Quality of care and access to care at birth in low- and middle-income countries

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ACADEMIC DISSERTATION

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To my family

TABLE OF CONTENTS

List of abbreviations **6**

List of mortality definitions **8**

Abstract **9**

Summary in Finnish **11**

List of original publications **13**

1 INTRODUCTION **14**

2 REVIEW OF THE LITERATURE **17**
2.1 Early neonatal mortality **17**
2.1.1 Definition, distribution and causes 17
2.1.2 Factors affecting child survival 18
2.2 Quality of care at birth **19**
2.2.1 Definition of quality of care 19
2.2.2 Indicators of quality 21
2.2.3 Factors affecting quality 22
2.2.4 Structure 24
2.2.5 Processes 27
2.2.6 Outcomes 34
2.2.7 Facility delivery and early neonatal mortality 34
2.3 Access to care at birth **37**
2.3.1 Definition of access 37
2.3.2 Factors affecting access 37
2.3.3 Measuring geographic access 38
2.3.4 Distance to care at birth and early neonatal mortality 39
2.3.5 Measuring socioeconomic inequalities in access to care 43
2.3.6 Socioeconomic position and early neonatal mortality 46
2.4 Summary of the literature review **51**

3 AIMS OF THE STUDY **53**

4 METHODS **54**
4.1 Ethical considerations **54**
4.2 Quality of care at birth in Brong Ahafo region, Ghana **54**
4.2.1 Brong Ahafo region 54
4.2.2 Health Facility Assessment 55
4.2.3 Participants 56
4.2.4 Newhints trial surveillance 57
4.2.5 Analysis of quality of care in four dimensions 58
4.2.6 Analysis of health provider competence 62

4.3 Distance to care at birth in rural Malawi and Zambia 65
4.3.1 Malawi 65
4.3.2 Zambia 65
4.3.3 Malawi and Zambia Health Facility Censuses 65
4.3.4 Demographic and Health Surveys 65
4.3.5 Participants 66
4.3.6 Distance measurement 67
4.3.7 Classification of facilities 67
4.3.8 Analysis 69
4.4 Socioeconomic inequalities at birth in 72 countries 70
4.4.1 Low- and middle-income countries 70
4.4.2 Data and participants 72
4.4.3 Analysis 72

5 RESULTS 75
5.1 Quality of care at birth in Brong Ahafo region, Ghana 75
5.1.1 Quality in four dimensions 75
5.1.2 Competence of health professionals 78
5.2 Distance to care at birth in rural Malawi and Zambia 83
5.2.1 Association with early neonatal mortality and facility delivery 83
5.2.2 Facility delivery in the cluster and early neonatal mortality ... 86
5.3 Socioeconomic inequalities at birth in 72 countries 88
5.3.1 Inequalities in early neonatal mortality 88
5.3.2 Inequalities in postneonatal infant mortality 88
5.3.3 Inequalities in facility delivery 88
5.3.4 Facility delivery in the cluster and early neonatal mortality ... 90
5.3.5 Sensitivity analyses 90

6 DISCUSSION 97
6.1 Summary of main findings 97
6.2 Strengths and limitations 99
6.3 Quality of care at birth 104
6.4 Access to care at birth 107
6.5 Implications for future research and policy 111

7 CONCLUSIONS 119

Acknowledgements 121

References 123

Original publications 141

LIST OF ABBREVIATIONS

AMDD	Averting Maternal Death and Disability
ANC	Antenatal care
BEmO(N)C	Basic Emergency Obstetric (and Newborn) Care
CS	Caesarean section
CEmO(N)C	Comprehensive Emergency Obstetric (and Newborn) Care
CI	Confidence interval
CIA	Central Intelligence Agency
COPE®	Client Oriented, Provider Efficiency
CSTS+	Child Survival Technical Support Project
DHS	Demographic and Health Survey(s)
EmNC	Emergency Newborn Care
EmO(N)C	Emergency Obstetric (and Newborn) Care
ENAP	Every Newborn Action Plan
END	Early neonatal death
FASQ	Facility Audit of Service Quality
GPS	Global positioning system
HFA	Health facility assessment
HFC	Health Facility Census
ICM	The International Confederation of Midwives
JICA	Japan International Cooperation Agency
KHRC	Kintampo Health Research Centre
KMC	Kangaroo Mother Care
LMIC	Low- and middle-income country
MDG	Millennium Development Goal
MEASURE	Monitoring and Evaluation to Assess and Use Results
OR	Odds ratio
PMTCT	Prevention of mother-to-child transmission of HIV
PROM	Premature Rupture of Membranes
Q	Wealth quintile
R-HFA	Rapid Health Facility Assessment
RII	Relative Index of Inequality
RR	Risk ratio
SAM	Service Availability Mapping
SARA	Service Availability and Readiness Assessment
SBA	Skilled birth attendant

SDG	Sustainable Development Goal
SII	The Slope Index of Inequality
SPA	Service Provision Assessment
UN	United Nations
UNFPA	United Nations Population Fund
UNICEF	United Nations International Children's Emergency Fund
UTM	Universal Transverse Mercator
WHO	World Health Organization
WHR	World Health Report
WGS 1984	World Geodetic System 1984

LIST OF MORTALITY DEFINITIONS

In the literature and in this thesis, the term 'mortality rate' refers to *deaths per population per year*, although in strict epidemiological terms this definition is a risk, rather than a rate.

Early neonatal death: Death within the first seven days of life. Mortality rate is expressed as deaths per 1,000 live births per year.

Late neonatal death: Death within the first 28 days of life, excluding early neonatal deaths. Mortality rate is expressed as deaths per 1,000 live births per year.

Neonatal death: Death within the first 28 days of life. Mortality rate is expressed as deaths per 1,000 live births per year.

Stillbirth: Death of a baby at or after 28 weeks of gestation (i.e. late foetal death or third trimester stillbirth). Stillbirth rate is expressed as deaths per 1,000 births per year.

Perinatal death: Stillbirths and early neonatal deaths. Mortality rate is expressed as deaths per 1,000 births per year.

Infant death: Death within the first year of life. Mortality rate is expressed as deaths per 1,000 live births per year.

Postneonatal infant death: Death within the first year, excluding neonatal deaths (i.e. death between day 28 and 1 year). Mortality rate is expressed as deaths per 1,000 live births per year.

Under-five child death: Death within the first five years of life. Mortality rate is expressed as deaths per 1,000 live births per year.

Maternal death: Mother's death during pregnancy or within 42 days of delivery due any cause related to or aggravated by the pregnancy or its management. Mortality ratio is expressed as deaths per 100,000 live births per year.

ABSTRACT

Background

Over two million newborns die at birth or during their first week of life every year. Globally, deaths during this early neonatal period account for more than a third of all mortality among children under five years and occur mainly in low- and middle-income countries (LMICs). The majority of these deaths could be prevented with high-quality care at birth.

Aims

This thesis studies the determinants of early neonatal mortality in low- and middle-income countries, focusing on quality of care and on geographic and socioeconomic inequalities in access to care at birth. Furthermore, the aim was to elucidate whether birth in a facility improves survival of the newborn.

Main methods

Quality of emergency obstetric and newborn care, routine care and non-medical care were studied through a health facility assessment in seven districts of Brong Ahafo region in Ghana. In addition, clinical vignettes describing pre-eclampsia and ante-partum haemorrhage were used to assess competence of health professionals in managing obstetric emergencies. To study coverage of high-quality care and delivery workload in health facilities in the area, surveillance data collected in the context of two clinical trials were linked with the quality classification of health facilities.

To investigate whether and to what extent birth in a health facility improves newborn survival, the effects of two distal determinants (distance to a health facility and socioeconomic inequalities) on early neonatal mortality and on facility delivery were studied; Distance effects were studied using Demographic and Health Survey (DHS) data from rural Malawi and Zambia and Health Facility Census data from both countries. Socioeconomic inequalities were quantified using DHS data on 679,818 live births from 72 low- and middle-income countries with high mortality burdens.

Findings

Hospitals and large health centres provided the highest quality of care in all four dimensions of care, managed the most patients and employed the most competent staff among the 64 delivery facilities in Brong Ahafo region of Ghana. Quality of care was poor in the smallest facilities and they were unlikely to improve health outcomes. Although coverage of facility delivery was fairly high at 68%, coverage of high-quality care at birth was only 18% indicating a large quality gap.

Doctors, midwives and nurses working in larger health facilities that provided emergency obstetric care (EmOC), such as hospitals and health centres, achieved higher scores than health workers in low-volume facilities that did not provide EmOC. Lack of health provider competence may have limited emergency care more than shortages of necessary drugs and equipment for management of these emergencies. Higher average workload in health facilities was associated with higher respondent competence in the vignettes, suggesting delivery workload needs to be sufficiently high to maintain competence.

Although distance to a health facility was a strong barrier to delivery care in rural Malawi and Zambia, proximity to a delivery facility or higher level of care at the closest delivery facility were not associated with lower early neonatal mortality. Similarly, while socioeconomic inequalities in coverage of delivery care were found to be large in the 72 countries studied, inequalities in early neonatal mortality by wealth and education were small in most countries and compared with inequalities in facility delivery and postneonatal infant mortality.

Conclusions

This thesis studied quality of care at birth at three levels (facility level, country level and multicountry level) and in three dimensions (structure, processes and outcomes). The findings of this thesis point to insufficient quality of care at birth in the seven districts of Brong Ahafo region in Ghana, in Malawi and Zambia and in the 72 DHS countries. Early neonatal mortality remains a global health problem that has not been solved by increasing coverage with institutional deliveries. Improving quality of care rather than increasing coverage should be prioritized in the future.

SUMMARY IN FINNISH

Tausta ja tavoitteet

Maailmassa kuolee vuosittain yli kaksi miljoonaa lasta synnytyksen tai ensimmäisen elinviikon aikana. Kuolleisuus on suurinta matalan tulotason ja keskitulotason maissa. Suurin osa varhaisen vastasyntyneisyyskauden kuolemista voitaisiin kuitenkin estää, jos synnytyksen hoito olisi korkealaatuista.

Väitöskirjassa tutkittiin synnytyksen hoidon laatua ja saatavuutta Ghanan maaseudulla, Malawissa ja Sambiassa sekä laajassa 72 matalan ja keskitulotason maata kattavassa analyysissä. Väitöskirjassa verrattiin sosioekonomisia ja maantieteellisiä eroja hoidon saatavuudessa ja varhaisessa vastasyntyneisyyskuolleisuudessa. Tavoitteena oli arvioida, pelastaako synnytyksen hoito synnytyssairaalassa vastasyntyneiden henkiä.

Menetelmät

Synnytyksen hoidon laatua tutkittiin 64 synnytyssairaalassa Brong Ahafon alueella Ghanassa. Tietoa kerättiin hoitovälineistä, lääkkeistä ja keskeisistä synnytyksen hoitoon liittyvistä hätätoimenpiteistä. Lisäksi kunkin synnytyssairaalan kokeneimman terveydenhuollon ammattilaisen osaamista hoitaa synnytykseen liittyviä hätätilanteita testattiin potilastapausten avulla. Alueen synnytysten jakautumista synnytyssairaaloiden kesken arvioitiin koko alueen synnytykset kattavaa seuranta-aineistoa käyttäen.

Maantieteellisen etäisyyden, hoidon laadun ja varhaisen vastasyntyneisyyskuolleisuuden yhteyttä tutkittiin Malawissa ja Sambiassa hyödyntämällä maiden maaseudulta kerättyjä Demographic and Health Survey (DHS) -poikkileikkausaineistoja ja synnytyssairaaloista kerättyjä Health Facility Census -aineistoja. Sosioekonomisia eroja varhaisessa vastasyntyneisyyskuolleisuudessa, vastasyntyneisyyskauden jälkeisessä imeväiskuolleisuudessa ja synnytyksen hoidon saatavuudessa tutkittiin 72 maan DHS-aineistoissa, joissa oli mukana yhteensä 679 818 syntymää.

Tulokset

Synnytysten hoidon laadun todettiin olevan matala kaikilla hoidon neljällä osa-alueella eli perushoidossa, synnyttäjän ja vastasyntyneen hätätilanteiden hoidossa sekä ei-lääketieteellisessä hoidossa. Ilmiö korostui erityisesti tutkimukseen

osallistuneissa pienissä synnytyssairaaloissa Brong Ahafon alueella. Vaikka yli kaksi kolmasosaa alueen lapsista syntyi synnytyssairaaloissa, vain alle viidennes heistä syntyi korkealaatuista hoitoa tarjoavissa sairaaloissa.

Lääkärit, kätilöt ja hoitajat sekä suurissa, hyvälaatuisissa synnytyssairaaloissa työskentelevät terveydenhuollon ammattilaiset saivat korkeammat pisteet hätätilanteiden hoidon osaamista kartoittavissa potilastapauksissa kuin pienissä ja huonolaatuisissa sairaaloissa työskentelevät henkilöt. Puutteet henkilökunnan osaamisessa saattoivatkin rajoittaa synnytysten hätätilanteiden hoitoa enemmän kuin puutteet hoitovälineiden tai lääkkeiden saatavuudessa.

Lyhyt maantieteellinen etäisyys kotoa synnytyssairaalaan lisäsi laitossynnytyksen todennäköisyyttä Malawissa ja Sambiassa. Lyhyempi etäisyys tai parempi hoidon laatu eivät kuitenkaan vähentäneet varhaista vastasyntyneisyyskuolleisuutta. Tulokset viittaavat siihen, etteivät synnytyssairaalat kyenneet pelastamaan maaseudun vastasyntyneiden henkiä Malawissa tai Sambiassa.

Analyysit koskien 72 matalan tulotason ja keskitulotason maata osoittivat, että varakkaat ja koulutetut naiset synnyttivät suurelta osin synnytyssairaaloissa, mutta varattomat ja kouluttamattomat synnyttivät useimmiten kotona. Sosioekonomiset erot varhaisessa vastasyntyneisyyskuolleisuudessa olivat pieniä useimmissa maissa ja verrattuna eroihin synnytyksen hoidon saatavuudessa ja vastasyntyneisyyskauden jälkeisessä imeväiskuolleisuudessa. Syntymä sairaalassa ei siis useimmiten parantanut vastasyntyneen ennustetta kotona syntyneeseen lapseen verrattuna.

<u>Johtopäätökset</u>

Synnytyksen hoidon laatu oli puutteellista valtaosassa tutkimukseen osallistuneista synnytyssairaaloista Brong Ahafon alueella Ghanassa, Malawissa ja Sambiassa sekä useassa matalan tulotason ja keskitulotason maassa. Varhainen vastasyntyneisyyskuolleisuus on maailmanlaajuinen ongelma, jota synnytyssairaaloiden ja laitossynnytysten määrän lisääminen ei ole valitettavasti ratkaissut. Tämän vuoksi maiden, joissa on korkea vastasyntyneiden kuolleisuus, tulisi laitossynnytysten määrän lisäämisen sijaan keskittyä synnytysten hoidon laadun varmistamiseen ja parantamiseen.

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications (studies I–IV), and some unpublished material.

I. Nesbitt R.C., **Lohela T.J.**, Manu A., Vesel L., Okyere E., Edmond K., Owusu-Agyei S., Kirkwood B.R., Gabrysch S. (2013) Quality along the continuum: a health facility assessment of intrapartum and postnatal care in Ghana. *PLoS One* 8, e81089.

II. **Lohela T.J.**, Nesbitt R.C., Manu A., Vesel L., Okyere E., Kirkwood B.R., Gabrysch S. (2016) Competence of health workers in emergency obstetric care: an assessment using clinical vignettes in Brong Ahafo region, Ghana. *BMJ Open* 6, e010963.

III. **Lohela T.J.**, Campbell O.M., Gabrysch S. (2012) Distance to care, facility delivery and early neonatal mortality in Malawi and Zambia. *PLoS One* 7, e52110.

IV. **Lohela T.J.**, Nesbitt R.C., Pekkanen J.R., Gabrysch S. Comparing socioeconomic inequalities between early neonatal mortality and facility delivery: Cross-sectional data from 72 low- and middle-income countries. (*submitted for publication*)

1 INTRODUCTION

The United Nations' (UN) Millennium Declaration in 2000 set out an unparalleled international effort to achieve eight time-bound and measurable goals for poverty reduction and development by 2015 (UN, 2015). These goals are known as the Millennium Development Goals (MDGs) (Table 1). Each goal had specific measurable targets and indicators, and progress was monitored and reported regularly, addressing each goal and target separately at global, regional and country levels.

Table 1. The Millennium Development Goals (UN, 2015).
Goal 1. Eradicate extreme poverty and hunger
Goal 2. Achieve universal primary education
Goal 3. Promote gender equality and empower women
Goal 4. Reduce child mortality
Goal 5. Improve maternal health
Goal 6. Combat HIV/AIDS, malaria and other diseases
Goal 7. Ensure environmental sustainability
Goal 8. Develop a global partnership for development

The Millennium Development Goals Report of 2015 called the MDGs 'the most successful anti-poverty movement in history' stating that one billion people were lifted out of poverty, millions of lives were saved and many more improved during the MDG era (UN, 2015). For example, globally, the maternal mortality ratio (MDG 5) declined by 45% from 380 deaths to 210 per 100,000 live births and mortality among children under five years old (MDG 4) reduced from 12.7 million to 6 million child deaths (UN, 2015). Despite the progress in reducing child and maternal mortalities, the MDGs 4 or 5 were not achieved globally (Table 2) (UN, 2015).

Table 2. The Millennium Development Goals (MDGs) 4 and 5 with their respective targets and progress indicators (UN, 2015).		
MDG	**Target**	**Progress indicator**
4. Reduce child mortality	A. Reduce by two thirds, between 1990 and 2015, the under-five mortality rate.	4.1 Under-five mortality rate 4.2 Infant mortality rate 4.3 Proportion of 1-year old children immunized against measles
5. Improve maternal health	A. Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio. B. Achieve, by 2015, universal access to reproductive health.	5.1 Maternal mortality ratio 5.2 Proportion of births attended by skilled health personnel

One major reason for MDG 4 not being reached was the high number of neonatal deaths (0 to 27 days) that did not decline nearly as much as later child mortality (UN, 2015). In consequence, the proportion of neonatal deaths among under-five child mortality rose from 40 to 45% between 2000 and 2015 (Unicef, 2016) and international attention turned to improving neonatal survival (Shiffman, 2010). Newborns are specifically addressed in the only health-related goal of the Sustainable Development Goals (SDGs) that succeeded the MDGs in 2015 (UN, 2017). The SDG 3 targets are to reduce neonatal mortality to no more than 12 deaths per 1,000 live births and under-five child mortality to no more than 25 deaths per 1,000 live births by 2030 (Table 3) (UN, 2017).

Every year, approximately one million babies die on the day of their birth, mainly in low- and middle-income countries (LMICs) (Baqui et al., 2016; Lawn et al., 2014). High-quality care at birth is generally considered the main intervention to reducing deaths related to childbirth and requires that women in labour have access to skilled birth attendants (SBAs) (Bhutta et al., 2014; Campbell et al., 2016; WHO et al., 2004).

Skilled birth attendant refers to a health professional with midwifery skills who can manage a normal delivery and diagnose and treat or refer complications further (World Health Organization [WHO et al., 1999]). Although today three out of four deliveries are managed by skilled attendants in health facilities (United Nations Children's Fund [Unicef, 2016]), early neonatal mortality has not been declining at the expected rate likely due to poor quality of care at birth (Campbell et al., 2016). The studies presented in this thesis were conducted to understand determinants of early neonatal mortality in LMICs, with particular emphasis on quality of care and geographic and socioeconomic access to care at birth.

I will first review the relevant literature regarding the epidemiology of early neonatal mortality, quality of care and access to care at birth. The thesis will then be divided into two parts. The first part will focus on quality of care at birth in seven districts of rural Brong Ahafo region in Ghana. The second part of the thesis studies the associations between access to care at birth (geographic and socioeconomic), facility use for delivery and early neonatal mortality. Geographic access to care at birth will be studied using data from rural Malawi and Zambia while socioeconomic inequalities in access and early neonatal mortality are quantified using data from 72 low- and middle-income countries.

Table 3. Sustainable Development Goal 3 (SDG 3) with its targets and progress indicators related to maternal and child health (UN, 2017).

SDG 3	Target	Progress indicator
Good Health and Well-Being: Ensure healthy lives and promote well-being for all at all ages	3.1 By 2030, reduce the global maternal mortality to less than 70 per 100,000 live births.	3.1.1 Maternal mortality ratio 3.1.2 Proportion of births attended by skilled health personnel
	3.2 By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-five mortality to at least as low as 25 per 1,000 live births.	3.2.1 Under-five mortality rate 3.2.2 Neonatal mortality rate

2 REVIEW OF THE LITERATURE

2.1 Early neonatal mortality

2.1.1 Definition, distribution and causes

Early neonatal mortality refers to deaths at childbirth and during the first week of life (0 to 6 days). Every year, over two million newborns die during the early neonatal period accounting for three quarters of global neonatal mortality (0 to 27 days) and over a third of mortality among children under five years old (i.e. under-five child mortality) (Wang et al., 2016).

Nearly all neonatal deaths occur in LMICs, with the highest numbers in sub-Saharan Africa and South Asia (Figure 1). Countries with highest early neonatal mortality rates (deaths per 1,000 live births) are in sub-Saharan Africa with mortality rates exceeding 40 neonatal deaths per 1,000 live births (Lawn et al., 2014). In contrast, mortality rates and absolute numbers are very low in high-income countries, where there are also fewer births. For example, Finland with 59,000 births in 2015 had one of the lowest rates of neonatal mortality in the world (1 per 1,000 live births) (Unicef, 2016).

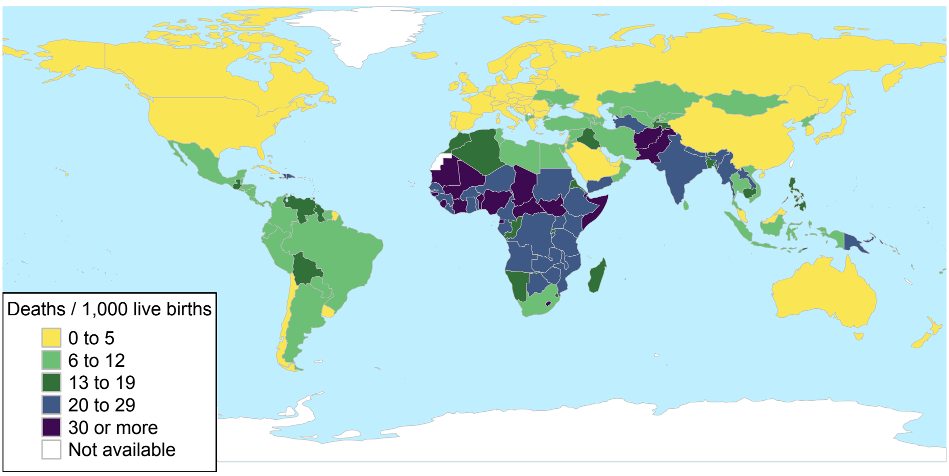

Figure 1. Global distribution of neonatal deaths. This map was created using the World Bank 2017 neonatal mortality estimates (World Bank, 2018) and the R package rworldmap (South, 2011).

