turkey, United Arab Emirates, Egypt, El Salvador and Peru had large relative reductions in NMR and general fertility rate (Supplementary Data Web Annex C4). Reductions in total fertility likely contributed to MMR reduction as well as NMR, as shown in Nepal and Bangladesh (Pradhan *et al*. 2012; Rubayet *et al*. 2012). The marginally negative association with skilled birth attendance may be related to the dominance of countries in this regional group that had constant universal skilled birth attendance throughout the decade, e.g. South Korea, Colombia and the Philippines, hence limiting statistical associations.

Financial resources for newborn health

On average for the Countdown to 2015 priority countries, total health expenditure more than tripled since 2000 (Figure 8a) (WHO 2011b). Average per capita total health expenditure increased from $40 to $108, which is above the Commission on Macroeconomics and Health's suggested minimum $34 per capita annual expenditure needed for an essential package of health interventions ($53 at constant 2008 USD) (WHO 2001). In 2000, 50% of total health expenditure was from direct costs to families but this decreased to 41% in 2010 (WHO 2011b; Hercot *et al*. 2011). Average government spending on health was 9% of overall government expenditure, much lower than the Abuja target of 15% (Figure 8a) (WHO 2011b).

Donor contributions for health increased. Between 2003 and 2008, ODA for MNCH more than doubled, although some countries experienced significant fluctuations (Pitt *et al*. 2010). ODA for child health received the majority of the value of disbursements to MNCH (Figure 8b). Before 2005, newborns were rarely mentioned in donor disbursements, but from 2003 to 2008, the value of donor disbursements to the 68 Countdown priority countries mentioning newborns increased from $25.0m to $233.7m (constant 2008 USD). Yet by 2008, the most recent year for which MNCH estimates are available, only 6.1% of the value of MNCH ODA to the Countdown countries even mentioned newborns (Pitt *et al*. 2012), despite neonatal deaths accounting for more than one-third of all maternal and child deaths. Of all the funding related to newborn care from 2002–2009, the USA contributed a total of $619.5m, almost four times the next country, Canada, at $163.9m. The top five recipient countries for aid containing any mention of newborns are Bangladesh ($283.3m), Tanzania ($96.9m), Pakistan ($95.5m), Afghanistan ($82.9m) and India ($81.9m). Four of these five countries are in South Asia, where over half

Table 3 Countries (193) organized according to five levels of neonatal mortality, showing the variation in context, health system capacity and funding around the year 2010

	Category 1 Very low mortality NMR ≤5	**Category 2** Low mortality 6 – 15	**Category 3** Moderate mortality 16 – 30	**Category 4** High mortality 31 – 45	**Category 5** Very high mortality ≥45
Birth outcomes					
Births	13 263 000	40 541 000	24 307 000	50 967 000	5 606 000
# of countries	*50*	*68*	*43*	*27*	*5*
Neonatal deaths	**41 700**	**427 700**	**562 600**	**1 780 400**	**235 600**
[ARC NMR 2000–2010]	*[−4.0%]*	*[−3.4%]*	*[−2.5 %]*	*[−1.3%]*	*[−0.6%]*
Stillbirths	42 800	438 000	524 500	1 478 700	158 000
Total Fertility Rate (median)	1.7	2.1	3.4	5.1	6.5
[ARC total fertility rate 2000–2010 average]	*[0.2%]*	*[−0.1%]*	*[−1.2%]*	*[−1.2%]*	*[−0.8%]*
Contextual factors					
Gross national income per capita (US$ median)	33 990	4640	2536	1202	847
[ARC GNI 2000–2010 average]	*[3.9%]*	*[4.6%]*	*[4.6%]*	*[3.5%]*	*[5.3%]*
Female literacy rate (% median)	96	91	77	49	29
[ARC female literacy rate 2000–2010 average]	*[0.1%]*	*[0.4%]*	*[1.0%]*	*[2.3%]*	*[1.7%]*
Maternal newborn and child care services					
Birth attendant coverage (%)					
Skilled attendance at birth (median)	100	98	70	54	42
[ARC SBA average]	*[0%]*	*[0.3%]*	*[1.7%]*	*[1.9%]*	*[2.5%]*
Traditional birth attendant (median)	–	13	15	28	45
Caesarean delivery (median coverage)	24	19	5	3	3
Neonatal intensive care with ventilator support	Full coverage	High coverage	Low coverage (e.g. teaching hospitals)	Very low coverage (e.g. capital city only)	Extremely low coverage and quality
	Very high quality	Moderate/high quality may be variable	Variable quality, but increasing survival and disabled survivors	Low quality	
Nurses and midwives per 10 000 population	664	291	195	57	20
(total number in level)	(7 802 500)	(6 970 700)	(1 757 700)	(1 670 300)	(52 400)
% of global total	*42.7%*	*38.2%*	*9.6%*	*9 %*	*0.3%*
Physicians per 10 000 population	312	139	35	15	7
(total number in level)	(3 120 400)	(4 429 300)	(549 700)	(1 008 400)	(14 200)
% of global total	*34.2%*	*48.6%*	*6.0%*	*11 %*	*0.2%*
Health system funding					
Government spending on health per capita (US$ median)	1794	212	37	14	8
Out-of-pocket expenditure on health as percentage of total expenditure on health (median %)	18%	31%	35%	42%	65%