While infections cause the majority of late neonatal deaths (7 to 27 days) and postneonatal infant deaths (28 days to 1 year) (Lawn et al., 2014; Liu et al., 2015; Oza et al., 2015; Sankar et al., 2016; Wang et al., 2016), early neonatal deaths are mainly caused by prematurity or intrapartum-related events, such as birth trauma or asphyxia (Figure 2) (Lawn et al., 2014; Oza et al., 2015). Effective care at birth is identified as a key intervention to reducing early neonatal deaths (Black et al., 2016; Campbell et al., 2016). In addition, 300,000 maternal deaths and 1.3 million intrapartum stillbirths could be reduced with high-quality care during labour and immediate postpartum period (Lawn et al., 2014; Lawn et al., 2016).

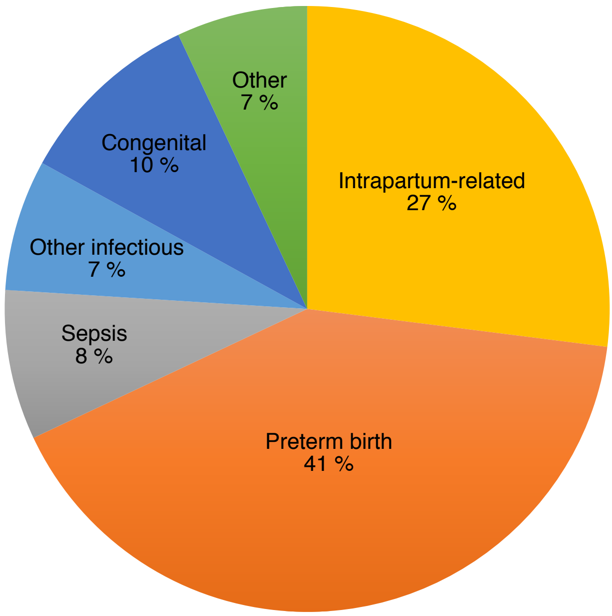

Figure 2. Causes of early neonatal mortality, adapted from Lawn et al. (2014).

2.1.2 Factors affecting child survival

In 1984 Henry Mosley and Lincoln Chen proposed an analytical framework for studying child survival in LMICs (Figure 3). According to this framework, child survival depends on distal determinants that work through proximal determinants to influence sickness, health and survival. The distal determinants refer to socioeconomic factors and the proximal determinants are biological causes of disease and mortality. The model highlights that all socioeconomic factors work through biological routes, and that sickness and health often have a socioeconomic background that is linked to the biological cause (Mosley & Chen, 1984).

In their model, Mosley and Chen (1984) described three levels of distal socioeconomic determinants: individual level (such as education, productivity, traditions, norms and attitudes), household level (such as household wealth) and community level (such as ecological factors and health system). These socioeconomic variables are thought to influence child morbidity and mortality through five proximal determinants i.e. maternal factors, environment, nutrition, injury and personal illness control that influences health through prevention and treatment of diseases (Mosley & Chen, 1984). Out of the determinants of child survival portrayed in the framework, the focus of this thesis is on distal determinants through geographic access and quality of care at birth.

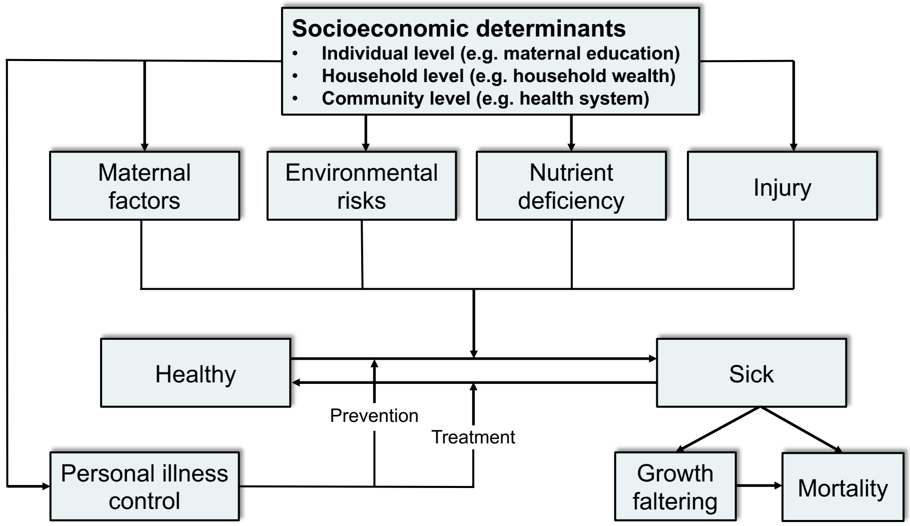

Figure 3. Analytical framework of child survival, adapted from Mosley & Chen (1984).

2.2 Quality of care at birth

2.2.1 Definition of quality of care

Quality of care is a multidimensional concept without a universally accepted definition (Pittrof et al., 2002; Raven et al., 2012). While the first definitions of quality of care emphasized biomedical care and outcomes, the more recent ones additionally include different aspects of quality, such as patient and provider satisfaction, values, emotional and cultural dimensions, equity, resource use and performance according to standards (Raven et al., 2012).

WHO defines quality of care for all patients based on the Institute of Medicine's definition (2001) as 'the extent to which health care services provided to individuals and patient populations improve desired health outcomes' (Tuncalp et al., 2015). In order to achieve this, health care must include the following six dimensions (WHO, 2006a):

1) Safety: Care minimises harm and risks to service users.
2) Effectiveness: Care is based on need and evidence and results in improved health outcomes for individuals and communities.
3) Accessibility: Care is timely, geographically accessible and provided in an environment where skills and resources meet medical needs.
4) Efficiency: Care maximises resource use and minimises waste.
5) Equity: Quality of care is unaffected by personal characteristics, such as gender or race.
6) People-centredness: The preferences of individual service users and their cultural context is taken into account.

It has been suggested that maternity care requires its own quality definition due to its unique nature and many of these definitions underline the importance of patient satisfaction (EngenderHealth, 2003; Hulton et al., 2000; Pittrof et al., 2002). In their definition of quality of maternity care, Hulton et al. (2000) emphasize the importance of reproductive rights. EngenderHealth (EngenderHealth, 2003) lists seven client rights and four provider needs in their COPE® (Client Oriented, Provider Efficiency) quality improvement tool.

The definition by Pittrof et al. (2002) specifically mentions newborn babies: 'High quality of care maternity services involves providing a minimum level of care to all pregnant women and their newborn babies and a higher level to those who need it. This should be done while obtaining the best possible medical outcome, and while providing care that satisfies women and their families and their care providers. Such care should maintain sound managerial and financial performance and develop existing services in order to raise the standards of care provided to all women.' In addition, Pittroff et al. list four elements that differentiate maternity care from other fields of health care (Table 4).

Table 4. Elements of quality of maternity care according to Pittrof et al. (2002).
• Over-medicalisation is a risk and should be avoided as it may lead to iatrogenic complications and waste of resources.
• Providers must be cautious not to undertreat mothers and babies as life-threatening conditions that need higher level of care may develop.
• There are at least two recipients of care (the mother and the baby) and risks and benefits of care for each should be evaluated and counterbalanced.
• Cultural and emotional aspects might be more important in maternity care compared with other fields of health care.

2.2.2 Indicators of quality

Health indicators are quantitative variables that can be used to measure health of a population. Global health indicators can be divided into socioeconomic (distal) and health (proximal) determinants, such as disease or deaths, as is done in the framework for child survival by Mosley and Chen (1984)(2.1.2 and Figure 3). As low- and middle-income countries are frequently devoid of vital registries and health information systems, many countries have adopted alternative and inexpensive data collection systems, such as household surveys, surveillance systems and verbal autopsies.

Due to limited resources in these contexts, it is necessary to choose few health indicators and measure them carefully (Larson & Mercer, 2004). While numerous criteria for a good health indicator have been listed in the literature, the following aspects are most often included and have been listed as selection criteria for a global health indicator (Larson & Mercer, 2004; WHO, 2018):

- Definition: Indicator should be clearly defined, and its measurement should be consistent to enable international comparisons.
- Validity. The indicator should be valid, reliable and easily interpreted.
- Feasibility. Collecting information on the indicator should be easy, inexpensive and not overburdening.
- Utility. The indicator should provide useful information for policy-makers that can be used at local, national and international levels.

Reliability of an indicator refers to whether measurement can be replicated and whether it is consistent between different settings. The validity of an indicator means that an indicator measures what it is supposed to measure and has three dimensions:

1) Face validity: An indicator is valid as judged by participants, such as physicians and patients (Mainz, 2003).
2) Construct validity: The validity of an indicator is based on tradition or theory (Beattie et al., 2014; Cronbach & Meehl, 1955; Mainz, 2003).
3) Content validity: The indicator measures everything that it is supposed to measure and is based on evidence (Beattie et al., 2014; Cronbach & Meehl, 1955; Mainz, 2003).

WHO has compiled a list of priority global health indicators that are referred to as core and additional indicators. A core indicator is one that fulfils all four requirements listed below whereas additional indicators are often new indicators and therefore the third requirement of extensive experience in measurement is not required for additional indicators (WHO, 2018). The following criteria are listed for a WHO core indicator (WHO, 2018):

1) The indicator is linked to a global agreement or identified as a priority indicator in specific programme areas through international mechanisms.
2) The indicator is scientifically robust, useful, accessible, understandable and SMART (specific, measurable, achievable, relevant and time-bound).
3) There is extensive experience in measurement of the indicator.
4) The indicator is used by countries in monitoring of national plans and programmes.

The two main health indicators of this thesis – early neonatal mortality and coverage of high-quality care at birth – are nearly identical with two WHO core indicators (neonatal mortality and skilled birth attendance) and therefore fulfil all criteria for a core indicator and a sound global health indicator.

2.2.3 Factors affecting quality

Due to the complexity of the definitions alone, measuring even one aspect of quality can be challenging. Quality models aim to classify the multiple dimensions of quality into a structure that enables better comprehension, evaluation and measurement of quality. Classic examples of these conceptual frameworks for quality of care include the systems, perspectives and characteristics models.

The systems model is frequently referred to as 'the Donabedian model' after Avedis Donabedian who introduced the model in 1966. This model groups quality into three entities that can each be evaluated and measured separately;

1) quality of resources (structure),
2) quality of health services (processes), and
3) outcomes (Donabedian, 1966).

The perspectives model focuses on quality as perceived by the patients, health providers and health care managers (Ovretveit, 1992). The characteristics model includes six dimensions of quality – access, relevance, effectiveness, equity, acceptability and efficiency (Maxwell, 1984). In addition to these three examples, several other conceptual frameworks have been described in the extensive literature on quality.

Although the quality frameworks described were developed for high-income settings, they form the foundation of quality frameworks used to improve care in LMICs. The WHO vision for a quality framework for pregnant women and newborns is based on the Donabedian systems model (Figure 4) (Tuncalp et al., 2015). This structure-process-outcome model incorporates the special features of maternal and newborn care, such as the need for routine and emergency care, functional referral systems and the importance of experience of care including emotional support, respect and dignity. The three dimensions of a systems model – structure, processes and outcomes – and their components that are relevant to this thesis are discussed in the following paragraphs.

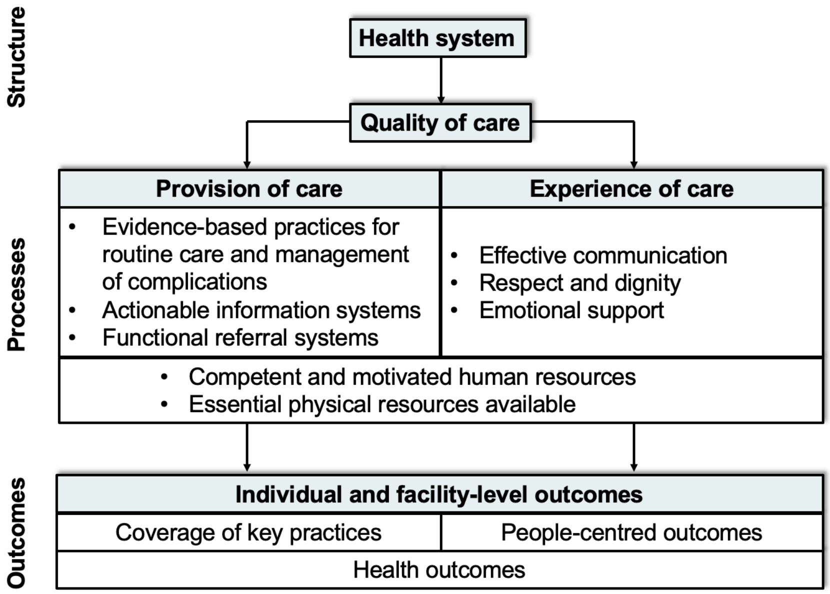

Figure 4. World Health Organization Quality of Care Framework for maternal and newborn health, adapted from Tunçalp et al. (2015).

2.2.4 Structure

Quality of care can be measured at all three levels of quality: at the level of structure (i.e. health system), the level of services (i.e. processes) and the level of outcomes (Figure 4). In the Donabedian model, structure refers to the environment where care takes place, including material resources, health facilities, numbers and training of human resources and organisational structure (Donabedian, 1988). In the WHO model, structure is an umbrella term referring to a health system that 'consists of all organizations, people and actions whose primary intent is to promote, restore or maintain health' (WHO, 2007). WHO (2007) further divides a health system into six building blocks:

1) service delivery
2) health workforce information
3) medical products
4) vaccines and technologies
5) financing, and
6) leadership/governance.

If quality is to be improved at the level of a health system, the quality-improving intervention needs to be linked with an outcome or a process (Donabedian, 1988). The main potential benefit of this systems approach is that it aims at comprehensive health systems strengthening instead of tackling one disease at a time. One of the main challenges is the donors' need to achieve short-term goals rapidly instead of investing in more sustainable development of health systems (WHO, 2009b).

Health facility assessments

Health facility assessments (HFAs) are useful tools for gathering information on structures as defined by Donabedian (1988). They can be used to evaluate, monitor and compare the capacity, infrastructure, quantity and quality of available health services at the level of the health facility (Hozumi et al., 2008). Some of the more commonly used tools for collecting data at health facilities are listed in Table 5 (Gabrysch et al., 2012a; Hozumi et al., 2008).

HFAs are suitable for collecting data on obstetric and newborn care. In addition, there are several HFA tools that are adapted to local context or to answer a particular study question. For example, the Newborn Services Rapid Health Facility Assessment includes indicators on service availability, equipment and supplies, documentation, trained staff and supervision that particularly concern newborns (Inter-agency Newborn Indicators Technical Working Group, 2012).

The different tools vary in their level of detail, time taken to conduct the surveys, cost and the recommended frequency of repetition intervals, ranging from ongoing monitoring to five years intervals (Hozumi et al., 2008). Despite their differences, most tools gather information on numbers of staffing, equipment, infrastructure and services provided.

Table 5. Health facility assessment tools (Gabrysch et al., 2012a; Hozumi et al., 2008).

Name of the tool	Developer	Focus
EmONC Needs Assessment Toolkit	Averting Maternal Death and Disability (AMDD)	Availability, accessibility and quality of EmONC
Rapid Health Facility Assessment (R-HFA)	Child Survival Technical Supportplus Project (CSTS+)	Rapid assessment of key indicators for maternal, newborn and child health services
Health Facility Census (HFC)	Japan International Cooperation Agency (JICA)	Assets and their condition, availability and location of health services and human resources
Service Provision Assessment (SPA)	Monitoring and Evaluation to Assess and Use Results Demographic and Health Surveys (MEASURE DHS)	Resources, systems to support quality services and observed practices in the health sector
Facility Audit of Service Quality (FASQ)	MEASURE Evaluation	Availability and quality of local reproductive and child services
Service Availability Mapping (SAM)	World Health Organization (WHO)	Availability and location of health services, human resources and physical infrastructure
Service Availability and Readiness Assessment (SARA)	World Health Organization (WHO)	Service availability and readiness in the health sector

EmONC, Emergency Obstetric and Newborn Care.

A general, nationally used and still detailed HFA tool is the Health Facility Census (HFC) developed by the Japan International Cooperation Agency (JICA) that measures up to 105 service indicators, particularly availability and condition of equipment and infrastructure including buildings, utilities (e.g. water and electricity), communication (e.g. radio and phone), transportation, location of health facilities using Global Positioning System (GPS) coordinates, availability of services (such as signal functions), and numbers of staff (Hozumi et al., 2008).

The HFC can be used to collect information on all public, semi-public and major private health facilities. The data can be collected by two persons in one day in primary health care facilities, in two to three days in secondary level hospitals and within six days in tertiary level hospitals (Hozumi et al., 2008). A major weakness of the HFC is that it does not include information on details of care processes (e.g. indications for interventions), patient satisfaction or staff training (Hozumi et al., 2008).

2.2.5 Processes

Measuring processes in healthcare may provide an efficient alternative to measuring outcomes because processes can be measured more frequently (Peabody et al., 2000). Further, processes may be more sensitive measures of quality compared with outcomes as not all erroneous processes lead to a bad outcome (Brook et al., 1996). Potential disadvantages of process indicators are that they might not be easily understood by the public and they might lead to inappropriate focus on the measured process at the cost of neglecting other important unmeasured factors (Rubin et al., 2001). A prerequisite of measuring process indicators is that they must be evidence-based with an established link to health outcomes (Mainz, 2003; Palmer, 1998). In addition, process indicators need to be adjusted for case-mix (Donabedian, 1966).

Obstetric care

Obstetric care at birth is at the heart of quality improvement for mothers and newborns as complications are often life-threatening and require rapid diagnosis and management (Lawn et al., 2014). Attempts to reduce mortality during the MDG era have focused on preventing and treating the three specific obstetric emergencies that cause more than half of all maternal deaths: haemorrhage, hypertensive disorders and sepsis (Say et al., 2014).

The level of emergency obstetric care in delivery facilities is often measured by availability of key interventions that target the major causes of maternal deaths (Table 6). These interventions are referred to as signal functions and evolved from a WHO document describing essential obstetric procedures for hospitals in 1991 (WHO, 1991). The signal functions were first defined by Unicef, United Nations Population Fund (UNFPA) and WHO in a guideline for monitoring emergency obstetric care in 1997. Newborn resuscitation was added as a signal function only in the 2009 revised edition that was published by WHO, UNFPA, Unicef and Averting Maternal Death and Disability (AMDD) programme by Columbia University. This 2009 UN handbook is widely used as a reference tool for measuring availability of emergency obstetric care in low- and middle-income settings.

Table 6. Signal functions according to Monitoring emergency obstetric care – a handbook (WHO et al., 2009).

Signal function	BEmOC[a] functions	CEmOC[b] functions
1) Administer parenteral antibiotics[c]	X	X
2) Administer uterotonic drugs[d]	X	X
3) Administer parenteral anticonvulsants for eclampsia and pre-eclampsia	X	X
4) Manually remove the placenta	X	X
5) Remove retained products	X	X
6) Perform assisted vaginal delivery	X	X
7) Perform basic neonatal resuscitation (i.e. with bag and mask)	X	X
8) Perform surgery (e.g. caesarean section)		X
9) Perform blood transfusion		X

[a]Basic Emergency Obstetric Care
[b]Comprehensive Emergency Obstetric Care
[c]Injection or intravenous infusion.
[d]Uterotonic drugs are administered to prevent and to treat postpartum haemorrhage.

A facility that provides seven basic interventions is identified as one providing Basic Emergency Obstetric Care (BEmOC) whereas blood transfusions and emergency surgery are available in a Comprehensive Emergency Obstetric Care (CEmOC) facility in addition to the seven basic functions. To be qualified as a fully functional BEmOC or CEmOC facility, the signal functions have to be available 24 hours per day and seven days per week and been performed during the past three months (WHO et al., 2009). In addition, evaluation of signal functions should include information on training and authorization of health care staff to perform the interventions, availability and functionality of necessary equipment and indications for providing the intervention (WHO et al., 2009).

According to this classification, most deliveries could be managed by midwives in primary care facilities that offer BEmOC, such as maternity homes or health centres (WHO et al., 2009). These facilities should additionally be able to diagnose, start treatment and refer unexpected complications to secondary or tertiary hospitals that offer CEmOC (WHO et al., 2009).

Neonatal care

To underline the importance of newborns in emergency care, EmOC is now called Emergency Obstetric *and Newborn* Care (EmONC). Although care and outcomes of the foetus and the mother are often intertwined and shared during pregnancy and labour, effective neonatal postpartum care can significantly improve neonatal survival.

A significant research effort has been put into identifying key interventions to improve newborn outcomes during the past decade. This is reflected by the multitude of series papers published in *The Lancet* that review interventions for newborn survival, for example, *the Lancet Child Survival Series* in 2003 (Jones et al., 2003), *Neonatal series* in 2005 (Darmstadt et al., 2005), *Stillbirth Series* in 2011 (Bhutta et al., 2011), *Nutrition Series* in 2013 (Bhutta et al., 2013a), *Diarrhoea and Pneumonia Series* in 2013 (Bhutta et al., 2013b) and *Every Newborn Series* in 2014 (Bhutta et al., 2014).

A Delphi study attempted to develop paediatric quality indicators for inpatient care (including newborn care) in LMICs, but failed to narrow down the set of indicators as the two expert panels accepted nearly all indicators and rejected none (Ntoburi et al., 2010).

A paper by Gabrysch et al. (2012a) used expert survey and consensus method to identify three routine care functions, six basic emergency care functions and two additional interventions for comprehensive emergency newborn care (Table 7). Prevention of mother-to-child transmission of HIV (PMTCT) was included for high prevalence settings although the authors pointed out that PMTCT is not strictly a newborn function, but rather an intervention that reduces infant and child mortality (Gabrysch et al., 2012a). In addition to emergency care functions, the authors suggested general requirements and routine care functions for a facility managing deliveries and newborns (Gabrysch et al., 2012a).

The Every Newborn Action Plan (ENAP) initiative by WHO and Unicef aims to help countries to reduce neonatal mortality to the SDG target of 12 deaths per 1000 live births and stillbirths to less than 12 deaths per 1000 births (WHO & Unicef, 2014). The initiative was launched in 2014 and endorsed by the 194 UN member states at the 67th World Assembly. The initiative reviewed available evidence to formulate ten core and ten additional indicators (Moxon et al., 2015; WHO & Unicef, 2014). These indicators, that closely resemble those suggested by Gabrysch et al. (2012), are listed in Table 7.

Out of the ten ENAP core indicators, the first three concerning mortality are impact indicators and the remaining seven are coverage indicators of key interventions (Table 7). In addition, some interventions are included in the ENAP service delivery packages of small and sick newborns, for example, warmth, oxygen therapy and feeding support. The additional ENAP impact indicators include intrapartum stillbirths, low birth-weight rates, small for gestational age rates, preterm births, neonatal morbidity and disability due to neonatal conditions, and the additional coverage indicators include antenatal care, exclusive breastfeeding up to six months, caesarean section and cord cleansing with chlorhexidine (Moxon et al., 2015; WHO & Unicef, 2014).

Table 7. Newborn signal functions according to Gabrysch et al.(2012) and the Every Newborn Action Plan (ENAP) indicators (Moxon et al., 2015; WHO & Unicef, 2014). Corresponding indicators are highlighted. ENAP core indicators are numbered.

Dimension of facility care: Gabrysch et al. (2012)/ENAP	Newborn signal functions by Gabrysch et al.	ENAP indicator
General requirements / Care for all mothers and newborns	Reliable electricity, water supply, heating, clean toilets	1. Maternal mortality ratio
	Service available 24/7	2. Neonatal mortality rate
	Referral service to higher-level care, communication tools	3. Stillbirth rate
	Skilled providers in sufficient numbers	4. Skilled attendant at birth
Routine care / Care for all mothers and newborns	Thermal protection[a]	5. Early postnatal care for mothers and infants (timing and definition is still unclear)[b]
	Immediate and exclusive breastfeeding	6. Essential newborn care (tracer: early breastfeeding)
	Infection prevention including hygienic cord care[c]	
Basic emergency care / Care for newborns at risk or with complications	Corticosteroids in preterm labour	7. Antenatal corticosteroid use
	Resuscitation with bag and mask of non-breathing baby	8. Neonatal resuscitation
	KMC for premature/very small babies	9. KMC
	Injectable antibiotics for neonatal sepsis	10. Treatment of severe neonatal infections
	Alternative feeding if baby unable to breastfeed (breastmilk expression, cup/spoon feeding)[d]	
	Antibiotics for preterm/prolonged PROM to prevent infection	
	PMTCT if HIV-positive mother and depending on HIV prevalence	
Comprehensive emergency care / Service delivery packages to improve quality of care	Safe administration of oxygen[d]	Care of small and sick newborns[e]
	Intravenous fluids	Every Mother, Every Newborn quality initiative with measurable norms and standards[f]
		Birth registration (input indicator)

[a]Thermal protection: Immediate drying of baby after birth, skin-to-skin with mother, wrapping, no bath during the first 6 hours. [b]Postnatal contact(s) (e.g. home visit or clinic appointment) postpartum. [c] Hygienic cord care: cutting with sterile blade, application of 4% chlorhexidine on tip of the cord (listed as an additional ENAP indicator). [d]Included in the 'Care of small and sick newborns' service delivery package of ENAP. [e]Includes warmth, feeding support, safe oxygen therapy, effective phototherapy and prevention and treatment of infections. [f]Includes criteria and standards for facility-based maternal and newborn care.
KMC, Kangaroo mother care; PMTCT, Prevention of mother-to-child transmission of HIV; PROM, Premature rupture of membranes.

Human resources

Care provided by skilled attendants is a progress indicator of the MDG 5 and SDG 3 highlighting the internationally recognised importance of this key process in obstetric and neonatal care (Tables 2 and 3). Skilled attendance means the process by which the mother and newborn receive good quality care during pregnancy, delivery and the postpartum period (MacDonald & Starrs, 2002). Skilled attendance entails that, in addition to provider skills, the environment in which the SBA works must be supportive (referred to as enabling environment) at the level of the health system and in terms of equipment, supplies and infrastructure (MacDonald & Starrs, 2002).

An SBA does not necessarily have to be a midwife. A midwife is defined by The International Confederation of Midwives (ICM) as follows: 'A midwife is a person who has successfully completed a midwifery education programme that is based on the ICM Competencies for Basic Midwifery Practice and the framework of the ICM Global Standards for Midwifery Education and is recognized in the country where it is located; who has acquired the requisite qualifications to be registered and/or legally licensed to practice midwifery and use the title 'midwife'; and who demonstrates competency in the practice of midwifery (ICM, 2005).' It is estimated that midwives would be competent to manage 87% of the services needed by women and newborns, however, midwives form only 36% of the available midwifery staff (UNFPA et al., 2014).

The 2005 World Health Report (WHR) estimated that a district with a population of 120,000 and 3,600 annual births requires 20 midwives or SBAs with an average workload of 175 births per year per person (WHO 2005). In addition, the report estimated that at least three doctors would be needed to provide back-up care, such as surgery, to the estimated 600 to 650 mothers and newborns out of 3,600 births (approximately 18%) needing higher level care (WHO 2005). These minimum required numbers of staff amount to 6.39 (23/3.6) skilled attendants per 1,000 births or 0.192 (23/120) skilled attendants per 1,000 population.

The following WHR in 2006 considerably raised this demand estimate for SBAs to 2.28 per 1,000 population (WHO, 2006b). This higher estimate was based on density of SBAs in countries with at least 80% coverage of births managed by skilled attendants. *The global strategy on human resources for health: Workforce 2030* –report from 2016 set health worker need to 4.5 staff per 1,000, but this estimate included demand needs for all SDG indicators (i.e. five indicators for infections and four for non-communicable diseases in addition to the indicators for maternal, child and newborn health) (WHO, 2016). In an associated manual designed to calculate staffing needs, the feasible workload estimate for SBAs remained practically unchanged (189 births per year per person) (WHO, 2010) compared with the 2005 WHR (175 births per year per person).

The human resource crisis affects the entire health sector in LMICs, not only maternal and newborn health (WHO, 2016). The global shortage of doctors, nurses and midwives is projected to amount to 7.6 million nurses, 2.3 million doctors and a total of 14.5 million health professionals by 2030, with the highest shortage in Africa (estimated at 6.1 million health workers) (WHO, 2016).

The mismatch between demand and supply has led to training cadres other than midwives, such as traditional birth attendants (Sibley et al., 2012; Wilson et al., 2011), community health workers (Gogia & Sachdev, 2010) or lay health workers without professional training (Lewin et al., 2010), to manage deliveries and newborns. As a result, these cadres possess heterogeneous training, skills, competencies, roles and responsibilities although they might all be referred to as skilled attendants (Renfrew et al., 2014; UNFPA et al., 2014).

Assessing health worker competence

Clinical skills can be assessed by at least four alternative ways: use of standardized patients, direct observation, chart abstraction and use of clinical vignettes. Standardized patients are actors who present to a health care provider with a clinical condition and record whether providers fulfil predefined criteria for sufficient clinical performance (Beullens et al., 1997).

The benefits of using standardized patients are that they allow for control of case-mix and blinding of the provider, their use does not involve real patients, and they are often considered the gold standard of competence assessments (Badger et al., 1995; Colliver et al., 1993; De Champlain et al., 1997; McLeod et al., 1997; Pieters et al., 1994; Rethans & van Boven, 1987). However, standardized patients take comparably much time from the provider, are costly and can be used in a limited number of clinical situations only (Beullens et al., 1997; Peabody et al., 2000). For example, they cannot be used to investigate obstetric or neonatal emergencies.

Unlike standardized patients, chart abstraction does not consume time from a health care provider that could be used to treat patients, and patient charts can be used to evaluate all kinds of clinical situations (Gilbert et al., 1996;

Luck et al., 2000; McDonald et al., 1997). The major limitation of chart abstraction is recording bias due to time constraints even in high-income settings (Peabody et al., 2000) and particularly in LMICs where documentation is often missing or inadequate (Luck et al., 2000; Peabody et al., 2000). In addition, chart abstraction requires expertise to understand patient charts (Ashton et al., 1995; Norman et al., 1993).

Direct observation means observing real clinical situations. The limitations are that double-blinding (provider and patient) is difficult (Peabody et al., 2000) and studying rare events, such as obstetric or neonatal complications, is time-consuming and costly.

Clinical vignettes are written clinical case scenarios that are presented to a health care provider. Competence is assessed based on provider's account on what the provider would do in a corresponding real-life clinical situation. Vignettes are less time-consuming and less costly than direct observation and standardized patients, and they can be used to study all kinds of clinical situations. Similar to chart abstracts, one limitation of clinical vignettes is that they do not measure provider-patient interactions that are an important aspect of high-quality care (Veloski et al., 2005).

2.2.6 Outcomes

Outcomes are often measured as they are easily defined and they are generally easily understood as measures of quality (Donabedian, 1966). On the other hand, health outcomes are often rare (such as death or complication), develop slowly (disease), and their measurement might take a long time or need large datasets leading to high costs (Peabody et al., 2000), particularly in LMICs where vital registries are rarely available (MEASURE Evaluation, 2015). In addition, outcomes tell little about where or how quality of care should be improved. Despite these limitations, outcomes arguably 'remain the ultimate validators of the effectiveness and quality of medical care' as Avedis Donabedian argued half a century ago (Donabedian, 1966).

2.2.7 Facility delivery and early neonatal mortality

Early neonatal death is one of the main health outcomes of delivery care. In LMICs where a significant proportion of deliveries takes place at home, care is often sought only when complications arise. This leads to selection of high-risk deliveries in health facilities making delivery in a health facility look harmful. Further, mortality may actually be highest in the biggest and best facilities as these often function as referral institutions managing the most complicated cases. Complications thus confound the association between delivery in a health facility and early neonatal mortality as they increase early neonatal mortality and are associated with increased care seeking (Figure 5). In this thesis, the adverse accumulation of high-risk deliveries in health facilities is called "confounding by case-mix" and delivery in a health facility is referred to as "facility delivery".

Facility delivery can only reduce mortality if quality of care is sufficiently high to save lives. High-quality care by a skilled attendant necessitates birth in a health facility in most contexts and is promoted as the key intervention to reduce neonatal and maternal mortalities (Campbell et al., 2016). While a number of studies have found a protective effect of facility delivery on neonatal or perinatal mortality (Feng et al., 2011; Malqvist et al., 2010; McDermott et al., 1996; Nankabirwa et al., 2011; Titaley et al., 2008; Tura et al., 2013; Upadhyay et al., 2012; Walraven et al., 1995; Yakoob et al., 2011), many report no significant difference in mortality among home births compared with facility births (Chinkhumba et al., 2014; Diallo et al., 2010; Fink et al., 2015; Jehan et al., 2009; Matendo et al., 2011; Moyer et al., 2013; Nathan & Mwanyangala, 2012; Schmiegelow et al., 2012).

In a prospective cohort-study from Bangladesh, care in a health facility was even reported to increase perinatal mortality (Ronsmans et al., 2010). The missing or even harmful effects of facility delivery are often attributed to confounding by case-mix (Scott & Ronsmans, 2009). Indeed, confounding by case-mix makes it difficult to study the benefit facility delivery on early neonatal mortality at individual level, particularly as reliable data on complications are rarely available.

One way of indirectly assessing the survival benefit associated with facility delivery is to study mortality at community level instead of individual level (Scott & Ronsmans, 2009). The assumption that facility delivery is protective comes from the experience in high-income countries where facility delivery is near-universal and mortality is very low, or from ecological studies showing an inverse linear correlation between average mortality and average coverage of facility-based deliveries or deliveries assisted by skilled attendants (Scott & Ronsmans, 2009).

However, country-level correlation analyses possess the risk of ecological fallacy due to confounding country-level factors, such as country income (Scott & Ronsmans, 2009). Therefore, the impact of facility delivery has been investigated at the level of subnational aggregates, such as a village or community, instead (Hounton et al., 2008; Montgomery et al., 2014; Randive et al., 2013; Titaley et al., 2008). This approach requires adjustment for community-level confounding factors, such as average wealth in community.

Another approach of overcoming confounding by case-mix (i.e. delivery complications) is to study the effect of distal determinants on early neonatal mortality (Figure 5). These distal determinants must be selected so that their effect is conveyed largely through facility delivery. Distal determinants, such as socioeconomic position or distance to delivery care, can be used to investigate the influence of unmeasured key interventions (such as facility delivery) on survival as long as the effect of the distal determinants is conveyed through these interventions (Figure 5). Higher wealth or education leads to higher facility use at birth that improves early neonatal survival. The prerequisite is that quality of care in health facilities is high enough to save lives. In contrast, long distances to care can increase mortality through decreased access to facility delivery (Figure 5).

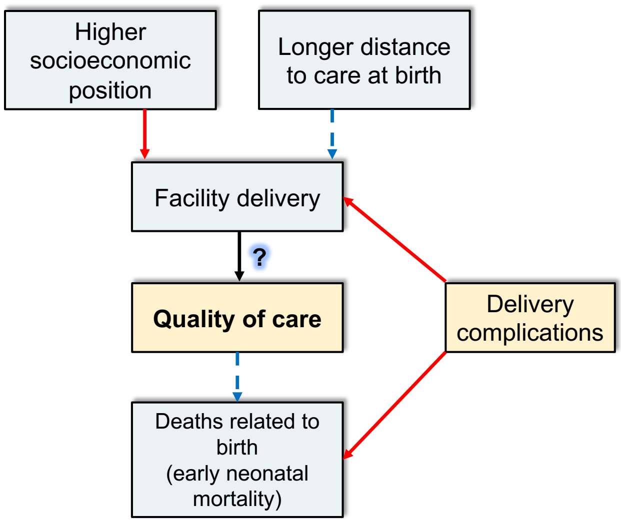

Figure 5. Influence of distance and socioeconomic position on facility delivery and mortality. Higher socioeconomic position increases facility deliveries and longer distance to care reduces access to facility delivery. The effects of distance and socioeconomic position on early neonatal mortality are largely conveyed through health facility delivery – a key intervention that reduces mortality. Facility delivery will, however, only reduce mortality if quality of care is sufficient in health facilities (black arrow). The association between facility delivery and early neonatal mortality is confounded by delivery complications. Red solid arrow represents increasing effect and blue dashed arrow represents reducing effect. Variables that are highlighted yellow are hard to measure and easily measured variables are highlighted light green.

2.3 Access to care at birth

2.3.1 Definition of access

Access to care has multiple definitions and dimensions. One commonly used definition of access to care identifies five dimensions: affordability, acceptability, accommodation, availability and accessibility (Penchansky & Thomas, 1981). In addition, access can be divided into potential and realized access that refer to availability and use of services in an area, respectively (Higgs, 2004).

2.3.2 Factors affecting access

In their review Thaddeus and Maine (1994) presented three delays in access to care for obstetric complications in LMICs. As treatments for obstetric complications exist, they argued that maternal mortality is determined by delays in:

1) decision to seek care,
2) arriving at a health facility, and
3) receiving appropriate care (Thaddeus & Maine, 1994).

According to Thaddeus and Maine (1994), the decision to seek care is influenced by physical access, cost, perceived quality of care, severity of complication and socioeconomic factors. The second delay is influenced by geographic distance to a health facility capable of providing appropriate care and by the mode of transport, and receiving high-quality care (third delay) can be hindered by shortages of competent staff, equipment and drugs, or delays in diagnosing and administering appropriate treatment (Thaddeus & Maine, 1994).

The three delays model is based on the preconception that obstetric care is sought in emergencies only whereas skilled attendants are now promoted for all deliveries, including routine deliveries. As factors affecting preventive care-seeking for routine deliveries are likely to differ from emergency care-seeking, the framework suggested by Thaddeus and Maine was expanded by Gabrysch and Campbell (2009) to include preventive care. For example, cost of treatment may play a smaller role in emergencies than in routine care-seeking and it is therefore important to distinguish between preventive and emergency care-seeking.

In their review, Gabrysch and Campbell (2009) found that higher maternal age, low parity, higher maternal education and higher household wealth were associated with skilled care at birth. Similarly, attending antenatal care, facility use for previous delivery and living in urban areas (as opposed to rural areas) were associated with facility use for delivery (Gabrysch & Campbell, 2009). However, they identified important gaps in objective research on several aspects influencing care seeking, for example, quality of care, complications and geographic access to care (Gabrysch & Campbell, 2009). This thesis focuses on quality of care and geographic and socioeconomic inequalities in access to care.

2.3.3 Measuring geographic access

Geographic information system (GIS) is a computer program that enables linking attributes to a geographic location. One early documented example of linking geographic information with health outcomes comes from 1854 when a pioneer in anaesthesiology and epidemiology, Dr. John Snow, was able to identify a water pump acting as the source of a cholera outbreak in London based on the distribution of water pumps and cholera deaths (Vinten-Johansen et al., 2003). Although the GIS of today is much more complex compared with Dr. Snow's map, the idea behind is the same; cholera deaths and water pumps were mapped to draw conclusions about their geographical distribution relative to each other.

A GIS needs a coordinate system and a datum (Owens et al., 2014). A geographic coordinate system expresses location in terms of angles from the centre of the Earth to the surface. Equator divides the Earth into Southern and Northern hemispheres, and latitude measures angles north (up to +90° in the North Pole) or south (down to -90° in the South Pole) of the equator that is located at a latitude of 0°. The Greenwich Prime Meridian divides the Earth vertically into Eastern and Western hemispheres. Longitude is measured -180° westward or +180° eastward from the Prime Meridian that is located by definition at a longitude of 0°. This grid formed by latitudes and longitudes is linked to the shape and size of the Earth by a datum, for example, the commonly used World Geodetic System (WGS) and its latest revision WGS 1984 (Owens et al., 2014).

To create a two-dimensional flat map out of the curved surface of the Earth, a projection is needed (Owens et al., 2014). A projection always introduces an error in one or more dimensions of the map (i.e. area, shape, distance or direction). Depending on the purpose, one of these dimensions can be prioritized by choosing an appropriate projection. For example, the Universal Transverse Mercator (UTM) is designed to preserve a balance between all four dimensions.

The geographic data are portrayed as layers in a GIS, one layer representing one type of geographic information (e.g. points, lines or polygons) and displayed on top of each other (Owens et al., 2014). The data are saved as 'a shapefile' that can also store information on attributes. The data frame created in a GIS can then be used in numerous applications. For instance, the GIS can be used to study catchment areas of health facilities or to measure distances from populations to health services.

Distance is most easily measured as a Euclidean distance i.e. a straight-line between two points. Whether straight-line is a good approximation for the actual distance travelled or time taken depends on the context. Straight-line distance may not be an appropriate measure in areas with large barriers as was found in two separate studies from mountainous regions in rural Kenya (Noor et al., 2006) and rural Ethiopia (Okwaraji et al., 2012). In contrast, straight-line distance correlated highly with five other methods of measuring travel impedance in a study from the rural and flat Brong Ahafo region of Ghana (Nesbitt et al., 2014).

A GIS enables assigning different travel times for different parts of the road or terrain. However, modes of travel may vary from walking to an ambulance and calculating travel times along road networks may not be appropriate as walking is a common mode of transportation in many settings. In addition, travel times are affected by at least terrain cover, topography (e.g. mountains or large water bodies), man-made barriers and season. Detailed data on these factors are rarely available from LMICs (Tanser & le Sueur, 2002).

2.3.4 Distance to care at birth and early neonatal mortality

Longer distances and/or travel times to a delivery facility have been shown to reduce facility use for delivery and skilled care in several studies from LMICs including Bangladesh (Chowdhury et al., 2006; Scott et al., 2013), Burkina Faso (De Allegri et al., 2011; Diallo et al., 2011; Diallo et al., 2010; Hounton et al., 2008), Ghana (Johnson et al., 2015; Masters et al., 2013; Nesbitt et al., 2016), Indonesia (Scott et al., 2013), Kenya (Hodgkin, 1996; Magadi et al., 2000; Mwaniki et al., 2002), Malawi (van den Broek et al., 2003), Tanzania (Hanson et al., 2015; Mpembeni et al., 2007; Rockers et al., 2009; Spangler & Bloom, 2010), Vietnam (Malqvist et al., 2010), Zambia (Gabrysch et al., 2011a), and in a multicountry analysis from 21 LMICs (Karra et al., 2017).

Studies linking distance with neonatal mortality have been inconclusive (Table 8). Proximity to a health facility has been associated with lower neonatal mortality in Vietnam, India, Ethiopia and in a multicountry analysis including 21 LMICs (Table 8). Studies from Burkina Faso, Madagascar and India found no association between distance and neonatal mortality (Table 8) and a few studies reported decreasing mortality with increasing distance (Karra et al., 2017; McKinnon et al., 2014a; Rammohan et al., 2013).

Table 8. Studies on the association between distance to a health facility and neonatal mortality in low- and middle-income countries.

Country (Reference)	Study design and distance measurement	Outcome and participants	Main result: Is longer distance to care associated with higher mortality?
Vietnam (Malqvist et al., 2010)	Retrospective case-control study. Euclidean distance to closest facility.	Neonatal mortality (28 days). 197 deaths, 686 controls	OR of death 1.96 in remote (≥1,257 m) vs close (<1,257 m) areas; In stratified analysis the association held only among mothers with <5 years of schooling or poor mothers.
India (Rammohan et al., 2013)	Cross-sectional study. Distance to closest hospital; distances to community and primary health centres.	Neonatal mortality (28 days). 99,735 rural live births, 2% mortality.	1 death per 1,000 live births more per 10 km increase in distance to district hospital. (Mortality decreased with increasing distance to a primary health centre.)
Ethiopia (Gizaw et al., 2014)	Retrospective analysis of surveillance data. Distance to hospital.	Neonatal mortality (28 days). 803,370 person-days, 1,055 deaths	OR of death 1.5 if living 5 to 9 km vs <5 km from a hospital. (Risk was not higher if living ≥10 km from a hospital.)
Ethiopia (McKinnon et al., 2014a)	Cross-sectional study. Euclidean distance to closest facility and to closest EmONC facility.	Early neonatal mortality (7 days). 7,668 rural live births, 231 deaths.	14.4 deaths per 1,000 live births more if living >80 km vs <10 km from a CEmONC facility. (Mortality was lower among those living 5 to 10 km vs <5 km from a delivery facility.)
21 LMICs (Karra et al., 2017)	Cross-sectional study. Euclidean distance to closest facility.	Neonatal mortality (28 days). 126,835 live births, 3,806 deaths.	Pooled sample OR of death higher if living ≥2 km, ≥3 km, ≥5 km or ≥10 km vs <1 km from a health facility. (Mortality was lower at >10 km distances in 9 surveys [significant in Nigeria]).

Table 8. Studies on the association between distance to a health facility and neonatal mortality in low- and middle-income countries (continued).			
Country (Reference)	**Study design and distance measurement**	**Outcome and participants**	**Main result: Is longer distance to care associated with higher mortality?**
Burkina Faso (Diallo et al., 2010)	Prospective cohort study. Euclidean distance to closest facility.	Early neonatal mortality (7 days). 895 births, 23 deaths.	No effect.
Burkina Faso (Diallo et al., 2011)	Prospective cohort study. Euclidean distance to closest facility.	Neonatal mortality (28 days). 864 live births, 40 deaths	No effect. In unadjusted analyses OR of death 2.1 ($p=0.09$) if living <5 km vs ≥5 km from a health facility.
Madagascar (Kashima et al., 2012)	Cross-sectional study. Euclidean distance to closest health centre.	Neonatal mortality (28 days). 12,345 singleton live births, 259 deaths.	No effect.
India (Upadhyay et al., 2012)	Cross-sectional study. Distance to closest secondary level hospital.	Neonatal mortality (28 days). 10,392 live births, 248 deaths.	No effect.
(C)EmONC, (Comprehensive) Emergency Obstetric and Newborn Care; km, kilometre; LMICs, Low- and middle-income countries; OR, Odds ratio.			

2.3.5 Measuring socioeconomic inequalities in access to care

Socioeconomic position

Table 9 lists common measures of socioeconomic position and their main strengths and limitations: education, asset-based measures, consumption expenditure and occupation (Howe et al., 2012). Other measures include participatory wealth ranking and subjective measures that base the estimate of socioeconomic position on community or participant opinion, respectively (Howe et al., 2012). In addition, certain regions and countries have their specific measures of socioeconomic position, such as the caste-system in India (Howe et al., 2011). The asset index is used as a measure of wealth in this thesis.