(continued)

Table 3 Continued

	Category 1 Very low mortality NMR ≤5	Category 2 Low mortality 6 – 15	Category 3 Moderate mortality 16 – 30	Category 4 High mortality 31 – 45	Category 5 Very high mortality ≥45
Official development assistance (US$)					
To maternal/neonatal health per live birth (median with min/max range)		5.1 (0 – 22)	28.56 (5.4 – 427.8)	20.70 (5.00 – 96.1)	33.49 (14.8 – 53.00)
To child health per child (median with min/max range)		1.5 (0 – 10.3)	14.07 (1.27 – 151.53)	15.10 (1.80 – 51.40)	15.38 (12.70 – 17.10)
Value of MNCH official development assistance with reference to newborn health as % of total MNCH ODA (median)		4.9%	2%	2.3%	4%
# of countries		*8*	*30*	*26*	*5*

Data sources: State of the World's Children 2011 (UNICEF 2011), UN 2011 (UN 2011), WHO Global Atlas (WHO 2011a), WHO National Health Accounts (WHO 2011b), Pitt *et al*. (2010) with special analysis for supplement.

Note: Country groupings by level of NMR adapted from *The Lancet* Neonatal Series 2005 (Knippenberg *et al*. 2005) and adapted in 2009 (Lawn *et al*. 2009a). Abbreviations used: ARC = average annual rate change; MNCH = maternal, newborn and child health; NMR = Neonatal Mortality Rate; ODA = Official Development Assistance. Gross national income and government spending on health per capita in 2009 constant USD. Official development assistance in 2008 constant USD.

of under-five deaths take place in the neonatal period, but given their large populations, the value per birth is still very low. The amount of non-research ODA exclusively targeted at newborns in the priority countries was extremely low at $5.49m in 2009, but if newborn research funding, all of which was provided by the Bill & Melinda Gates Foundation in 2009, is included, this increases to $55.93 million (Pitt *et al*. 2012).

Implications

This is the first multi-country analysis of neonatal mortality reduction, highlighting global progress since 2000, while considering variation between regions and countries. Newborn survival interventions can be integrated with those for mothers and for children after the newborn period, but have received limited attention until very recently (Shiffman 2010). Since 1990, mortality rates during the first month of life (NMR) have declined at a slower pace compared with maternal deaths and deaths in children aged 1–59 months. Since 2000, NMR reduction globally has accelerated by 40%, compared with the 1990s (Hill *et al*. 2012), but still lags behind maternal and under-five survival gains. The rich–poor survival gap continues to widen as high-income countries have continued to reduce NMR rapidly at an average of 3% per year since 2000. However, in sub-Saharan Africa, the poorest region, the rate of reduction is still extremely slow despite slight improvement (1.5% from 2000 to 2010 compared with 0.6% from 1990 to 2000). Unless further accelerated, it will be over 150 years before African babies have the same chance of survival as those born in high-income countries (Oestergaard *et al*. 2011). Some low-income countries, such as Bangladesh, Nepal and Rwanda, have made dramatic progress in reducing the NMR by more than 30% in the last decade.

Our analysis here and the country case studies elsewhere in this supplement provide insights on the variation in progress achieved and underline priorities for improving data for future programme monitoring evaluation. The standard framework, tools and analyses used by an inclusive national review group to assess change in countries may be adapted for analysing progress in scaling up care for other health priorities, particularly those which involve service delivery packages and wider demand and supply system changes.

Understanding NMR change

The new cause of death trend analysis for the decade (Liu *et al*. 2012) gives useful insights on which causes, and potentially which linked programmes, have made most progress. The reduction in neonatal tetanus is most obvious with an average annual rate of reduction at a dramatic 9.5% per year (Liu *et al*. 2012). Neonatal infections that can be reduced through child health programmes are reducing noticeably. For example, diarrheoa reduced on average 4% per year and pneumonia reduced 2.2% per year. Neonatal sepsis shows less progress. Intrapartum-related neonatal deaths reduced at 2.4% per year, perhaps as a 'trickle down' from maternal health care investment as obstetric care has the highest impact on this cause. Additional benefit would be expected from systematically ensuring that neonatal resuscitation is available for all babies

Predictors (2000-2010)	Developed region	Sub-Saharan Africa	Other regions*
ARC of NMR average	**-3.00%**	**-1.50%**	**-3.20%**
ARC of gross national income	(1) -0.34		
ARC of general fertility rate	(2) -0.41		(1) 0.15
ARC of female literacy rate	(3) -3.80		
ARC of total health expenditure	(4) 0.11		
ARC of DTP3 vaccine coverage	(5) -1.35		
ARC of skilled birth attendance	(6) -2.19		(3) -0.0053
ARC of government effectiveness	(7) 0.026		
ARC of adolescent fertility rate	(8) 0.042		
NMR level 2000	(9) -0.00019	(2) 5.16×10^{-6}	(2) 0.00013
ARC of political stability	(10) 0.0046		
ARC of HIV prevalence in women 15-49	(11) -0.0038		
ARC of PAB	-12	(1) 0.043	

Figure 7 Ranking of predictors for their influence on ARC of NMR in the period 2000–2010, and estimated regression coefficients in the multiple linear regression model. *Note*: Empty cells indicate no influence when accounting for other predictors. Of the included predictors in each model fit, relative influence of each predictor on ARC of NMR 2000–2010 is indicated in parenthesis with most important predictor as (1). The estimated coefficients for the intercept in each of the models were: −0.027 for developed regions; −0.018 for sub-Saharan Africa; and −0.032 for other countries. Ranking of predictors is based on fitting the multiple linear regression model net model to standardized predictors. Estimated coefficients are from modelling on original scale of predictors. As the original scale varies between predictors one cannot assess relative influence from the value of the estimated coefficients. A positive regression coefficient for a predictor indicates that countries with larger positive values of the predictor tended to have experienced slower declines in NMR over the period. In contrast, a negative regression coefficient means that countries with large negative values of the predictor were more likely to experience a faster decline. ARC: annual rate of change. Millennium Development Goal regions available from http://mdgs.un.org/unsd/mdg/Host.aspx?Content=Data/RegionalGroupings.
*The group ''other regions'' includes from North Africa, Asia and Latin America and Caucasus and Central Asia.

who do not breathe at birth. Deaths due to preterm birth complications reduced at 2% per year (Liu *et al*. 2012) and addressing these deaths requires specific skills, such as for feeding support and Kangaroo Mother Care, and at least some basic commodities. Indeed, it was the care of preterm babies that prompted the development of neonatology in high-income countries. Based on a Lives Saved Tool (LiST) analysis, major mortality reduction could be achieved before adding neonatal intensive care through high coverage (95%) of antenatal corticosteroids (almost 400 000 lives saved in 2015) and Kangaroo Mother Care (450 000 lives saved in 2015) (March of Dimes *et al*. 2012). Over the last decade, the main message for global newborn care has been to integrate within existing service delivery packages (Figure 1). However, to accelerate progress for preterm deaths, there is an urgent need to transit to more specialized newborn care, particularly in countries where the NMR is reducing towards 15 per 1000, the mortality level when neonatal intensive care came into play in high-income countries (March of Dimes *et al*. 2012).