The asset index

The asset index is a measure based on household goods or assets that has been used in numerous studies from LMICs and was largely developed for the Demographic and Health Surveys (DHS) (Rutstein & Johnson, 2004). The asset index is constructed by weighting each asset variable to create a continuous score. Various methods can be used to do this, but principal component analysis is the most frequently used. The asset index may include any indicators of durable assets, housing characteristics and access to infrastructure and services, but typically includes the following variables: floor type, number of people per bedroom, land ownership, availability of electricity, water supply, servants, vehicles, refrigerator, radio, tv, phone and sanitation facilities (Rutstein, 2000).

Due to the limited number of variables included, the index may capture urban inequalities better compared with rural inequalities as the index frequently includes infrastructure that is more often available in urban areas (such as electricity) whereas rural assets (such as livestock) are less frequently measured (Howe et al., 2012). This is referred to as urban bias. Despite its limitations, measuring the asset index has many advantages over consumption expenditure or occupation measures, and it is frequently used as a measure of socioeconomic position particularly in LMICs (Table 9) (Barros et al., 2012).

Table 9. Measures of socioeconomic position in low- and middle-income countries (LMICs), adapted from Barros et al. (2013) and Howe et al. (2012).
Asset-based measures • include durable (household) assets that are weighted (e.g. by principal component analysis) to build an asset index. • **Strengths:** fast and simple method of collecting data; relatively stable; developed for LMICs • **Limitations:** assesses only relative wealth; affected by the choice of assets, community-level assets and 'urban bias'; modest inter-observer/test-retest reliability; context-specific; may result in unbalanced groups
Consumption expenditure • measures (household) spending adjusted to need (i.e. number of household members) over time. • **Strengths:** measures long-time socioeconomic position; more stable than income; requires a relatively short list of items • **Limitations:** costly and time-consuming; loss to follow-up; misreporting; affected by whom the data are collected from, recall period, season, types of expenditures included, domestic production of goods and in-kind exchanges
Education • measures years of education, completed degrees, or literacy. • **Strengths:** easy to measure • **Limitations:** may directly influence health; may result in unbalanced groups; comparison between countries may be difficult; highly dependent on the context; influence varies for different birth cohorts
Occupation • measures current or longest employment. • **Strengths:** reflects social position; correlates with income; reflects social standing • **Limitations:** may directly influence health; formal employment is rare in LMICs and various definitions of informal employment exist; people not working excluded; different for different birth cohorts and geographical areas

The asset index is often divided into categories, such as wealth quintiles in the DHS, that reflect the relative socioeconomic position. Use of wealth quintiles has many limitations. Typically, differences are compared between the highest and lowest quintiles leading to exclusion of 60% of the sample (Barros et al., 2012).

Second, the highest and lowest quintile do not necessarily have highest and lowest coverage of interventions, respectively, leading to underestimates of true inequalities (Barros et al., 2012). Third, in many low- and middle-income contexts, the poorest quintile may actually include more than a fifth of births due to higher number of children among poorest people, and similarly, less than a fifth of the sample belong to the richest quintile leading to unbalanced groups (Barros et al., 2012). This is demonstrated in Table 10 using the 2011 Cameroon DHS where 23.7% belonged to the poorest and 15.7% to the richest quintiles. Finally, comparing coverage of interventions between quintiles may lead to imprecision in estimates as coverage of interventions among the poorest is often low (Barros et al., 2012).

Table 10. Live births by wealth quintile in the Cameroon Demographic and Health Survey 2011 (DHS Program, 2018).

Quintile	Live births[a] (% of quintile[b])	Facility deliveries[a] (% of quintile[b])
Poorest (Q1)	2,506 (23.7)	473 (17.2)
Poorer (Q2)	2,752 (21.6)	1,486 (53.0)
Middle (Q3)	2,531 (20.0)	1,793 (72.7)
Richer (Q4)	2,199 (19.0)	1,904 (87.4)
Richest (Q5)	1,744 (15.7)	1,657 (95.9)
Total	11,732 (100)	7,313 (61.8)

[a]unweighted population count [b]weighted percentage. Q, Wealth quintile.

Socioeconomic inequality

Table 11 presents commonly used measures of absolute and relative inequality and demonstrates inequalities in coverage of facility deliveries in Cameroon using the DHS data presented in Table 10. A simple absolute measure of inequality is the difference in coverage or a health outcome between the richest (Q5) and poorest (Q1) quintiles. A corresponding relative measure is the richest-poorest ratio. However, using wealth quintiles has important limitations that were discussed earlier in this paragraph.

The slope index of inequality (SII) is an absolute measure of inequality that ranks individuals according to their socioeconomic position (Kroll, 2013; Mackenbach & Kunst, 1997). The rank indicates the cumulative proportion of the population with a lower position in the hierarchy. If there are several individuals in one group, the SII indicates the cumulative proportion below the midpoint of the group range. This results in a rank where the most disadvantaged individual/household is assigned rank close to zero and the most advantaged a rank close to 1. The rank can then be regressed against, for instance, a health outcome or coverage indicator and the resulting slope reflects the difference in the chosen outcome between the most and the least advantaged group. The related relative index of inequality (RII) is a ratio of the rank of the most advantaged group divided by the rank of the least advantaged group (Barros et al., 2012). The benefit of these measures over comparing highest and lowest wealth quintiles is that the entire socioeconomic distribution is included in the analysis.

Table 11. Measures of inequality and estimated inequality in facility deliveries, Cameroon Demographic and Health Survey 2011 (n=11,732) (DHS Program, 2018).

Absolute	**Example calculation**	**Comments**
Q5-Q1 (richest-poorest quintile difference)	95.9-17.2 = 78.7%	Q2-Q4 excluded
SII (richest-poorest household difference)	97.0-12.7 = 84.3%	Accounts for the entire population
Relative		
Q5/Q1 (richest/poorest quintile ratio)	95.9/17.2 = 5.6	Q2-Q4 excluded
RII (richest/poorest household ratio)	97.0/12.7 = 7.6	Accounts for the entire population

Q, Wealth quintile; SII, The Slope Index of Inequality; RII, Relative Index of Inequality

In addition to the measures presented here, there are several other methods of assessing socioeconomic inequalities, such as the concentration index, the Theil index, population attributable risk and the composition coverage index.

2.3.6 Socioeconomic position and early neonatal mortality

Socioeconomic position can influence early neonatal mortality through several mechanisms (Figure 3) and facility-based delivery is promoted as the main intervention to reduce mortality (Campbell et al., 2016). Large socioeconomic inequalities in coverage of delivery care exist; higher socioeconomic position is known to be associated with higher coverage of delivery care and better access to caesarean section (Barros et al., 2012; Fenn et al., 2007; Houweling et al., 2007; McKinnon et al., 2016; Ronsmans et al., 2006). These socioeconomic inequalities in coverage of facility delivery should result in inequalities in early neonatal mortality if facility delivery is effective in reducing mortality.

Socioeconomic inequalities in under-five child mortality are well-documented in the literature and remain substantial (Gakidou et al., 2010; McKinnon et al., 2014b; O'Hare et al., 2013; Rutstein, 2000; Wang et al., 2016; Wang et al., 2014; Wang, 2003). Only few studies from LMICs have investigated socioeconomic inequalities in early neonatal mortality previously: two analyses with sub-national data from multiple countries (Chomba et al., 2017; Dhaded et al., 2015) and some sub-national or institution-based studies (Barros et al., 2012; Garba et al., 2017; Gray et al., 1991).

In the two multicountry studies, newborns of the less educated mothers had higher odds of early neonatal mortality (OR 1.3 in women with ≥8 years of education compared with <8 years; OR 1.6 among women with university education compared with no education) (Chomba et al., 2017; Dhaded et al., 2015). One of the two multicountry studies presented sub-national data from rural areas in six countries (Chomba et al., 2017) and the other from surveillance sites in seven countries (Dhaded et al., 2015). Wealth-related inequalities were not reported, and both studies presented pooled estimates only without showing country estimates.

Multicountry studies on inequalities in early neonatal and neonatal mortalities are presented in Table 12. While literature on inequalities in *early* neonatal mortality is scarce, more evidence on socioeconomic inequalities in neonatal mortality exists. In addition to the five multicountry analyses, several sub-national and national studies on socioeconomic determinants of neonatal mortality have been conducted, most of them reporting socioeconomic inequalities in neonatal mortality (Bapat et al., 2012; Chalasani, 2012; Chan et al., 2010; Choe et al., 1999; Dettrick et al., 2014; Fenn et al., 2007; Ghosh, 2012; Ghosh & Sharma, 2010; Gizaw et al., 2014; Gonzalez et al., 2009; Grady et al., 2017; Hong et al., 2017; Huicho et al., 2016; Kayode et al., 2014; Kraft et al., 2013; Malqvist, 2011; McKinnon et al., 2014b; Neal & Matthews, 2013; Razzaque et al., 2007), but some reporting no association between wealth and/or education and neonatal deaths (Bloland et al., 1996; McCurdy et al., 2011; McKinnon et al., 2016; More et al., 2009; Sutan & Berkat, 2014; Yirgu et al., 2017). Although it is often assumed that inequalities in early neonatal mortality correspond to those in neonatal mortality, no large-scale evidence for or against this assumption has previously existed.

Table 12. Multicountry studies on wealth- and education-related inequalities in early neonatal and neonatal mortality.

Countries (Reference)	Study design	Outcome (study definition of outcome)	Participants	Main result: Is wealth or education associated with mortality?
7 countries: Argentina, Guatemala, India, Kenya, Pakistan and Zambia (Dhaded et al., 2015)	Prospective study using surveillance data. Among other variables, education-related inequalities in early neonatal mortality were analysed. Wealth-inequalities were not analysed. Pooled sample data shown, no country level estimates.	Early neonatal mortality (7 days) and neonatal mortality (28 days).	All women in the study surveillance sites that included six to twenty clusters each.	Early neonatal mortality was higher among mothers with no education compared with university education (RR 1.6). Neonatal mortality was higher among mothers with no compared with university education (RR 1.7).
6 countries: Argentina, Dem. Rep. of the Congo, Guatemala, India, Pakistan, Zambia (Chomba et al., 2017)	Secondary analysis of a study investigating the effect of WHO Essential Newborn Care on early neonatal mortality and stillbirths, by maternal education. Comparison of pre-and post-intervention mortality. Wealth-inequalities were not analysed. Pooled sample data shown, no country level estimates.	Early neonatal mortality (7 days) and fresh stillbirths.	96 rural communities with at least 300 births per year within the study sites. Altogether 57,642 pregnant women (pre-intervention n=22,625; post-intervention n=35,017)	Early neonatal mortality was higher among mothers with <8 years compared with ≥8 years of education pre-and post-intervention (RR 1.3 in adjusted analyses).
8 countries: Bangladesh, Benin, Cambodia, Eritrea, Haiti, Malawi, Nepal, Nicaragua (Fenn et al., 2007)	Cross-sectional DHS study on mortality and coverage of interventions (including skilled delivery) by wealth quintile. Education-related inequalities not analysed. Country estimates shown, no pooled sample.	Neonatal (28 days), infant (1 year) and under-two (2 years) mortality and coverage of interventions.	Households: Bangladesh n=10,500; Benin n=5,796; Cambodia n=12,236; Eritrea n=9,389; Haiti n=9,595; Malawi n=13,664; Nepal n=8,602; Nicaragua n=13,060	Lowest/highest wealth quintile neonatal mortality ratio varied from 0.8 in Haiti to 2.1 in Nicaragua. No statistical testing done.

Table 12. Multicountry studies on wealth- and education-related inequalities in early neonatal and neonatal mortality (continued).

Countries (Reference)	Study design	Outcome (study definition of outcome)	Participants	Main result: Is wealth or education associated with mortality?
24 LMICs: 16 Sub-Saharan African, 4 Southern/ Southeast Asian countries and 4 Latin American/Caribbean countries (McKinnon et al., 2014b)	Cross-sectional DHS study on wealth- and education-related inequalities (SII and RII) in neonatal mortality and their change over time (i.e. 10 years).	Neonatal mortality (30 days)	The latest dataset and data collected ten years prior to the latest dataset were used.	There were 8.5 deaths/1,000 live births more among the poorest compared with the richest (unadjusted); 11.6 deaths/1,000 live births more among the least compared with the most educated mothers (unadjusted).
48 LMICs: 10 South/Southeast Asian, 15 Southern/East African, 7 Latin American/Caribbean, 17 West/central/north African countries (McKinnon et al., 2016)	Cross-sectional DHS study on wealth-related (SII and RII) in mortality and interventions (ANC, CS, facility delivery). Country-level meta-regression used to analyse whether variation in neonatal mortality inequalities is associated with inequalities in coverage of interventions.	Neonatal mortality (the first month of life)	Recent datasets collected between 2006-2012 were used.	There were 6.7 deaths/1,000 live births more among the poorest compared with the richest. Greater public expenditure on health, expanded coverage of maternity services, and greater number of skilled health care workers were significantly associated with lower mean neonatal mortality.
7 East African and 7 West African countries. (Grady et al., 2017)	Cross-sectional DHS study on association between district-level neonatal mortality and district-level maternal education, delivery care and women's empowerment.	Neonatal mortality (30 days)	Nationally representative data. 69 districts in East Africa, 62 districts in West Africa.	In Eastern African districts: neonatal mortality was higher (up to OR 1.7) among women with no education compared with women with education. In Western African districts: neonatal mortality was higher (up to OR 6.4) among women with primary compared with university or secondary education.

ANC, Antenatal care; CS, Caesarean section; DHS, Demographic and Health Survey; LMICs, Low- and middle-income countries; OR, Odds ratio; RII, Relative Index of Inequality; RR, Risk ratio; SII, The Slope Index of Inequality; WHO, World Health Organization.

2.4 Summary of the literature review

This literature review was divided into three parts relevant to the studies presented in this thesis.

In the first part, I described the epidemiology of early neonatal mortality. Early neonatal death is one of the main health outcomes of childbirth care and is used as the main health outcome in this thesis. In addition, I described the framework for child survival in low- and middle-income countries proposed by Mosley and Chen (Figure 3).

The Mosley and Chen framework divides factors affecting child survival into socioeconomic (distal) determinants that act through biological (proximal) causes to influence mortality. The analyses on geographic and socioeconomic access to care that are presented in this thesis took advantage of the two levels in the framework to overcome confounding by case-mix (i.e. confounding caused by selection of high-risk deliveries in health facilities).

In the second part of the literature review, I briefly reviewed the multiple definitions of quality of care and health indicators and the requirements for core and additional indicators as defined by WHO. I then described factors affecting quality with a focus on the WHO quality of care framework for maternal and newborn health (Figure 4). This framework is a Donabedian structure-processes-outcomes model that highlights the experience of care in addition to provision of care. The most relevant elements of the framework to this thesis were reviewed in more detail, including signal functions for emergency obstetric and newborn care, competence and availability of human resources.

Health facility assessments and health facility censuses were described as tools for gathering information on quality of care at the level of the health facility and they were used in the quality assessments of this thesis. At the end of the second part, I reviewed the ambiguous evidence on the link between facility-based delivery and reduction of early neonatal mortality. I concluded the second part with a framework that depicts how quality of care is confounded by delivery complications and how quality can be studied indirectly using distal determinants.

The third part focused on access to care at birth. I briefly defined access to care and factors affecting access to emergency obstetric care according to Thaddeus and Maine. I then went on to describe how their framework was extended in 2009 to include determinants of preventive care seeking. As the focus of this thesis is on geographic and socioeconomic aspects of access, ways of measuring distance, socioeconomic position and socioeconomic inequalities were described. Geographic information systems, the asset index and the slope index of inequality were explained in more detail as they are central to the methods used in this thesis. I then reviewed the inconclusive literature on the link between distance to care and early neonatal mortality. As literature on inequalities in early neonatal mortality was found to be limited to only few studies, I summarised studies on socioeconomic inequalities in early neonatal and neonatal mortality.

3 AIMS OF THE STUDY

The aim of this thesis is to evaluate quality of delivery care in health facilities, to study geographic and socioeconomic inequalities in access to care at birth and to elucidate the association of facility delivery with early neonatal mortality.

The specific objectives of this thesis study were:

I. To evaluate quality of care at birth in four dimensions and effective coverage of emergency obstetric and neonatal care in all health facilities providing obstetric care in seven districts of Brong Ahafo region in Ghana: routine delivery care, emergency obstetric care, emergency newborn care and non-medical care.

II. To investigate health worker competence in managing obstetric emergencies using clinical vignettes in seven districts of Brong Ahafo region in Ghana.

III. To investigate the association of distance to the closest delivery facility and level of care on early neonatal mortality in rural Malawi and Zambia.

IV. To investigate facility delivery as a pathway between socioeconomic position and early neonatal mortality by comparing socioeconomic inequalities in early neonatal mortality and facility delivery in pooled and country-level analyses using data from 72 low- and middle-income countries.

4 METHODS

4.1 Ethical considerations

The London School of Hygiene & Tropical Medicine (United Kingdom) and the Kintampo Health Research Center (Ghana) granted ethical approval to evaluate quality of care and to investigate health worker competence in the seven study districts of Brong Ahafo region in Ghana. All women of reproductive age and health workers in the Brong Ahafo region study area signed a written informed consent to use the facility assessment data and surveillance data in the Newhints trial and associated studies (Newhints trial [Kirkwood et al., 2010b] – clinicaltrials.gov, NCT00623337).

An ethical approval was obtained from the London School of Hygiene & Tropical Medicine (application number 5172) to study the associations between distance, level of care and early neonatal mortality. The standard DHS and country-specific questionnaires have been approved by the ICF Institutional Review Board to ensure that the United States Department of Health and Human Services regulations for the protection of human subjects are followed (DHS Program, 2018). In addition, each country survey is usually approved by the local review board to ensure that it conforms to the legislation with each country (DHS Program, 2018). No separate ethical approval was needed to use the data from 72 low- and middle-income countries.

4.2 Quality of care at birth in Brong Ahafo region, Ghana

4.2.1 Brong Ahafo region

The study area comprised of seven rural districts in the Brong Ahafo region of central Ghana: Kintampo North, Kintampo South, Wenchi, Tain, Techiman, Nkoranza North and Nkoranza South (Figure 6). During the study period, the total population of the study area was approximately 600,000, of which 120,000 were women of reproductive age (Kirkwood et al., 2010b). The number of births was about 15,000 per year, the maternal mortality ratio was 377 per 100,000 live births and the neonatal mortality rate was 31 per 1,000 live births (Kirkwood et al., 2010b).

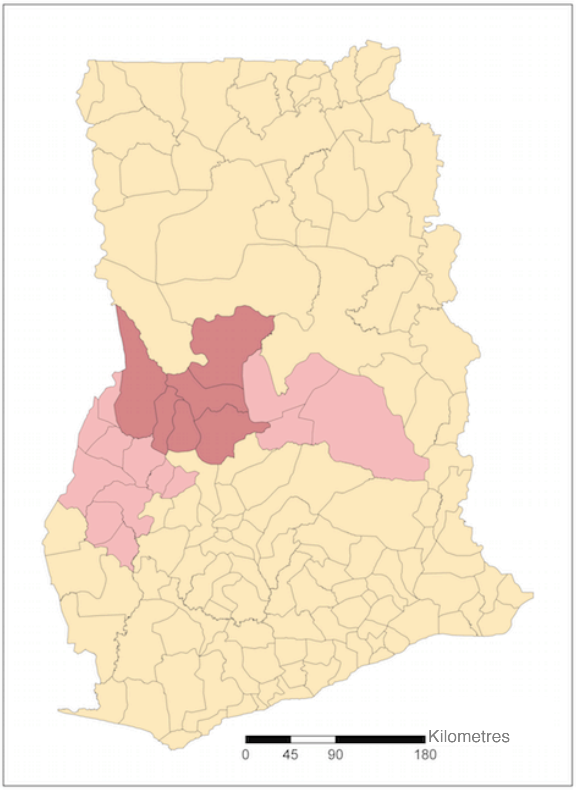

Figure 6. Map of Ghana including the study area in rural central Ghana (dark red) within Brong Ahafo region (pink). Nkoranza North and Nkoranza South are merged in the map. The map is courtesy of Dr. Robin C. Nesbitt.

Ecologically the area is forest-savannah transitional zone with two rainy seasons (from April to July and from September to October), and the main source of livelihood is subsistence agriculture (Kirkwood et al., 2010b). Ninety percent of the population in the study area lived in rural villages, typically in compounds with mud walls and thatch or aluminium roofing (Kirkwood et al., 2010b).

4.2.2 Health Facility Assessment

We conducted an HFA in all 86 health facilities in the Brong Ahafo study area to evaluate quality of care in health facilities managing deliveries and newborns. The HFA was conducted in October and November 2010 (see 2.2.3 for more information on HFAs). The interviews were conducted by myself and a research assistant in English or rarely, if necessary, in Twi.

We collected data on over 50 items of infrastructure, equipment, drugs, numbers of healthcare professionals working in obstetric and newborn care, availability of signal functions for EmOC (Table 6) and newborn and routine care signal functions as defined by Gabrysch et al. in 2012 (Table 7). Availability of tracer items and cleanliness of the bathroom were observed in all facilities. In addition, clinical vignettes were used to evaluate provider competence including the following two case-scenarios: 1) a woman presenting with pre-eclampsia and 2) a woman presenting with severe ante-partum haemorrhage (see 2.2.4 for more information on clinical vignettes in assessing competence).

Sixty-four out of the total 86 facilities were included in the analyses of quality of care and health worker competence as these facilities managed deliveries. There were 11 hospitals including one large regional public hospital that is located outside the study area but functioned as the regional referral hospital and was used by some study women. In addition to the regional hospital, the following health facilities were included in the analyses:

A) 10 public, semi-public and private hospitals (i.e. 4 district hospitals, 4 Christian hospitals and 2 private hospitals)
B) 34 public health centres, and
C) 11 private maternity homes and 8 small public facilities (i.e. clinics, Community-Based Health Planning and Services and health posts) that are referred to as 'clinics'.

4.2.3 Participants

In each facility, we interviewed the most skilled provider managing deliveries and newborns who was present at the time of the interview. Each facility was visited once on a working day during daytime. Out of the 64 respondents, three were doctors (5%), five were medical assistants (8%), 38 were midwives (59%) and nine were nurses (14%) including community health nurses, public health nurses and staff nurses. In addition, there were nine professionals that are referred to as 'others' (14%) and included health assistants, health extension workers, trained traditional birth attendants and ward assistants. All doctors and medical assistants worked in hospitals or health centres whereas midwives worked in all facility types.

4.2.4 Newhints trial surveillance

To calculate effective coverage of EmONC and to investigate the association between delivery workload and staff competence, data from the HFA was linked with birth surveillance data from the same area.

The surveillance area included in the quality of care and competence analyses was established for a cluster-randomised double-blind placebo-controlled trial, ObaapaVitA, that was conducted by the London School of Hygiene & Tropical Medicine and the Kintampo Health Research Centre between 2000 and 2008. ObaapaVitA studied the effect of low-dose vitamin A on pregnancy-related mortality in over 200,000 women of reproductive age (14 - 45 years) (Kirkwood et al., 2010a). The study found no difference in mortality between intervention and control group (Kirkwood et al., 2010a).