Our three regional multiple linear regression models suggest that the last decade's reduction in NMR globally has differed by region. For all three regional models, the progress in reducing NMR seen in the last decade is associated with a country's NMR level at baseline. *The Lancet* Neonatal Series used NMR level to categorize countries, and the analysis presented in this paper (Table 3), with more data and countries, supports the value of using baseline NMR as a guide for prioritizing and phasing newborn care interventions. However, the association of NMR level and countries' progress for neonatal survival over time manifests differently around the world. For high-income countries, a relatively high NMR in 2000 allowed scope for rapid change, which in many cases was realised. For low-income countries, a high NMR in 2000 was associated with least change, especially in sub-Saharan Africa. Those countries with the highest NMRs may have challenges outside and/or within the health system and are also likely to have limited focus on scale up of neonatal survival interventions in these contexts. In Asia, Latin America and the Middle East, fertility reduction was more strongly associated with rapid NMR reduction.

The limited coverage data available were not strongly predictive in the model and indeed did not change much over the decade. Skilled attendance alone, as it is currently defined, is poorly predictive and this may be because saving lives, especially of babies who can die within minutes, depends on providers being equipped, skilled and supported, instead of merely present at birth. The main implication is that the progress to date for NMR reduction across all these countries cannot currently be attributed to a major increase in scale up of a key package, such as postnatal care, or a complex intervention, such as neonatal resuscitation. From the limited countries with some coverage or process data (most of which had more attention for newborn survival), we know these interventions are only starting to be scaled up (Khan *et al*. 2012; Mbonye *et al*. 2012; Pradhan *et al*. 2012; Rubayet *et al*. 2012; Zimba *et al*. 2012).

Tracking financial resources for newborn programmes in countries

Donor resources for MNCH have increased dramatically over the last decade, but there is no standard, national level information on government resources specifically for MNCH, let alone newborns. Donor funds are not the main recurrent inputs for health expenditure in most countries. Annual assessment of reproductive and MNCH government funding has been recommended as a measure of accountability (Hsu *et al*. 2011).

Despite a doubling of ODA for MNCH between 2003 and 2008 and increasing relative attention to newborns within funding

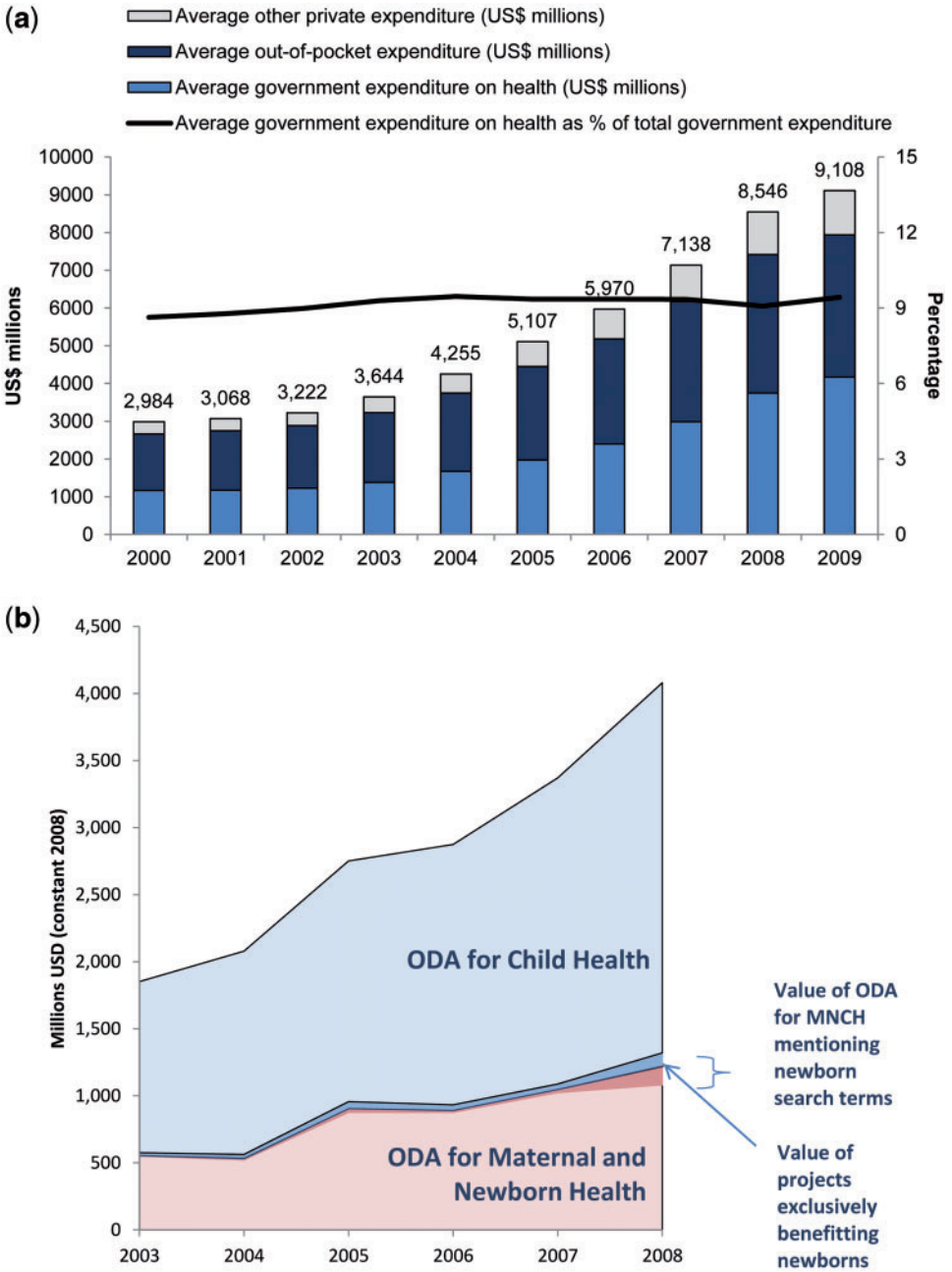


Figure 8 Changes in financial resources related to newborn survival, 2000–2009
(**a**) Average total health expenditure in Countdown priority countries 2000–2009 by government, out-of-pocket, and other private expenditure, (constant 2008 USD). *Data source*: World Health Organization National Health Accounts. *Note*: 69 countries included. Out of 75 Countdown priority countries the following countries were excluded due to missing data: Afghanistan, DPR Korea, Liberia, Somalia and Zimbabwe. South Sudan data included with Sudan. (**b**) Changes in newborn-related official development assistance (ODA) for maternal, newborn and child health (MNCH) for 68 Countdown to 2015 priority countries, 2003–2008 (constant 2008 USD) *Data source*: Data from Pitt *et al*. (2012). *Note*: Countdown to 2015 priority countries included with exception of countries added in 2011: Comoros, Kyrgyzstan, Solomon Islands, Sao Tome and Principe, Uzbekistan and Vietnam. South Sudan data included with Sudan.

descriptions, activities that benefit newborns specifically were only mentioned in a small fraction of donor funding for MNCH, and funding for newborns came from a very limited number of donors. USAID contributed the largest amount of funding that mentioned newborns, which was double the value of the next largest donor, The World Bank. A limitation of any analysis of the OECD databases is the varying quality of description of disbursements, which may result in the data not fully reflecting

the content of all donor programmes. Tracking of newborn-related and newborn-specific donor funding is feasible, and we believe is a useful quantitative marker of accountability (Pitt *et al*. 2012). Tracking government funding for MNCH is at least as important and remains a gap.

Considerably more investment and effort is required to accelerate scale up of evidence-based newborn care, to adjust interventions and packages to account for context, and to support the development of strong primary health care infrastructure, such as supported and trained community-level workers linked with functioning primary and referral level facilities. Engagement with the private sector or alternative financing models has received limited systematic attention to date.

Limitations in the data and analyses

This retrospective analysis aiming to understand progress across regions and countries for newborn survival faced the major challenge of limited national data, particularly most newborn survival interventions. For example, data are available for postnatal care for women in 22 countries, but only four countries report postnatal care for the baby with all-births as the denominator (Requejo *et al*. 2012). Coverage data on Kangaroo Mother Care are not routinely collected in household and facility-based surveys, or even routine health information systems. Some interventions that save the lives of mothers and children are also those that will impact newborn survival (e.g. skilled attendance at birth, breastfeeding) and more of those interventions have national trend data. However, some covariates of interest, such as caesarean section rates, have limited time series data for all countries and cannot be examined as covariates. Even where data exist, they may not always be disaggregated to reveal the care accessed by the poorest or most vulnerable populations, or by gender.