ObaapaVitA was followed by the Newhints trial that was a cluster-randomised trial evaluating the impact of a community-based intervention package on neonatal mortality and care practices (Kirkwood et al., 2010b). The intervention package was delivered through community-based surveillance volunteers and included interventions such as exclusive and early breastfeeding, skin-to-skin contact for babies with low birth weight, and sleeping under a bed net (Kirkwood et al., 2010b). The 8% reduction in neonatal mortality associated with the Newhints intervention was not powered to reach statistical significance (Kirkwood et al., 2013).

The regular surveillance covered all women of reproductive age and collected information on their pregnancies and vital events. The cohort used in the quality of care analysis included all pregnancies that lasted more than six months and ended in a live birth or stillbirth between 1 November 2008 and 31 December 2009 (corresponding to the Newhints dataset). After excluding those who were lost to follow-up (908 pregnancies, 5%), terminations of pregnancy before six months (1,216 pregnancies, 7%) and those who moved (156 pregnancies, 1%), the trial cohort consisted of 16,329 pregnancies that resulted in 16,168 live births. Out of these live births, the birthplace was known for 15,884 (98%) live births and this subsample was used in the quality of care analysis.

To study competence of health workers in emergency obstetric care, a subsample from the same surveillance was used. The subsample included all births during 2009, corresponding to 13,692 deliveries. In this analysis, stillbirths were counted as deliveries and multiple births were treated as one delivery episode.

4.2.5 Analysis of quality of care in four dimensions

Health facility classification

The facilities were classified to evaluate quality of care at birth in four dimensions of care:

1) routine delivery care,
2) emergency newborn care (EmNC),
3) emergency obstetric care (EmOC) and
4) non-medical care.

The details of the facility classification are presented in Table 13. This classification divided the facilities into four levels of quality: comprehensive (highest), basic (high), intermediate and low. Facilities that did not fulfil even the minimum requirement for lowest quality were defined 'substandard'. The levels were defined by the availability of signal functions, numbers of skilled staff and infrastructure. The health facility classification relied mainly on reported availability of signal functions, but for certain functions also the relevant equipment had to be reportedly available or tracer items had to be seen. In addition, for a routine function to be fully counted, it had to be reportedly performed "always", while performing it "often" or "sometimes" resulted in half a point.

The health facility classification and the health facility assessment presented in this thesis were planned and conducted in 2010. Therefore, the functions included in the classification differed somewhat from the functions that were proposed two years later (Gabrysch et al., 2012a). The routine care classification used in this thesis included all functions proposed by Gabrysch et al. in 2012 (Table 7) except hygienic cord care and baby wrapping. In addition, routine care in this thesis included three extra functions (blood pressure measurement, eye ointment and baby weighing). For emergency newborn care, six out of eight functions suggested by Gabrysch et al. (2012a) were included, leaving supplemental oxygen and antibiotics for premature rupture of membranes out. In addition to staff requirements, the classification of emergency obstetric care included all eight EmOC signal functions. Non-medical care included five proxy variables for acceptable delivery and no staff requirements.

To achieve the highest level of quality in the classification used in this thesis, the facilities needed to provide all functions of a dimension (for emergency newborn care and non-medical care) or all except one function (for emergency obstetric care and routine care). For highest level of routine care, any one function was allowed to be missing or two functions were allowed to be performed less frequently than 'always'. For highest level of emergency obstetric care, the only function that was allowed to be missing was assisted vaginal delivery as this is not regularly taught or used in Ghana (Ameh & Weeks, 2009; Paxton et al., 2003). In addition, at least three skilled health professionals (for routine care and emergency newborn care) or four skilled health professionals (for emergency obstetric care) were required for the highest level. Three staff members is the minimum number needed to ensure a true 24-hour functionality of a health facility with eight to nine-hour shifts. All facilities reported 24-hour functionality regardless of the available staff.

Table 13. Quality of care classification in 64 delivery facilities in Brong Ahafo region in Ghana in 2010.

	Comprehensive (highest)	**Basic (high)**	**Intermediate**	**Low**	**Function (item)**
1) ROUTINE CARE					1) Labour monitoring with partograph (*partograph*, *clock*, fetoscope) 2) Infection prevention (*sink, soap*, clean water source) 3) Blood pressure measurement (sphygmomanometer) 4) Controlled cord traction 5) Oxytocin within 5 min of delivery (*oxytocin*) 6) Uterine massage 7) Baby on mother's abdomen after birth 8) Dry baby immediately after birth 9) Eye ointment on baby's eyes after birth 10) Weigh baby after birth (weighing scale) 11) Initiate breastfeeding within 1 hour of birth 12) Delay bathing at least 6 hours after birth
Functions (max 12)	≥11 functions	8 functions	6 functions	4 functions	
Staff	≥3 skilled HP ≥2 midwives	3 skilled HP 1 midwife	2 skilled HP 1 midwife	1 skilled HP	
2) EMERGENCY NEWBORN CARE					1) Injectable antibiotics for sepsis (ampicillin or gentamicin) 2) Newborn resuscitation with bag and mask (*baby size bag and mask*) 3) Teach Kangaroo Mother Care or skin-to-skin care for babies with low birth weight 4) Teach mother to express breast milk and feed baby with cup and spoon if baby unable to breastfeed (measuring cup) 5) Dexamethasone to mother for premature labour (*dexamethasone*) 6) Intravenous fluids (intravenous fluids, infusion sets, small syringes & needles)
Functions (max 6)	All 6 functions	Functions 1-4 or more	3 functions	2 functions	
Staff	≥3 skilled HP ≥1 HP present ≥1 HP trained in newborn resuscitation	1 HP present 3 skilled HP	1 HP present 2 skilled HP	1 HP present 1 skilled HP	
Other	Electricity	Emergency referral + vehicle/phone	Phone	Phone	

Table 13. Quality of care classification in 64 delivery facilities in Brong Ahafo region in Ghana in 2010.					
	Comprehensive (highest)	**Basic (high)**	**Intermediate**	**Low**	**Function (item)**
3) EMERGENCY OBSTETRIC CARE (EmOC)					1) Administer parenteral antibiotics (ampicillin or gentamicin) 2) Administer uterotonic drugs (*oxytocin*) 3) Administer parenteral anticonvulsants (*diazepam* or *magnesium sulphate*) 4) Manually remove placenta 5) Remove retained products 6) Perform assisted vaginal delivery 7) Perform surgery, e.g. caesarean section 8) Perform blood transfusion
Functions (max 8)	≥ 7 functions (function 6 allowed to be missing)	Functions 1-5 or more	4 functions	2 functions	
Staff	≥4 skilled HP ≥2 skilled midwives ≥1 doctor present ≥1 doctor conducting CS	1 HP present 3 skilled HP 1 skilled midwife	1 HP present 2 skilled HP 1 skilled midwife	1 HP present 1 skilled HP	
4) NON-MEDICAL CARE					1) Delivery companion allowed 2) Facility has a patient toilet (toilet) 3) Patient toilet is clean (*clean toilet*) 4) Water for hand washing in patient toilet (*toilet, water*) 5) Soap for hand washing in patient toilet (*toilet, soap*)
Functions (max 5)	All 5 functions	3 functions	2 functions	1 function	

Observed tracer items are written in *italics*. All EmOC functions are based on the 2009 UN handbook. CS, Caesarean section; HP, health professional(s) (i.e. doctor, medical assistant, midwife, nurse). 'Skilled' refers to a health professional who is trained to manage obstetric complications.

Analysis of quality in four dimensions

The results were reported with percentage of facilities offering different levels of quality and with median number of functions and interquartile ranges for each facility.

The effective coverage was calculated as percentage of women who delivered in a facility offering basic (high) or comprehensive (highest) quality in all four dimensions of care among the 15,884 live births with a known birthplace in the Newhints trial. The analyses were conducted using Stata version 12 (StataCorp College Station, Texas, USA).

4.2.6 Analysis of health provider competence

Vignettes and competence score

Competence was investigated using clinical vignettes that described two obstetric emergencies: 1) pre-eclampsia and 2) severe antepartum haemorrhage. Each case had a diagnostic and management section. The vignettes were read to the health care provider as they appear in Table 14. We ticked off the correct answers from a checklist and continued asking whether there is anything else the provider would do in the given situations until the provider explicitly said 'no'. The correct vignette actions were based on WHO Pregnancy, Childbirth, Postpartum and Newborn Care guidelines (2006) for primary care, and included some additional interventions that can be performed at a referral facility, such as supplemental oxygen administration.

In general, each correctly mentioned action was given one point. If a given action could only or mainly be performed in a referral level facility (i.e. blood transfusion, caesarean section, supplemental oxygen and ultrasound), one point was given if the provider answered that they would refer the woman to a facility capable of performing, for example, a caesarean section. The vignette score was simply calculated summing the points, up to a maximum of 20 points (Table 14). Competence was categorized as 'high' for more than 75% (i.e. >15) of points, 'moderate' for 50 to 75% (i.e. 10–15) of points and 'low' for less than 50% (i.e. <10) of points.

Sensitivity analysis

Two alternative vignette scores were constructed as a sensitivity analysis. In one of them, the vignette actions were weighted according to their clinical importance. In the second alternative score, stating life-saving interventions was required to receive any points. There were no significant differences in results between the three scores, and the approach presented in Table 14 was chosen as it is simplest.

Table 14. Clinical vignettes and competence score (total max 20 points) used to assess competence in 64 delivery facilities in Brong Ahafo region in Ghana in 2010.

Case A: Pre-eclampsia, diagnosis. *A 26-year-old woman who is 7 months pregnant comes in complaining of headaches, blurred vision and epigastric pain and her face looks swollen. In this facility, what would you usually do to establish a diagnosis?*	
Checklist of vignette actions (max 5 points in this section)	Points per action
Measure blood pressure	+ 1 point
Check urine protein	+ 1 point
Check reflexes	+ 1 point
Check foetal heart rate	+ 1 point
Refer to another health facility or call a specialist	+ 1 point
Case A: Pre-eclampsia, management. *On examination, she had a blood pressure of 170/120 mmHg, 3+ protein in her urine and brisk reflexes. How would she be managed at this facility?*	
Checklist of vignette actions (max 4 points in this section)	Points per action
Administer antihypertensive drugs	+ 1 point
Administer magnesium sulphate or diazepam	+ 1 point
Have someone look after patient in case starts having seizures	+ 1 point
Refer to another facility or plan for delivery in 24 hours	+ 1 point
Case B: Ante-partum haemorrhage, diagnosis. *A 35-year-old woman who is 8 months pregnant comes to this facility because she has started to bleed heavily vaginally. She has no contractions and does not complain of any pain. In this facility, what would you usually do to establish a diagnosis?*	
Checklist of vignette actions (max 5 points in this section)	Points per action
Check vital signs	+ 1 point
Check foetal heart rate	+ 1 point
Abdominal examination	+ 1 point
Do not perform vaginal examination	+ 1 point
Refer to another facility or call a specialist	+ 1 point
Case B: Ante-partum haemorrhage, management. *The woman has a feeble pulse at 120/min, her systolic blood pressure is 85 mmHg and she is pale, sweating and breathing rapidly at 30 breaths per minute. Foetal heart sound is normal. There is no pain on abdominal examination. She is still bleeding bright, red blood vaginally. You suspect placenta praevia and, therefore, do not perform a vaginal examination. How would such a patient be managed now?*	
Checklist of vignette actions (max 6 points in this section)	Points per action
Elevate legs	+ 1 point
Administer intravenous fluids rapidly	+ 1 point
Administer supplemental oxygen, or refer to a facility with CS	+ 1 point
Perform ultrasound or refer to a facility with available CS	+ 1 point
Give blood transfusion or refer to a facility with available CS	+ 1 point
Refer to a facility with available CS or prepare for CS	+ 1 point
Actions written in red are from the WHO Pregnancy, Childbirth, Postpartum and Newborn care guidelines (2006). CS, Caesarean section.	

Analysis of delivery attendant competence

Median vignette scores were compared between respondent cadres and between facility types using Kruskal-Wallis tests. Whether clinical practice was dependent on competence or infrastructure was evaluated by comparing the vignette actions (e.g. foetal heart monitoring) and availability of corresponding equipment (e.g. availability of a foetal heart monitor).

The association of vignette score and average workload per skilled birth attendant was investigated for the 13,692 births in 2009 using linear regression. The workload was calculated by dividing the annual deliveries in a facility in 2009 by the number of skilled delivery attendants in that facility. Skilled birth attendant was defined as a doctor, medical assistant, midwife or nurse trained in managing deliveries. The analyses were conducted using Stata version 12 (StataCorp College Station, Texas, USA).

4.3 Distance to care at birth in rural Malawi and Zambia

4.3.1 Malawi

Malawi is a landlocked country surrounded by Mozambique, Tanzania and Zambia. Geographically Malawi is an elongated plateau with some hills and mountainous areas (Central Intelligence Agency [CIA, 2018]). The rainy season lasts from November to May (CIA, 2018). The main occupation is agriculture and 80% of the population reside in rural areas (CIA, 2018).

Malawi is one of the least developed and most densely populated countries in the world (CIA, 2018). The total fertility rate is 5.5 children per woman, the neonatal mortality rate is 23 per 1,000 live births and the maternal mortality ratio is 634 per 1,000 live births (CIA, 2018).

4.3.2 Zambia

Like Malawi, Zambia is a landlocked country in southern Africa that is geographically mostly high plateau with some hills and mountains (CIA, 2018). Zambia shares borders with Angola, Botswana, Democratic Republic of the Congo, Malawi, Namibia, Tanzania and Zimbabwe.

Zambia has one of the highest rates of urbanization in Africa (CIA, 2018). The total fertility rate is 5.6 children per woman, the neonatal mortality rate is 23 per 1,000 live births and the maternal mortality ratio is 224 per 1,000 live births (CIA, 2018).

4.3.3 Malawi and Zambia Health Facility Censuses

HFC data was used to evaluate level of care in Malawi and Zambia. The Malawi 2002 and Zambia 2005 HFC data were conducted by JICA (for details on HFCs see 2.2.3). The HFCs included information on equipment, infrastructure, location (GPS coordinates), services and health care staff numbers in all of the 1131 (Zambia) and 446 (Malawi) public, semi-public and larger for-profit facilities offering delivery care.

4.3.4 Demographic and Health Surveys

The DHS Program collects nationally representative public health data on a wide range of topics including fertility, family planning, maternal and child health, gender, HIV/AIDS, malaria, nutrition and environmental health through household surveys (Rutstein & Rojas, 2006). In addition to household surveys, the surveys include geographic information on the respondents and biomarker data on a variety of conditions (Rutstein & Rojas, 2006). The surveys are representative at national, regional (such as states) and residence (urban-rural) level (Rutstein & Rojas, 2006). Established in 1984 and funded by the United States Agency for International Development, to date more than 300 surveys have been conducted in more than 90 countries (DHS Program, 2018).

The DHS employ a stratified cluster design in two stages. First, the households are stratified based on residence (urban-rural) and by region (Aliaga & Ren, 2006). Enumeration areas are then chosen within each stratum with a probability that is proportional to the population size (or number of households) in the enumeration area (Aliaga & Ren, 2006). Enumeration areas refer to geographical areas that are created for the population censuses. All households within the selected enumeration area are then listed and updated (Aliaga & Ren, 2006). In the second stage, a number of households are chosen within the enumeration areas (Aliaga & Ren, 2006).

Following sampling, a household survey is conducted in the selected households to list all women of reproductive age (15 to 49 years), all children and all men (15 to 49, or in some surveys 15 to 54 years) (Rutstein & Rojas, 2006). Using information from the household survey, all eligible women of reproductive age and a subsample of men selected for the men's surveys are interviewed. The two-stage cluster sampling is efficient as it reduces travel and survey time, therefore saving costs, and it provides a representative cohort of the target population when a list of the target population is not available (Aliaga & Ren, 2006).

In this thesis, the children's datasets were used to investigate associations between early neonatal mortality and distance to care or socioeconomic position. They included information on a wide variety of variables related to reproductive health including birth histories of all children born up to five years before the survey, place of birth, information on survival and age at death (DHS Program, 2018). In addition, a range of socioeconomic, cultural and attitude characteristics of the mother, her spouse and her household were collected by the surveys (DHS Program, 2018).

4.3.5 Participants

Children's datasets were used to analyse the Malawi 2004 and the Zambia 2007 DHS. Rural births were included only, as distance is likely to play a major role specifically in rural areas, and excluding urban areas excludes potential unmeasured confounders of the urban areas, such as infrastructure.

As distance was measured using geographic coordinates of the DHS clusters, clusters lacking geographic data were excluded from the analyses. In addition, 7% (700 out of 9,542) of the Malawian and 11% (466 out of 4,237) of the Zambian live births were excluded as they took place before the mother moved to her current location.

As a result, the mortality analyses included 8,842 live births in Malawi and 3,771 live births in Zambia. For the facility-utilization analyses only the firstborn of multiple births was included, resulting a subsample of 8,537 deliveries in Malawi and 3,682 deliveries in Zambia.

4.3.6 Distance measurement

For Malawi, consistency checks of health facility locations were conducted by comparing locations of all 178 health facilities providing delivery care between a map created in the GIS and a map in the Malawi Health Plan 1999-2004 (Malawi Ministry of Health and Population, 1999) that included nearly all health facilities. When inconsistencies were found, Google Earth and internet searches were used to find the GPS coordinates for a health facility. The coordinates of the Zambian health facilities were cleaned using similar quality checks in the context of another academic dissertation (Gabrysch, 2009).

Straight-line distance was measured from the Malawi 2004 and Zambia 2007 rural DHS clusters to health facilities using GPS coordinates in the GIS platform ArcView 3.2 (Esri) with the Nearest Neighbor 3.6 extension. The WGS 1984 was used as a datum and the UTM as a coordinate system. Straight-line distance was used as data on roads, terrain or other geographical features was not available. To protect the privacy of the respondents, the DHS program randomly changes cluster coordinates resulting in a distance measurement error of up to ten kilometres in 1% of rural clusters and an error of up to five kilometres in all clusters (Burgert et al., 2013).

4.3.7 Classification of facilities

The Malawian and Zambian health facilities were classified according to their level of delivery care to investigate the association between level of care and facility use for delivery. In Zambia, a previously described classification of facilities was used (Gabrysch et al., 2011b). It was based on availability of eight emergency obstetric signal functions (Table 6, functions 1–6, 8 and 9) and information on staffing, opening hours and referral (Gabrysch et al., 2011b).

In brief, facilities providing all eight signal functions and electricity and having at least one midwife or doctor present 24 hours per day and at least three doctors registered, were classified as CEmOC facilities (Gabrysch et al., 2011b). BEmOC facilities were those offering six basic signal functions (Table 6, functions 1–6), electricity, referral, 24-hour presence of a midwife or a doctor and at least three registered health professionals (Gabrysch et al., 2011b). Further, there were lower subcategories for level of care, for example, CEmOC-1 or BEmOC-2, where one or two signal functions were allowed to be missing, respectively, and the staffing requirements were lower (Gabrysch et al., 2011b).

The Malawi HFC did not contain information on signal functions and therefore, the level of care was classified based on number of staff members, opening hours, blood transfusion services and an operating theatre (Table 15). First-level facilities offering full services had adequate staffing to maintain 24-hour functionality and were open 24 hours per day. Back-up facilities offering full services were typically hospitals with medical doctors, operating theatre and availability of safe blood transfusion services (defined as the ability to test for hepatitis B, HIV and syphilis as recommended by WHO (2009a)]). In the 'reduced' category, the requirements for services and numbers of staff were less strict compared with the 'full' services category (Table 15).

Table 15. Malawi facility classification using the Malawi 2002 Health Facility Census (n=446 delivery facilities).

Malawi facility classification	Back-up care		First-level care	
	Full n=32	Reduced n=16	Full n=58	Reduced n=72
Utilities	Main theatre, Blood transfusion[a]	Main theatre		
Staff	≥3 SBAs[b] ≥3 doctors[c] 24-h presence	≥3 SBAs[b] ≥1 doctor[c] 24-h presence	≥3 SBAs[b] 24-h presence	≥1 SBA[b] ≥3 health workers[d] 24-h on-call

[a]Defined as availability of blood transfusion and ability to test for hepatitis B, HIV and syphilis (WHO, 2009a).
[b]Skilled birth attendants (SBAs) defined as doctors, clinical officers, midwives or midwife/nurses.
[c]Doctors defined as medical doctors or clinical officers.
[d]Health workers defined as medical doctors, clinical officers, midwives, midwife/nurses, medical assistants, nurses and matrons.

4.3.8 Analysis

Association with mortality

The association between early neonatal mortality and distance to care or level of care was investigated first in unadjusted analyses and then in analyses adjusted for multiple confounders. The distance decay was studied as a linear effect per ten kilometres. All analyses were conducted separately for Malawi and Zambia.

Potential confounders were identified as variables that could be associated with the exposures and outcome of interest, but that were not considered to lie on the causal pathway between the exposures and outcome (such as caesarean section) (Table 16). Variables that changed the logOR of the associations between distance or level of care and mortality by a minimum of 10% were treated as confounders. These variables were then included one by one in descending order of magnitude in the model and kept in if they still changed the main association by at least 10%. Robust standard errors were used to account for clustering in the data.

Table 16. Potential confounding variables in mortality and facility utilisation analyses using the Malawi 2004 and Zambia 2007 Demographic and Health Surveys.

Level	Potential confounding variable
Newborn	birth order, multiple birth, newborn sex[a], newborn size estimate by the mother[a]
Birth	desired pregnancy, number of siblings under 7 years old
Mother	age, education, ethnic group, exposure to health information in media, fertility attitudes, frequency of media use, husband's education, husband's occupation, language, literacy, marital status, relationship autonomy, occupation, religion
Household	household wealth (asset index)
Cluster	men's fertility attitudes, men's media use, men's opinion on women's autonomy, women's fertility attitudes, women's financial autonomy, women's health-care seeking autonomy, women's media use, women's mobility autonomy, women's relationship autonomy

[a]Variable was not included in facility utilisation analyses.

Association with facility delivery

The analyses for facility utilisation were similar to those for early neonatal mortality. Association between the two exposures (distance to care and level of care) and facility delivery were analysed in Malawi and Zambia. The sample used was different than in the mortality analyses as only the firstborn of multiple births was included. The list of potential confounders was nearly identical with that of the mortality analyses, excluding newborn size estimate and newborn sex, as these variables are not confounders of the exposure-outcome association (Table 16). Robust standard errors were used to account for clustering in the data.

Facility delivery in the cluster and mortality

To understand the role of facility delivery better, mortality, caesarean section and hospital delivery were stratified by facility use in the cluster. The hypothesis was that in clusters with lower proportion of facility delivery, the mothers seek care in emergencies only and have a higher proportion of complications leading to higher rates of caesarean sections and hospital deliveries. These analyses were not adjusted for confounders.

4.4 Socioeconomic inequalities at birth in 72 countries

4.4.1 Low- and middle-income countries

DHS data from all six WHO regions included 72 LMICs: 37 African region countries, ten European countries, six South-East Asian countries, five Eastern Mediterranean countries, three Western Pacific countries and 11 countries from the Americas. Table 17 lists the countries included in study IV, sorted by on their gross national income level in the year that the DHS was conducted (World Bank, 2019).

According to the World Bank definition, a low-income economy refers to a country with a gross national income of $995 or less per capita in 2017 (World Bank, 2019). The middle-income countries are further classified into lower ($996 to $3,895 per capita per year) or higher middle-income ($3,896 to $12,055 per capita per year) (World Bank, 2019). Although the gross national income does not entirely measure development, it is a frequently available measure that correlates with other indicators of welfare and development, such as life expectancy, child mortality rates and school enrolment rates (World Bank, 2019).

Table 17. 72 Demographic and Health Survey (DHS) countries by income group and DHS year.	
Income group	**Country (DHS year)**
Low-income countries: 32 countries • African region: 22 • Americas: 2 • Eastern Mediterranean region: 1 • Europe: 2 • South-East Asia: 3 • Western Pacific: 2	Afghanistan (2015), Bangladesh (2011), Benin (2011), Burkina Faso (2010), Burundi (2010), Cambodia (2014), Central African Republic (1994), Chad (2014), Comoros (2012), Democratic Republic of the Congo (2013), Ethiopia (2016), Gambia (2013), Guinea (2012), Haiti (2012), India (2005), Kyrgyz Republic (2012), Liberia (2013), Madagascar (2008), Malawi (2010), Mali (2012), Mozambique (2011), Nepal (2016), Nicaragua (2001), Niger (2012), Rwanda (2014), Sierra Leone (2013), Tajikistan (2012), Togo (2013), Uganda (2011), United Republic of Tanzania (2015), Vietnam (2002), Zimbabwe (2015)
Lower middle-income countries: 33 countries • African region: 12 • Americas: 7 • Eastern Mediterranean region: 4 • Europe: 8 • South-East Asia: 3	Albania (2008), Armenia (2015), Azerbaijan (2006), Bolivia (2008), Cameroon (2011), Congo (2011), Côte d'Ivoire (2011), Dominican Republic (2013), Egypt (2014), Ghana (2014), Guatemala (2014), Guyana (2009), Honduras (2011), Indonesia (2012), Kazakhstan (1999), Kenya (2014), Lesotho (2014), Maldives (2009), Morocco (2003), Nigeria (2013), Pakistan (2012), Paraguay (1990), Peru (1996), Republic of Moldova (2005), Sao Tome and Principe (2008), Senegal (2010), South Africa (1998), Swaziland (2006), Timor-Leste (2009), Turkey (2003), Ukraine (2007), Uzbekistan (1996), Zambia (2013)
Upper middle-income countries: 7 countries • Africa: 3 • Americas: 2 • Eastern Mediterranean region: 1 • Western Pacific: 1	Angola (2015), Brazil (1996), Colombia (1995), Gabon (2012), Jordan (2012), Namibia (2013), Philippines (2013)
Countries are grouped by income based on the World Bank definition (2019).	

4.4.2 Data and participants

The latest available DHS data (for details on the DHS see 4.3.4) that were collected in 1990 or later were analysed. All countries with an available children's dataset by December 13th, 2017 and with information on wealth and mother's years of education were included. One survey per country was analysed. The latest datasets of Bangladesh, Colombia and Peru had a considerable amount of missing information on delivery location, and therefore a prior instead of the latest survey was used in these countries. Sixty-four out of 72 datasets were collected in 2000 or later.

The initial pooled dataset included 680,198 live births, but 0.06% (i.e. 380) live births were excluded due to missing information on date of death or mother's years of education. The mortality analyses included 679,818 live births. Multiple births were counted as one delivery in the analyses with facility delivery as an outcome resulting in a sample size of 670,107 deliveries. Out of these, 2,629 (0.4%) deliveries were excluded due to missing information on place of delivery and a sample of 667,478 deliveries was used in the analyses on facility delivery.

4.4.3 Analysis

Sample weights (*svy* suite of Stata commands) and robust standard errors were used in analyses to account for the clustered and stratified survey design of the DHS (for details on the survey design of DHS see 4.3.4). All analyses were performed at country-level first and data from the 72 countries were pooled using the inverse-variance DerSimonian and Laird method. Analyses were conducted using Stata MP2 version 15.1 (StataCorp College Station, Texas, USA).

In Uganda and Ukraine, strata were not defined and a stratum in each country was created by cross-tabulating region and residence. In addition, the datasets for the Democratic Republic of the Congo, Nigeria, Sao Tome and Principe, Swaziland and Vietnam contained one or more strata with a single primary sampling unit, and these strata were merged with another stratum from the same region and with similar urban-rural residence based on instructions from the DHS Program that were obtained by e-mail.

As a measure of wealth, the wealth index available in the DHS datasets was used. The wealth index has been created using principal component analysis (for details see 2.3.5). Mother's education was evaluated with years of education as reported in the DHS. The Slope Index of Inequality (SII) and the Relative Index of Inequality (RII) were used to estimate socioeconomic inequalities in the two mortality outcomes and facility use (for details on the SII and RII see 2.3.5). The RII is presented as an odds ratio (OR) and the SII is presented as difference in deaths per 1,000 live births.

Socioeconomic inequalities in mortality

The inequalities in early neonatal mortality (0 to 6 days) and postneonatal infant mortality (28 days to 1 year) between the richest and poorest households and between babies of the most and least educated mothers were investigated using the SII and the RII.

First, the live births were ranked according to their relative position in the wealth and education distributions within each country using the user-written *riigen* command in Stata (Kroll, 2013; Mackenbach & Kunst, 1997). Second, logistic regression was used to analyse the association between the wealth and education ranks and the two mortality outcomes to obtain the RII (i.e. an odds ratio). Third, these analyses were adjusted for urban-rural residence, for education (in the analyses on wealth) and for wealth (in the analyses on education). Finally, marginal probabilities (*margins* command in Stata) were used to estimate the SII i.e. deaths per live births at each end of the wealth and education distributions.

Comparison of inequalities in mortality and in facility delivery

To investigate the role of facility delivery as a pathway between socioeconomic position and early neonatal mortality, inequalities in facility delivery were investigated to be able to compare them with inequalities in early neonatal mortality. These analyses were adjusted for wealth, education and urban-rural residence.

In addition, the association between cluster-level facility delivery and early neonatal mortality were analysed. These cluster-level analyses were adjusted for average wealth in cluster, average education in cluster and urban-rural residence.

Both analyses were conducted using logistic regression and the SII and the RII i.e. logistic regression analyses were used to analyse associations between wealth and education ranks and facility delivery, and between facility delivery in cluster and early neonatal mortality.

Although cluster-level analyses were primarily used to overcome confounding by case-mix, individual-level association between facility delivery and early neonatal mortality were additionally analysed. These analyses were adjusted for wealth, education and residence to be comprehensive.

Sensitivity analyses

Mortality differences between the highest and lowest wealth quintiles (as defined by the DHS) and between mothers with a secondary or higher level of education and mothers with no education were compared using logistic regression. As there were no deaths in the highest wealth quintile in Brazil and in the lowest quintile in Armenia, these quintiles were merged with their adjacent quintiles for the logistic regression analyses. Similarly, there were no deaths among the highest or lowest educational groups in 16 countries and in these countries the groups with no deaths were merged with the adjacent educational level.

As sensitivity analysis for the facility delivery analyses, socioeconomic inequalities in use of skilled delivery attendants (instead of facility delivery) were investigated. The definition of a skilled attendant was based on DHS country reports. In seven countries skilled birth attendant was not defined by a country report mainly as data were collected before year 2000. In these cases, a skilled birth attendant was defined as a doctor, midwife or a nurse (with midwifery skills). Information on delivery attendant was missing for 2,693 (0.4%) out of 670,107 deliveries resulting in a sample size of 667,414 deliveries.

5 RESULTS

5.1 Quality of care at birth in Brong Ahafo region, Ghana

5.1.1 Quality in four dimensions

Health facility classification

In general, delivery facilities provided higher quality of routine and non-medical care than emergency care and emergency newborn care was the least available dimension of care in the 64 study facilities (Figure 7). Sixty-two percent of facilities provided low or lowest quality of EmOC and 58% provided low or lowest quality of EmNC. Only 8% and 19% all facilities provided at least high quality of EmNC and EmOC, respectively. Routine care was low or lowest in one third of all facilities and high or highest in 38% of facilities. Forty percent of facilities provided high or highest non-medical care.

Only four facilities (6%) including three hospitals and one health centre provided EmONC (i.e. high or highest level of EmOC and EmNC). While three health facilities provided high or highest quality in all four dimensions, one hospital provided highest quality in all four dimensions. The small facilities referred to as 'clinics' (i.e. clinics, CHPS compounds and health posts) provided the poorest emergency and medical care: quality of EmONC and quality of medical care (i.e. EmONC+routine care) was low or substandard in 88% of these facilities. None of the clinics provided a high quality of care in any dimension of medical care.

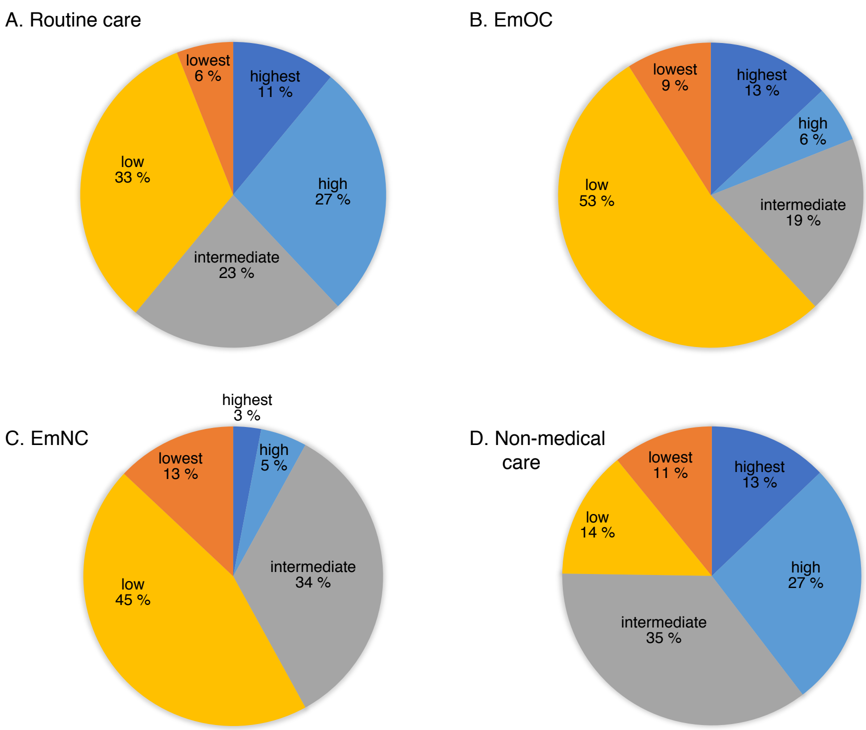

Figure 7. Quality of care in four dimensions among 64 health facilities providing delivery care in Brong Ahafo region in Ghana in 2010: A. Routine care, B. Emergency obstetric care (EmOC), C. Emergency newborn care (EmNC) and D. Non-medical care.

Effective coverage of care at birth

Out of the 15,884 deliveries in the Newhints subsample, 68% took place in a health facility. This translates into a coverage gap of 32% meaning that nearly a third of deliveries took place outside a health facility, mostly at home (Figure 8). The overall effective coverage was 18% meaning that 18% of all deliveries were managed in facilities providing a minimum of high level of care in all four dimensions. Half of all deliveries took place in facilities that did not provide a high level of care in all four dimensions, reflecting a quality gap of 50% (i.e. 68-18%). Out of the four dimensions, the quality gap was highest for EmNC and smallest for routine care. Only 0.4% of all deliveries were managed in the hospital that offered highest level of care in all four dimensions.

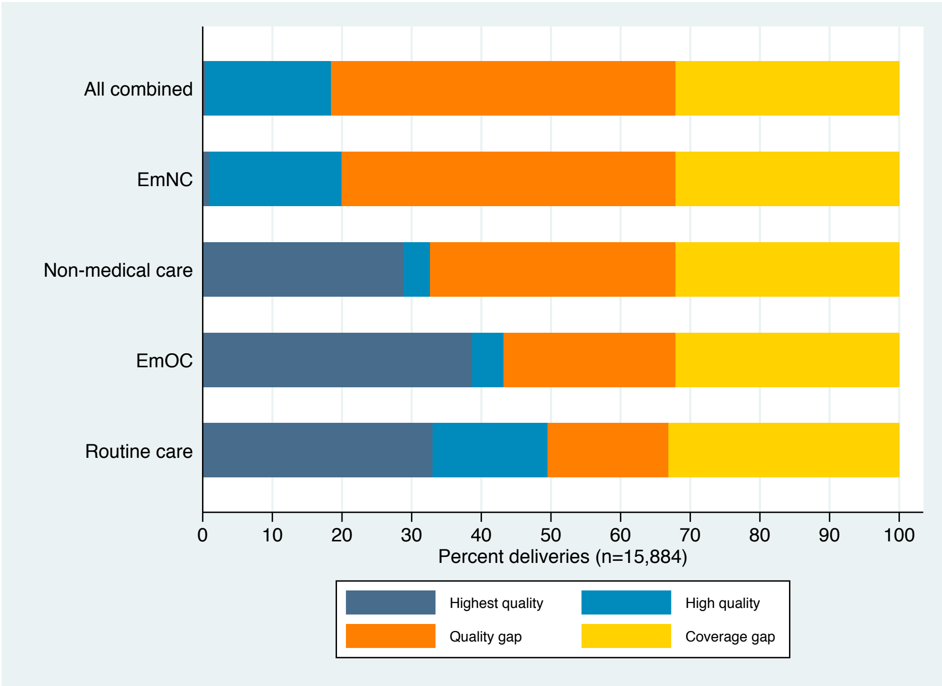

Figure 8. Effective coverage of four dimensions of quality among 15,884 deliveries in Brong Ahafo region in Ghana in 2010. EmNC, emergency newborn care; EmOC, emergency obstetric care.
Coverage gap = all deliveries – health facility deliveries; Quality gap = deliveries in any health facility – deliveries in facilities providing high or highest level of care.

Although delivery care was of high or highest quality in all four dimensions in only 5% of all facilities (3 out of 64), nearly one fifth of deliveries took place in these facilities. Similarly, only four facilities (6%) functioned at EmONC level, but 20% of deliveries took place in facilities offering EmONC. More than half of all deliveries were managed in facilities with high or highest level of routine care.

Although 17% of all facilities were hospitals, the majority of deliveries (43%) took place in hospitals whereas health centres managed 15% of deliveries despite being the most available facility type (53% of facilities) (Figure 9).

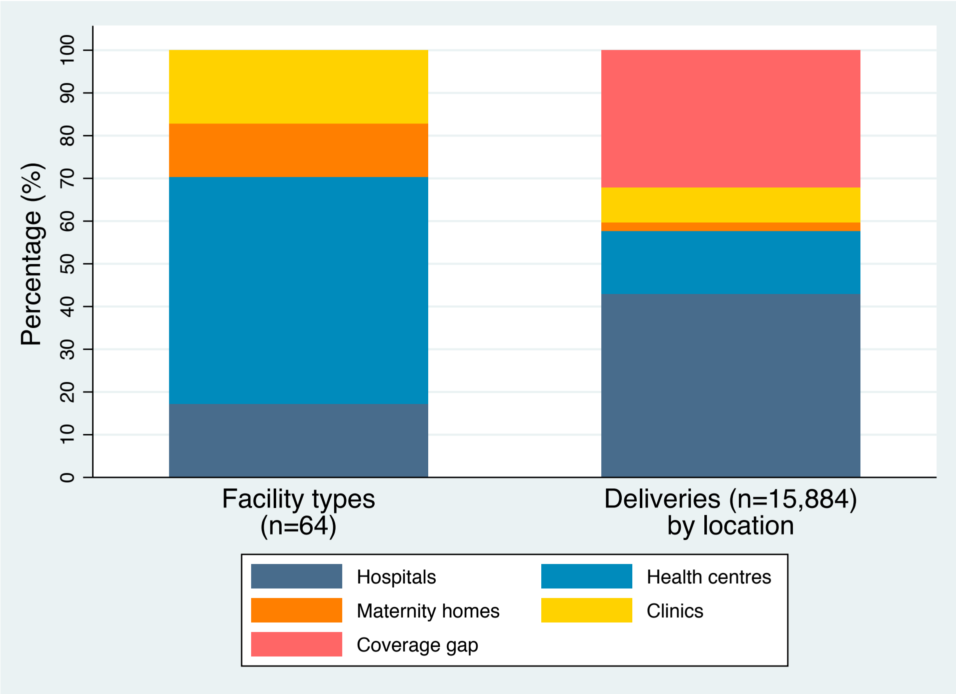

Figure 9. Distribution of delivery facility types (left) and deliveries by facility type (right) in Brong Ahafo region in Ghana in 2010.

5.1.2 Competence of health professionals

Association with facility type and cadre

Competence assessed in the vignettes varied significantly by respondent cadre (Figure 10A) and by facility type (Figure 10B). Competence varied from a median of 70% correct in the vignettes (range 60-75%) among doctors to a median of 25% correct (range 10-40%) among the 'other' cadres. Midwives had the second highest vignette score (median of 55% correct, range 45-75%) followed by nurses (median of 50% correct, range 5-75%) and medical assistants (median of 45% correct, range 25-70%). None of the 64 respondents achieved a high score (>75%).

The competence scores of different cadres were reflected in the vignette scores of facility types (Figure 10B). Hospital respondents achieved a median vignette score of 70% as 91% of hospital respondents were either doctors or midwives. Respondents in maternity homes and health centres were mostly midwives, and achieved median vignette scores of 53% and 50%, respectively.

Respondents working in private and public facilities had a lower vignette score (median of 55% correct) compared with semi-public facilities (median of 75% correct) (p=0.01). Providers in rural areas achieved a median of

55% correct, ranging from 5 to 75%, whereas urban respondents achieved a median of 60% with less spread (range 45-75%).

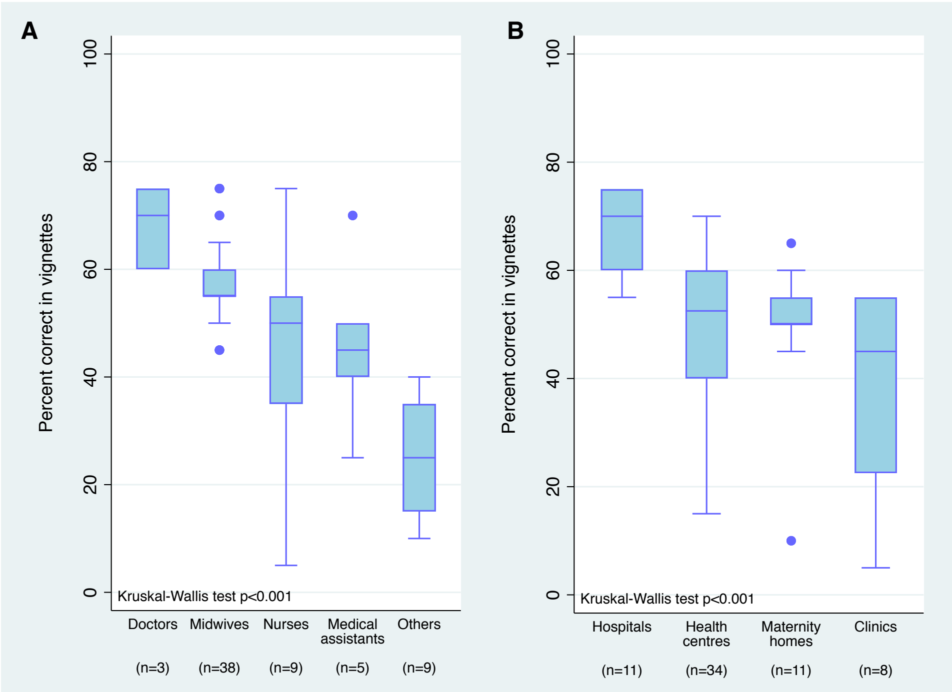

Figure 10. Percentage of correct vignette actions by cadre (A) and facility type (B) in 64 delivery facilities in Brong Ahafo region in Ghana in 2010. The boxes represent 50% of the scores, the whiskers show the range of score and the central horizontal lines show the median percentage correct. Group 'others' includes health assistants, health extension workers, traditional birth attendants and ward assistants.

A similar pattern was seen in competence of respondents by EmOC level with much higher competence of providers in facilities offering CEmOC compared with providers in facilities offering substandard care (Figure 11).

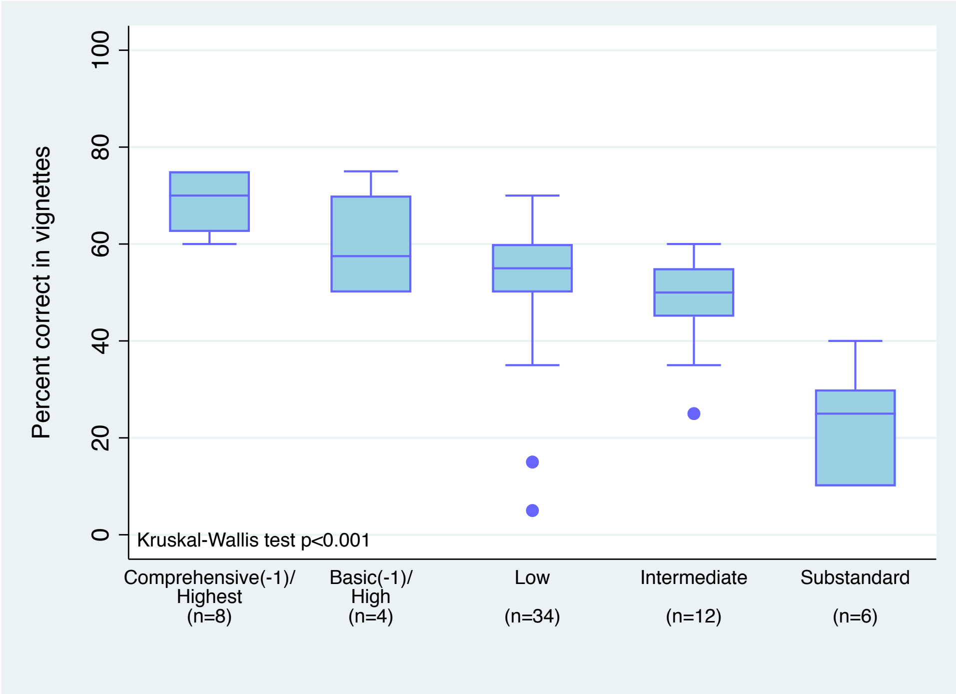

Figure 11. Percentage of correct vignette actions by level of Emergency Obstetric Care (EmOC) in 64 delivery facilities in Brong Ahafo region in Ghana in 2010. The boxes represent 50% of the scores, the whiskers show the range of score and the central horizontal lines show the median percentage correct.

Comparison with relevant infrastructure

Comparing vignette actions and availability of corresponding items (i.e. drugs and equipment) illustrated a lack of necessary items and competence to use them in practice. In general, drugs and equipment were more often available than their use was mentioned in the corresponding vignette cases (Figure 12). All six items were available in all hospitals, and respondents working in hospitals mentioned the corresponding actions more frequently than their peers working in other types of facilities. However, the limiting factor in all kinds of facilities including hospitals was the competence to use the equipment as shown in the vignette cases rather than the lack of equipment.