Our analysis of inter-country covariates of NMR reduction does not identify causal relationships between covariates and NMR trends; instead it seeks to understand the predictors of variation between countries' NMR reduction. Rigorous evaluation of change at scale in varying contexts is a high priority.

Changes over the last decade for newborn survival data

One of the key reasons for increasing attention to newborn survival has been the increased visibility arising from improved data, its interpretation for policy and programmes and the linkage with MDG 4, and also now with the UN's *Every Woman Every Child* strategy (Ban 2010). Before 2005, there were no regular NMR estimates, no published detailed methodology and NMR was not shown in key UN reports. Now there are credible estimates, inclusion in annual UN reports (Bryce and Requejo 2010; UNICEF 2011; WHO 2011c; Requejo *et al*. 2012) and time series for NMR (Oestergaard *et al*. 2011), and for early NMR (Lozano *et al*. 2011). In addition, stillbirth rates are now also reported (Cousens *et al*. 2011) (Table 1).

Programmatically relevant and technically credible cause of death estimates were a critical step in attention for millions of neonatal deaths and linking causes to programmatic solutions (Figure 5). Important gaps remain for counting deaths, improving vital statistics and cause of death data (Setel *et al*. 2007). While improvements in global, regional and national level estimation methods are welcome, better real-time data that can be used for decision making and programme planning is a long-term goal (The *PLoS Medicine* Editors 2010). Approaches to use data for action have been helpful; examples include the cause of death figures on the Countdown to 2015 profiles (Requejo *et al*. 2012) and national and sub-national situation analyses (Ministry of Health 2008; Federal Ministry of Health 2011; Manji 2009).

Coverage, quality and equity information gaps are especially critical in planning and tracking services. Inter-agency efforts are underway to improve measurement of intervention coverage and behaviours and will be addressed through large-scale surveys and national health information systems. Measurement improvements for the quality and availability of newborn care interventions have been improved, such as adding questions in facility assessment tools on the availability and quality of newborn-specific services and commodities, and assessing existing services against agreed standards for newborn care (Measure DHS 2011; Mbonye *et al*. 2012). Tracking policy change and benchmarks with wide country consensus are critical for advancing newborn survival on national agendas. However, as long as feedback mechanisms, such as improved tracking of coverage data, do not exist to raise the profile or maintain attention for newborns along with their mothers, progress to establish enabling policies and deliver programmes to address the causes of their deaths will continue to be tenuous (Shiffman 2010).

Conclusion

Given the relatively recent attention for neonatal survival, and the limited investment in countries with the highest numbers of deaths, it is not surprising that progress for reducing neonatal deaths is slower than for mortality amongst children aged 1–59 months and for maternal mortality. Inputs, including donor funding, have increased since 2005, but are not commensurate with the burden. Preterm birth is increasingly dominant as both a direct and an indirect cause of death and now the second leading cause of under-five child deaths. The global public health community urgently needs to respond to this challenge. Research in several regions has shown encouraging results through both community and facility-based initiatives.

Improvements in frequency and visibility of estimates for neonatal mortality and causes of death may have helped gain attention. Data gaps for morbidity, coverage of care and quality of services remain critical constraints to planning programmes and tracking progress, and to the wider economic benefits and effects of newborn survival. However, data improvements alone do not save lives—health system and coverage change are crucial. Findings from this supplement, particularly the country case studies, have the potential to inform context-specific, accelerated progress for newborn survival (Khan *et al*. 2012; Mbonye *et al*. 2012; Pradhan *et al*. 2012; Rubayet *et al*. 2012; Zimba *et al*. 2012).

The rapid progress for some countries shows that NMR can be halved within a decade. The countries with the most progress include mainly high- and middle-income countries; yet there are a few notable low-income country exceptions, such as

Bangladesh (Rubayet *et al*. 2012) and Nepal (Pradhan *et al*. 2012) that have both reduced by double the global average. Increased global and national attention to effective scale up of neonatal care in the highest burden countries would save many lives. Without major increased focus on the implementation of high impact newborn care, linked to MNCH programmes and investments, newborn mortality will be the most significant child survival challenge after the MDG target data in 2015 and the survival gap between babies born in the richest and the poorest countries will continue to increase.

Supplementary Data

Supplementary data are available at *Health Policy and Planning* Online.

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Conflict of interest

None declared.

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