In general, equipment and drugs were most available in hospitals and least available in clinics. Supplemental oxygen was the least available item present in only 48% of facilities; a third of all health centres, three-quarters of maternity homes and all hospitals had supplemental oxygen available. Only 5% of respondents said they would administer oxygen to a woman in a bleeding shock, and all of these respondents worked in hospitals. Intravenous fluid for management of shock was among the most available items (97% of facilities) and administering fluids for shock management was mentioned by 88% of respondents making it the most mentioned vignette action.

In addition to fluids, the sphygmomanometer, anticonvulsant drugs and foetal heart monitor (either a fetoscope or an electronic foetal heart monitor) were frequently available. However, only 22% of respondents replied they would assess foetal distress and 52% replied they would administer anticonvulsants to a pre-eclamptic woman. Antihypertensive drugs were available only in half of all facilities and management of pre-eclampsia with antihypertensive drugs was mentioned by 42% of respondents (27 out of 64) although 30% of these worked in facilities with no availability of antihypertensive drugs.

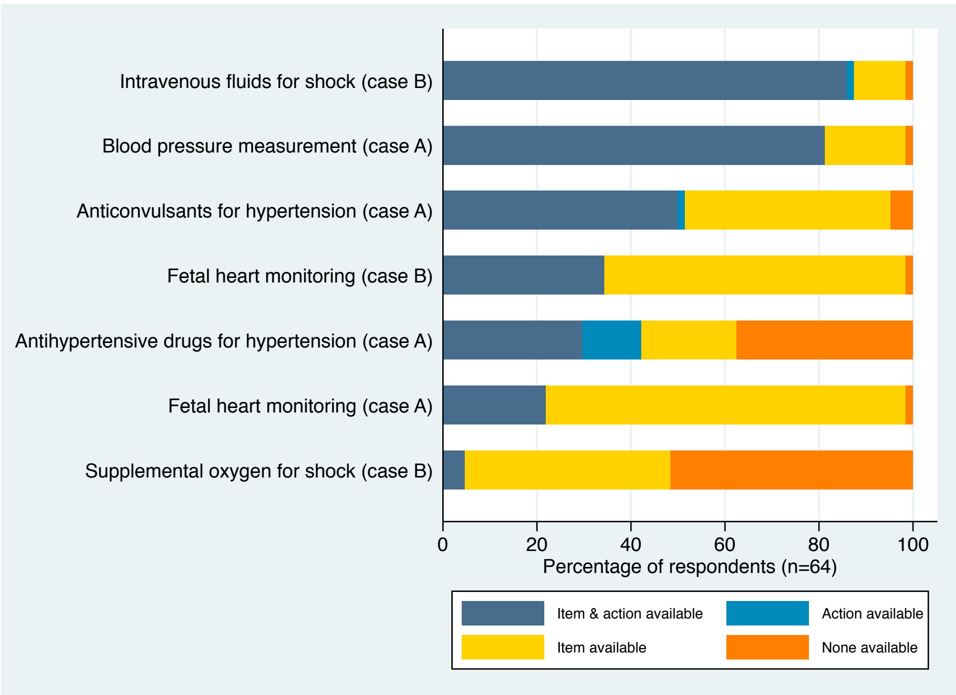

Figure 12. Percentage of correct vignette actions mentioned by the respondents and availability of corresponding items (i.e. drugs and equipment) in 64 delivery facilities in Brong Ahafo region in Ghana in 2010.

Association with workload

Out of the 13,692 births in 2009 in the surveillance area, 9,163 (67%) took place in the 64 facilities providing delivery care. The deliveries were unevenly distributed among health facilities and average delivery workload per SBA varied considerably between facilities. Fifty-seven deliveries were managed in three facilities with no SBAs and five facilities employed SBAs without managing any deliveries in 2009.

Hospitals employed a median of eight SBAs (range 3-53 SBAs) and managed a median of 191 deliveries (range 1-2398 deliveries). Hospitals had the highest workload with a median workload of 52 deliveries per SBA in 2009 (range 1-184). In three hospitals, the workload was over 100 deliveries per SBA and in four hospitals an SBA managed on average less than two deliveries during 2009. The median workload was 45 deliveries per SBA in maternity homes, 21 deliveries per SBA in health centres, 13 deliveries per SBA in clinics and 26 deliveries per SBA overall. The mean overall workload was 39 deliveries per SBA. Higher average workload per SBA was associated with a higher vignette competence (Figure 13).

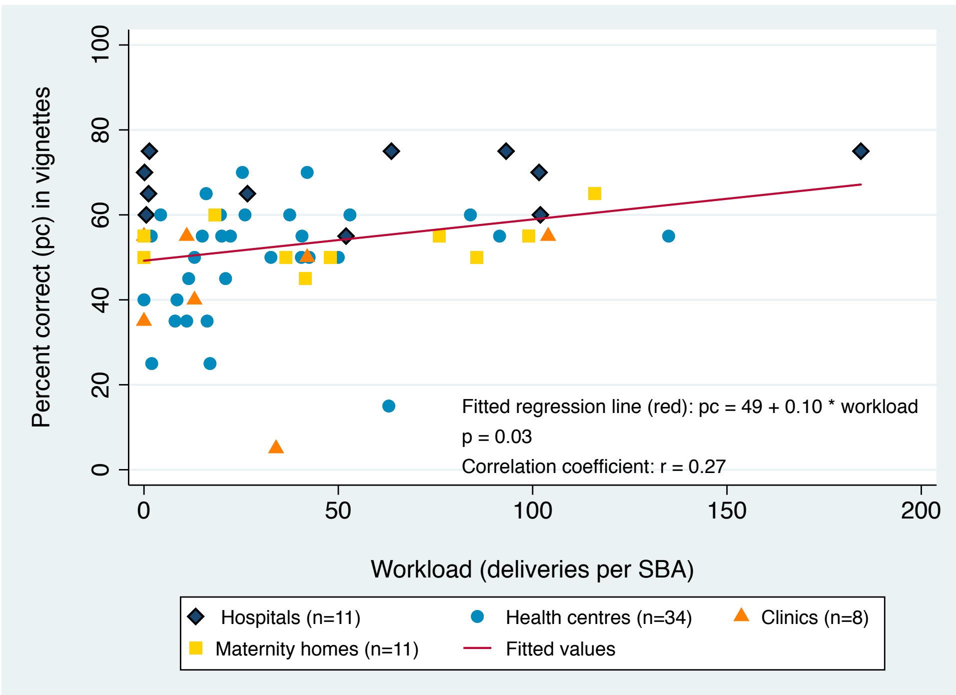

Figure 13. Correlation between average workload per skilled birth attendant (SBA) in 2009 and percent correct in clinical vignettes in 60 delivery facilities in Brong Ahafo region in Ghana in 2010. Four facilities without skilled birth attendants were excluded.

5.2 Distance to care at birth in rural Malawi and Zambia

5.2.1 Association with early neonatal mortality and facility delivery

Malawi

Early neonatal mortality was 22 per 1,000 live births among the 8,842 rural Malawian births. Half of all deliveries (52%) took place in a health facility and half of the sample (49%) lived within five kilometres of a facility providing delivery care. Fifteen percent lived ten or more kilometres away from a delivery facility.

Early neonatal mortality was not associated with distance to care or level of care in unadjusted or adjusted analyses in Malawi (Table 18A). However, the odds of facility delivery decreased considerably with distance; for every ten kilometres increase in distance to delivery care, the odds ratio of facility delivery decreased by 72% in unadjusted analyses and by 65% in adjusted analyses. Level of care was not associated with facility delivery in Malawi.

Zambia

In Zambia, early neonatal mortality was 26 per 1,000 live births among the 3,771 rural births. Thirty-eight percent of the women lived within five kilometres from the closest delivery facility, while one third lived more than ten kilometres away. One third of all deliveries took place in a facility.

In Zambia, longer distance to delivery care was associated with *lower* early neonatal mortality in unadjusted (OR 0.61) and adjusted (OR 0.55) analyses (Table 18B). The odds of facility delivery, however, reduced for every ten kilometres additional distance in unadjusted (OR 0.67) and adjusted (OR 0.73) analyses. Unlike in Malawi, higher level of care in the closest facility increased the odds of facility delivery in Zambia.

Table 18A. Unadjusted and adjusted associations of distance to closest delivery facility and level of delivery care with early neonatal mortality and with facility delivery in the Malawi 2004 Demographic and Health Survey.				
	MORTALITY (n=8,260)[a]		FACILITY DELIVERY (n=8,416)[a]	
	Unadjusted OR (95% CI)	Adjusted[b] OR (95% CI)	Unadjusted OR (95% CI)	Adjusted[c] OR (95% CI)
Distance to closest facility (per 10 km)	1.08 (0.70-1.68) p=0.72	0.97 (0.58-1.60) p=0.89	0.28 (0.21-0.36) p<0.001	0.35 (0.26-0.46) p<0.001
Level of care in closest facility (or 5 km from there)	0.99 (0.88-1.12) p=0.90	1.02 (0.90-1.16) p=0.74	1.05 (0.98-1.12) p=0.14	0.99 (0.93-1.05) p=0.66

[a]Sample sizes are reduced due to missing values of some confounders.
[b]Malawi mortality model was adjusted for the following variables: men's opinion on female autonomy in cluster, ethnicity, partner's occupation, partner's education, women's media use in cluster, education, wanted pregnancy, siblings <7 years old, mother's estimate of newborn size, men's media use in cluster, women's mobility autonomy in cluster, language, women's financial autonomy in cluster, multiple pregnancy, occupation, marital status, age at birth, modern attitudes, men's modern attitudes in cluster, exposure to health programmes in media, media use, child sex
[c]Malawi health facility delivery model was adjusted for the following variables: wealth, women's relationship autonomy in cluster, partner's education in years, education in years, partner's occupation, men's opinion on female autonomy in cluster, women's modern attitudes in cluster, women's financial autonomy in cluster, women's autonomy to seek health care in cluster
Level of care data were obtained from a Health Facility Census conducted by Japan International Cooperation Agency in 2002.
OR, Odds ratio; CI, Confidence interval; km, kilometre.

Table 18B. Unadjusted and adjusted associations of distance to closest delivery facility and level of delivery care with early neonatal mortality and with facility delivery in the Zambia 2007 Demographic and Health Survey.				
	MORTALITY (n=3,019)[a]		FACILITY DELIVERY (n=3,682)[a]	
	Unadjusted OR (95% CI)	Adjusted[b] OR (95% CI)	Unadjusted OR (95% CI)	Adjusted[c] OR (95% CI)
Distance to closest facility (per 10 km)	0.61 (0.39-0.96) p=0.03	0.55 (0.35-0.87) p=0.01	0.67 (0.50-0.89) p=0.005	0.73 (0.57-0.94) p=0.01
Level of care in closest facility (or 5 km from there)	1.04 (0.83-1.29) p=0.75	1.02 (0.82-1.26) p=0.87	1.19 (1.07-1.32) p=0.01	1.12 (1.00-1.24) p=0.04

[a]Sample sizes are reduced due to missing values of some confounders.
[b]Zambia mortality model was adjusted for the following variables: partner's education in years, relationship autonomy, partner's occupation, media use, women's financial autonomy in cluster, wealth, women's relationship autonomy in cluster, modern attitudes, mother's newborn size estimate, marital status, occupation, household composition and siblings <7 years, education, literacy, women's mobility autonomy in cluster
[c]Zambia facility delivery model was adjusted for: women's relationship autonomy in cluster, men's modern attitudes in cluster, language, wealth, women's autonomy to seek health care in cluster, men's opinion on female autonomy in cluster
Level of care data were obtained from a Health Facility Census conducted by Japan International Cooperation Agency in 2005.
OR, Odds ratio; CI, Confidence interval; km, kilometre.

5.2.2 Facility delivery in the cluster and early neonatal mortality

To understand the role of facility delivery better, the following characteristics of deliveries were stratified by proportion of facility delivery in the cluster: facility deliveries among all deliveries, hospital deliveries (as opposed to deliveries in smaller facilities) among facility deliveries, caesarean sections among facility deliveries and early neonatal mortality (Table 19). Cluster-level stratification was used to overcome confounding by case-mix inherent to unstratified individual-level analyses (see 2.2.6 for details on definition of confounding by case-mix).

In Malawi and in Zambia, the proportion of hospital deliveries among facility deliveries were more common in clusters with low percentage of facility deliveries. For example, in Malawi 65% of facility deliveries took place in a hospital in clusters with less than 15% of facility deliveries whereas 38% of facility deliveries took place in hospitals among clusters with more than 85% of facility deliveries. In addition, delivery by caesarean section was more common among clusters with low proportion of facility deliveries in both countries.

Proportion of facility delivery in the cluster was not associated with early neonatal mortality in Malawi (OR 1.46, 95% CI: 0.79-2.70) or in Zambia (OR 2.05, 95% CI: 0.89-4.73); crude mortality stratified by proportion of facility delivery in the cluster is shown in Table 19 (fifth column). Facility delivery was not associated with early neonatal mortality at the individual level in Malawi (OR 0.86) or Zambia (OR 1.33). In Zambia, early neonatal mortality among facility deliveries seemed to decrease with increasing proportion of cluster-level facility deliveries. In Malawi, this trend was not as clear.

Table 19. Characteristics of deliveries stratified by proportion of facility deliveries in the cluster in the Malawi 2004 and Zambia 2007 Demographic and Health Surveys.

Facility deliveries in cluster	Facility deliveries among all deliveries (%)	Hospital deliveries among facility deliveries (%)	Caesarean sections among facility deliveries (%)	Early neonatal mortality per 1,000 live births among all births[c]		OR of early neonatal mortality among facility vs home births[c]
				All	Facility / Home births	
Malawi n=8,679[a]	4,525 (52.1)	1,823 (40.3) p=0.003[b]	211 (4.7) p=0.004[b]	22	21 / 24	0.86 (0.65-1.14) p=0.29[d]
<15%	40 (8.7)	26 (65.0)	6 (15.0)	19	25 / 19	1.33 (0.16-10.99)
15-50%	1,212 (33.9)	502 (41.4)	66 (5.5)	21	14 / 25	0.54 (0.32-0.94)
50-85%	2,416 (65.4)	974 (40.3)	107 (4.4)	24	24 / 23	1.04 (0.67-1.62)
≥85%	857 (90.9)	321 (37.5)	32 (3.7)	22	21 / 35	0.58 (0.17-2.02)
Zambia n=3,682[a]	1,198 (32.4)	225 (21.3) p<0.001[b]	55 (4.6) p=0.02[b]	25	29 / 22	1.33 (0.87-2.04) p=0.08[d]
<15%	69 (7.2)	22 (31.9)	10 (14.5)	20	42 / 18	2.44 (0.69-8.61)
15-50%	574 (30.7)	146 (25.4)	23 (4.0)	24	31 / 21	1.51 (0.82-2.77)
50-70%	387 (58.9)	64 (16.5)	13 (3.4)	34	30 / 40	0.75 (0.32-1.72)
≥70%	168 (82.4)	23 (13.7)	9 (5.4)	24	18 / 56	0.30 (0.05-1.91)

[a]Only the first child of multiple births included. Place of delivery missing: 12 births in Malawi and 10 births in Zambia.
[b]p-values are from Chi square tests.
[c]n=8,830 in Malawi and n=3,761 in Zambia. Place of birth missing: 12 births in Malawi and 10 births in Zambia.
[d]p-values are from tests for trend of homogeneity of odds ratios over strata.
Percentages are row percentages by proportion of facility deliveries in cluster. OR, Odds ratio.

5.3 Socioeconomic inequalities at birth in 72 countries

5.3.1 Inequalities in early neonatal mortality

There were 13,643 early neonatal deaths among the sample of 679,818 live births and 667,477 deliveries. The weighted pooled early neonatal mortality was 18.5 deaths (95% confidence interval [95% CI]: 16.8, 20.2) per 1,000 live births.

There were 2.9 early neonatal deaths per 1,000 live births less among the richest compared with the poorest, and 3.9 deaths per 1,000 live births less among the most educated compared with the least educated mothers in unadjusted analyses. Adjusting for education (in wealth analyses) and wealth (in education analyses) and residence (both analyses), decreased the wealth- and education-related inequalities further to 1.8 deaths and 2.5 per 1,000 live births less, respectively (Table 20).

5.3.2 Inequalities in postneonatal infant mortality

For comparison, inequalities in postneonatal infant mortality were studied using the same sample of 678,818 live births. There were 12,920 postneonatal infant deaths and the weighted pooled postneonatal infant mortality was 17.1 (95% CI: 15.1, 19.1) per 1,000 live births.

The inequalities in postneonatal infant mortality were considerably larger compared with inequalities in early neonatal mortality: The wealth- and education-related inequalities were approximately 10 per 1,000 live births in unadjusted analyses and 6.4 per 1,000 live births in adjusted analyses (Table 20).

5.3.3 Inequalities in facility delivery

Facility delivery was 43% higher among the richest than the poorest and 37% higher among the most versus the least educated mothers. Adjusting for wealth, education and residence reduced the wealth-inequalities to 28% and the education-inequalities to 22% (Table 20). The overall weighted pooled prevalence of facility delivery was 68% (95% CI: 64, 72).

Table 20. Wealth-related and education-related inequalities in early neonatal mortality, postneonatal infant mortality and facility delivery in 72 low- and middle-income countries.

Outcome	Wealth-related inequalities (95% CI)	Education-related inequalities (95% CI)
Early neonatal mortality (n=679,818[a]) Average pooled and weighted mortality: 18.5 deaths/1,000 live births		
Mortality difference / 1,000 live births, unadjusted	-2.9 (-5.0, -0.8)	-3.9 (-5.8, -2.1)
OR of mortality, unadjusted	0.86 (0.76, 0.97)	0.77 (0.68, 0.87)
Mortality difference / 1,000 live births, adjusted[b]	-1.8 (-3.6, -0.1)	-2.5 (-4.1, -1.0)
OR of mortality, adjusted[b]	0.93 (0.82, 1.04)	0.85 (0.76, 0.95)
Postneonatal infant mortality (n=679,818[a]) Average pooled and weighted mortality: 17.1 deaths/1,000 live births		
Mortality difference/ 1,000 live births, unadjusted	-10.4 (-12.8, -8.0)	-9.7 (-11.6, -7.8)
OR of mortality, unadjusted	0.50 (0.42, 0.59)	0.43 (0.36, 0.51)
Mortality difference / 1,000 live births, adjusted[b]	-6.4 (-8.7, -4.2)	-6.4 (-8.2, -4.6)
OR of mortality, adjusted[b]	0.64 (0.55, 0.76)	0.58 (0.49, 0.68)
Facility delivery (n=667,478[a]) Average weighted and pooled facility delivery 68%		
Difference in facility delivery (%), unadjusted	42.9 (34.6, 51.2)	37.3 (31.0, 43.5)
OR of facility delivery, unadjusted	18.22 (12.99, 25.58)	20.10 (15.97, 25.30)
Difference in facility delivery (%), adjusted[b]	27.5 (23.0, 31.9)	22.2 (18.9, 25.5)
OR of facility delivery, adjusted[b]	6.76 (5.25, 8.70)	6.85 (5.79, 8.10)

[a]Unweighted population count.
[b]Wealth-related analyses adjusted for urban-rural residence and education, and education-related inequalities adjusted for urban-rural residence and wealth.
CI, confidence interval; OR, odds ratio.

Country-level comparisons illustrated that there were many countries with significant socioeconomic inequalities in postneonatal infant mortality and in facility delivery whereas the number of countries with significant inequalities in early neonatal mortality was lower. For example, early neonatal mortality was significantly lower (at $p<0.05$) among the richest compared with the poorest in nine countries, while the corresponding wealth-related inequalities in postneonatal infant mortality were significant (at $p<0.05$) in 31 countries (compare Figures 14A and B). The pattern was similar for education-inequalities (Figure 15). Further, wealth-related and education-related inequalities in early neonatal mortality were small in most countries, while wealth- and education-inequalities in coverage of facility deliveries were large in most countries (Figures 16 and 17).

5.3.4 Facility delivery in the cluster and early neonatal mortality

Association between cluster-level facility delivery and early neonatal mortality was analysed to further investigate the role of facility delivery and the problem of confounding by case-mix present in analyses investigating the association between individual-level facility delivery and mortality. In unadjusted analyses, there were 4.1 (95% CI: 2.2, 6.0) deaths per 1,000 live births less in clusters with the highest compared with the lowest proportion of facility deliveries. Adjusting for residence, average wealth rank and education rank in cluster reduced the inequality to 1.6 (95% CI: 0.5, 3.7) per 1,000 live births less, and the inequality was not significant anymore.

5.3.5 Sensitivity analyses

Individual-level facility delivery and birth with a skilled delivery attendant were both associated with slightly lower early neonatal mortality in unadjusted analyses, but these effects disappeared when analyses were adjusted for residence, wealth and education.

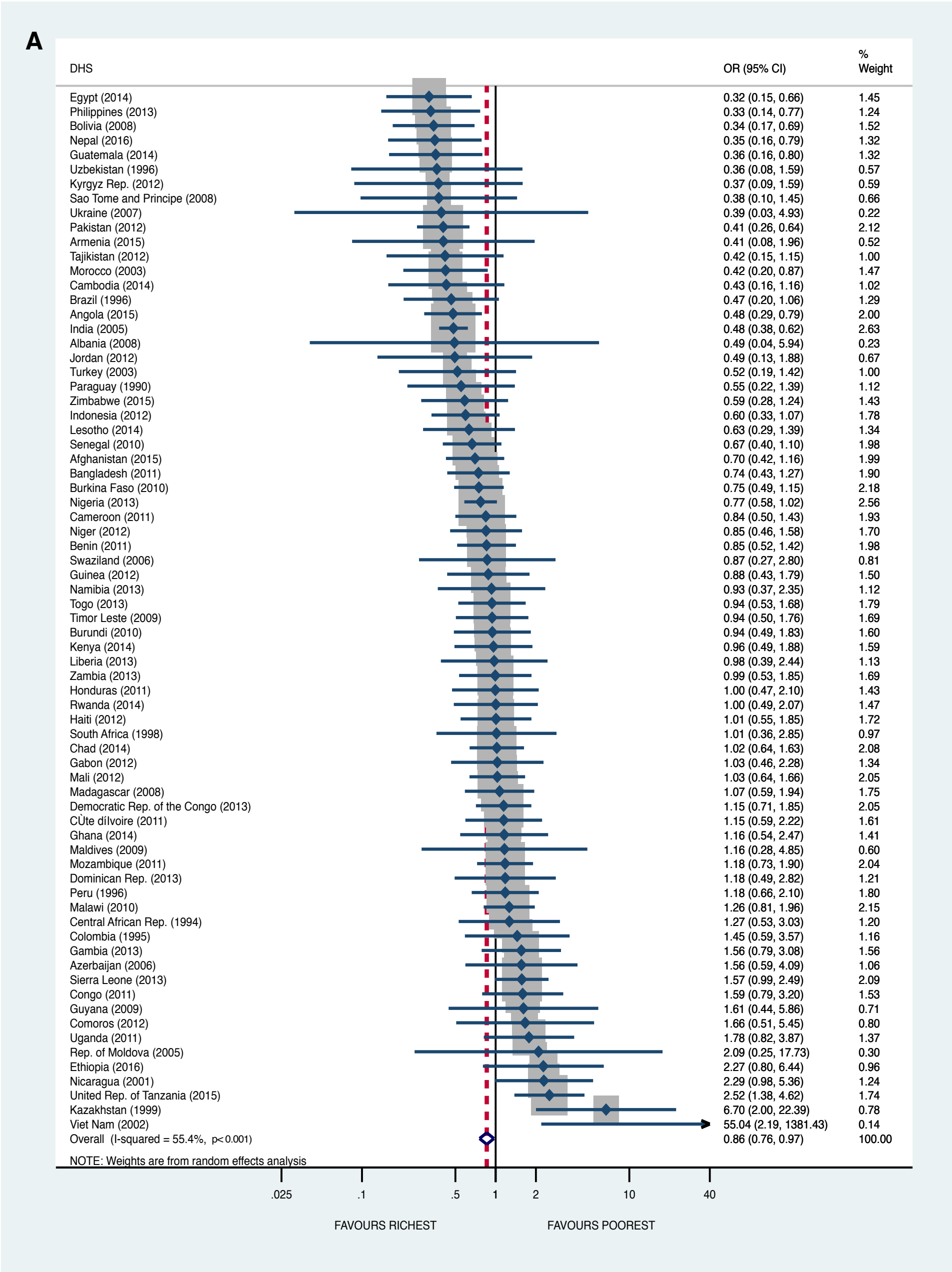

Figure 14A. Wealth-related country-level and pooled inequalities in early neonatal mortality in 72 low- and middle-income countries (unadjusted). DHS, Demographic and Health Survey; OR, Odds ratio. 95% CI, 95% Confidence interval.

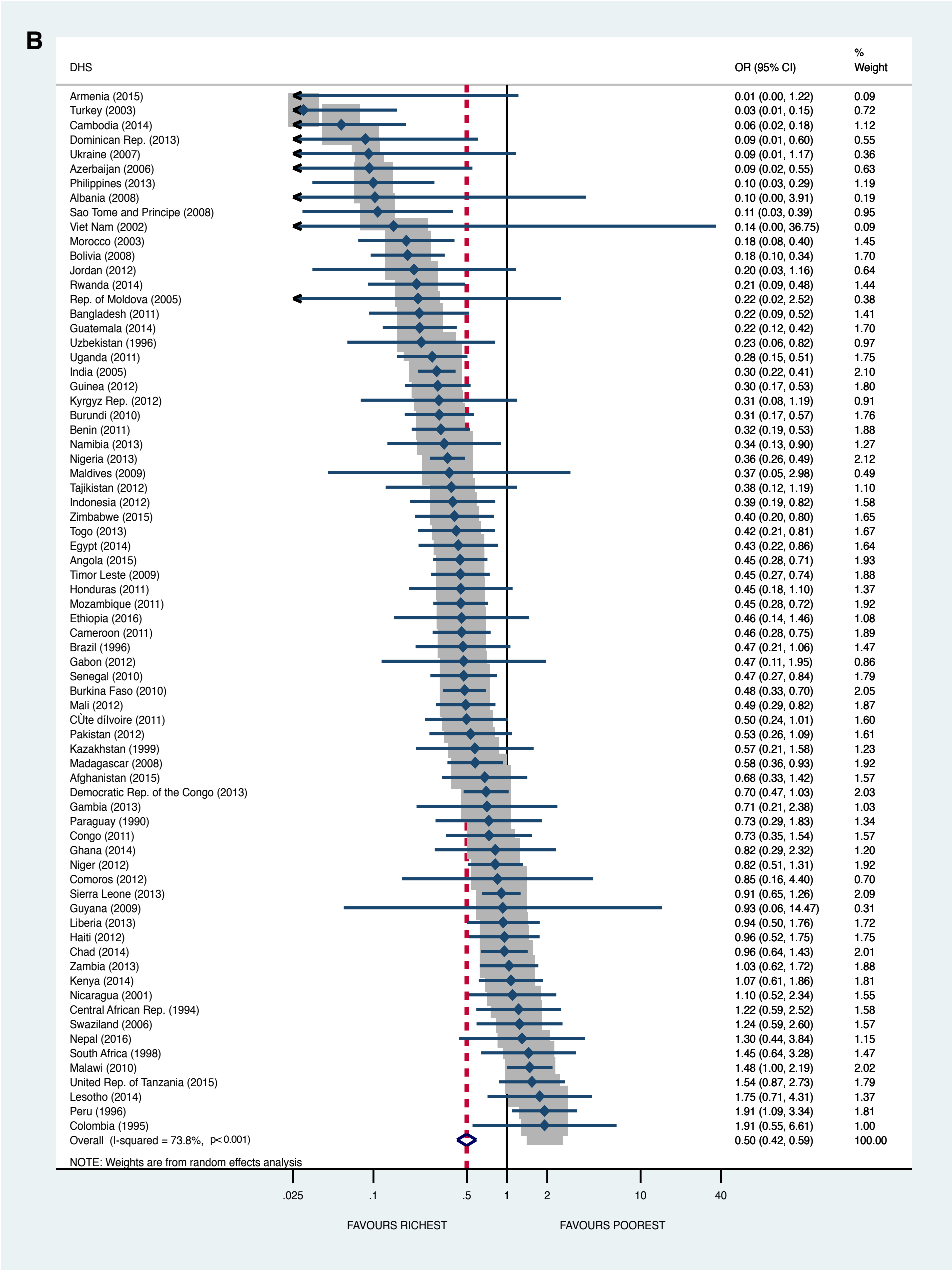

Figure 14B. Wealth-related country-level and pooled inequalities in postneonatal infant mortality in 72 low- and middle-income countries (unadjusted). DHS, Demographic and Health Survey; OR, Odds ratio. 95% CI, 95% Confidence interval.

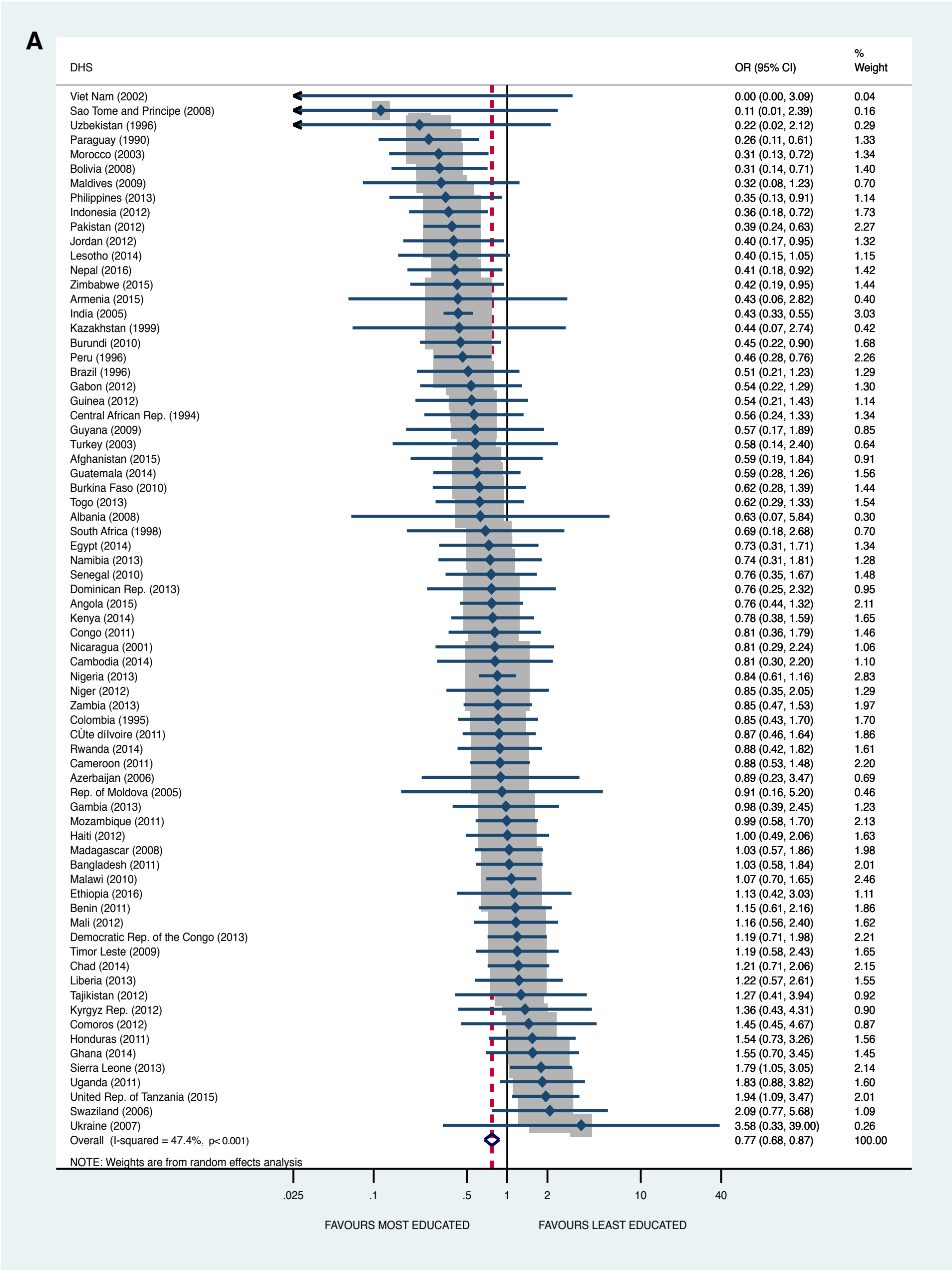

Figure 15A. Education-related country-level and pooled inequalities in early neonatal mortality in 72 low- and middle-income countries (unadjusted). DHS, Demographic and Health Survey; OR, Odds ratio. 95% CI, 95% Confidence interval.

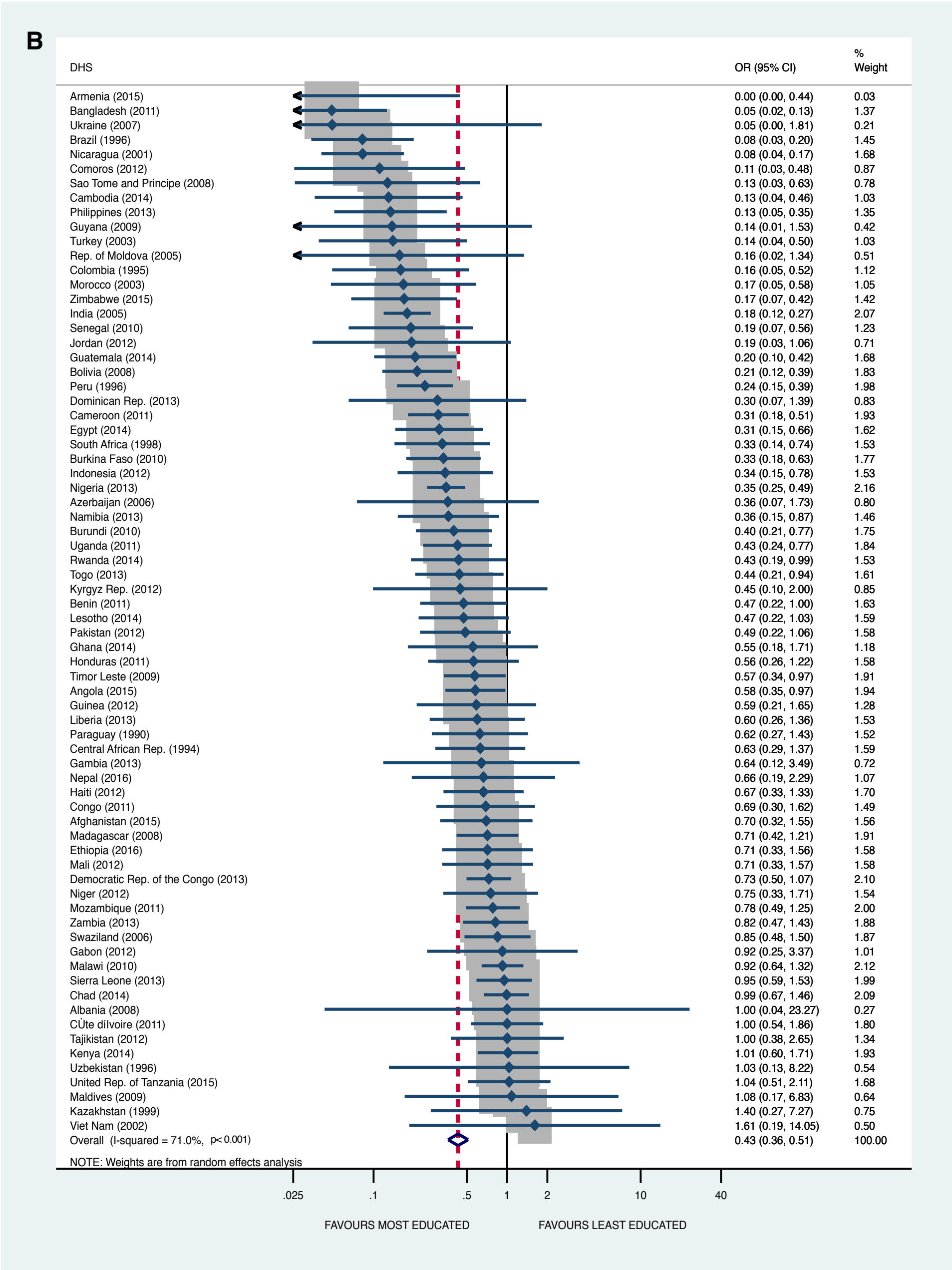

Figure 15B. Education-related country-level and pooled inequalities in postneonatal infant mortality in 72 low- and middle-income countries (unadjusted). DHS, Demographic and Health Survey; OR, Odds ratio. 95% CI, 95% Confidence interval.

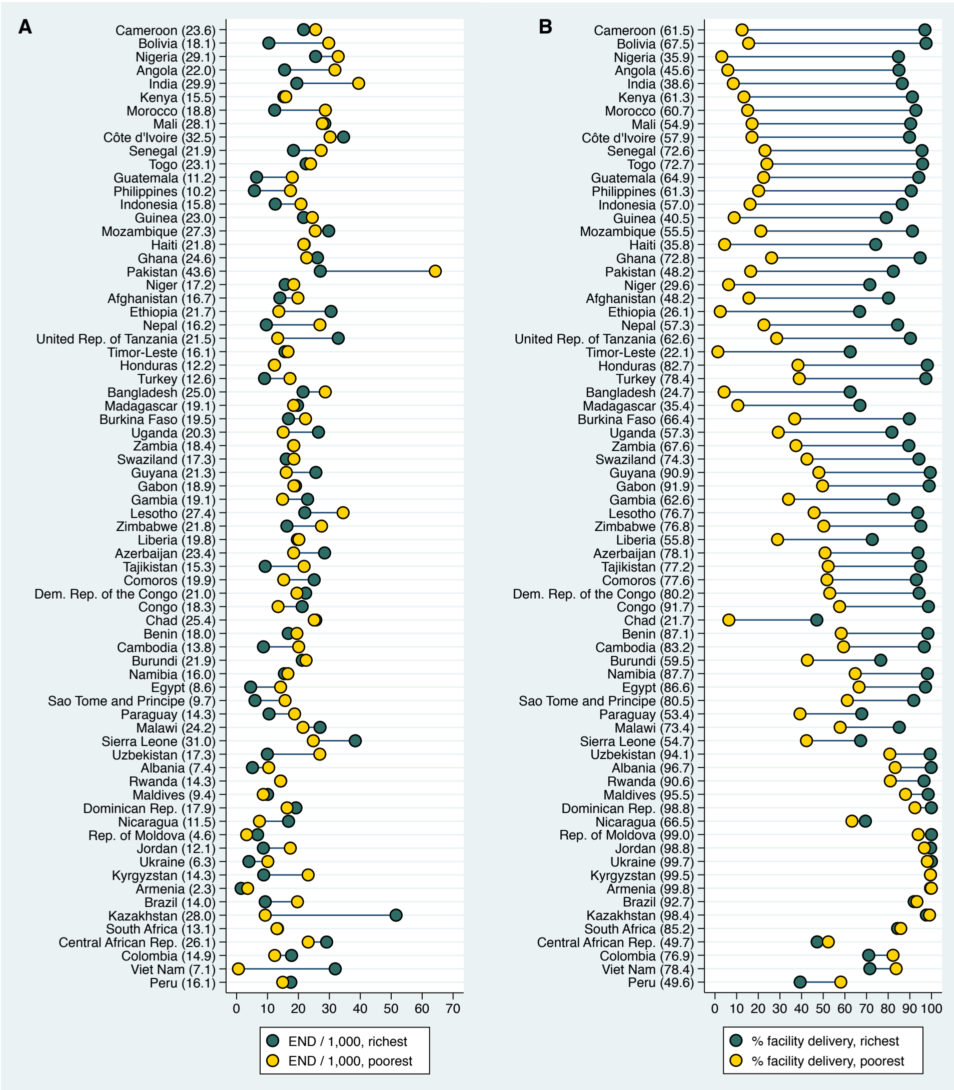

Figure 16. Wealth-related inequalities in early neonatal mortality (A) and coverage of facility delivery (B) in 72 low- and middle-income countries (unadjusted). Countries sorted in descending order of inequalities in coverage with facility delivery. END, early neonatal death.

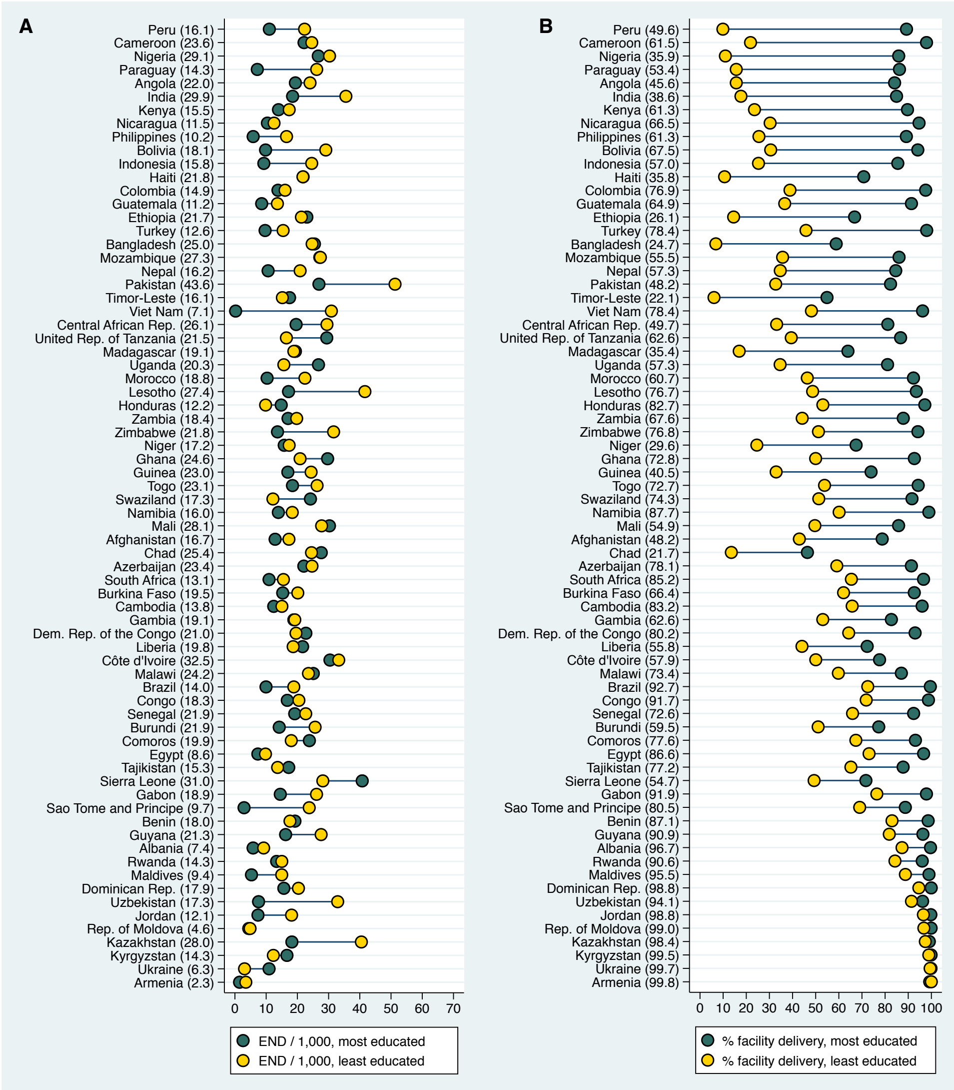

Figure 17. Education-related inequalities in early neonatal mortality (A) and coverage of facility delivery (B) in 72 low- and middle-income countries (unadjusted). Countries sorted in descending order of inequalities in coverage with facility delivery.

6 DISCUSSION

6.1 Summary of main findings

A health facility assessment was conducted to study quality of delivery and newborn care in 64 health facilities providing delivery care in Brong Ahafo region in Ghana. Quality care was assessed in four dimensions: 1) routine care, 2) emergency obstetric care, 3) emergency newborn care and 4) non-medical care.

Out of the four dimensions, emergency care was of poorest quality while quality of routine and non-medical care was higher. Further, facilities providing high quality care in one dimension did not necessarily provide high quality in another dimension. Quality of medical care (i.e. quality of routine and emergency obstetric and newborn care) was found to be generally low in the study facilities, and hospitals provided better care compared with smaller facilities.

Effective coverage of high-quality delivery care was assessed by linking surveillance data to quality of care in the 64 study facilities. Sixty-eight percent of deliveries took place in health facilities, but only 18% of babies were born in one of the three facilities providing high or highest level of care in all four dimensions, indicating a large gap between coverage and quality of care at birth.

Competence of delivery attendants was assessed using clinical vignettes. Competence varied by type of cadre and type of health facility and was highest among doctors and lowest among cadres other than doctors, midwives or nurses (i.e. health assistants, health extension workers, traditional birth attendants and ward assistants). Further, competence was generally better among providers working in hospitals and in CEmOC facilities compared with respondents working in smaller facilities. The only two cadres demonstrating moderate competence with reasonable spread in the vignettes were doctors and midwives. Median competence of nurses was also moderate, but competence varied from 5% to 75% within the cadre.

Comparison of availability of necessary items and competence to use these items in two vignettes describing obstetric emergencies illustrated that competence may limit clinical practice even more than lack of equipment. Higher average workload per skilled birth attendant correlated with higher competence in the two clinical vignettes.

It is difficult to study the effect of individual-level facility delivery on early neonatal mortality as this association is confounded by case-mix (i.e. adverse selection of complicated deliveries into facilities, see 2.2.6 and Figure 5).

Further, data on complications is rarely available or trustworthy (Bell et al., 2003; Glei et al., 2003). Therefore, the effects of two distal determinants (distance to a health facility and socioeconomic position) and of cluster-level facility delivery on early neonatal mortality were analysed.

The effects of distance to care and level of care on 1) early neonatal mortality and 2) facility use for delivery were studied using DHS data from rural Malawi and Zambia and health facility census data from both countries. The hypothesis was that proximity to a health facility and to a higher level of care is associated with higher delivery facility use and lower early neonatal mortality.

Although facility use decreased with increasing distance in both countries, distance or level of care were not associated with early neonatal mortality in Malawi. In Zambia, increasing distance to delivery facility unexpectedly *reduced* early neonatal mortality, but the level of care at the closest facility was not associated with early neonatal mortality. In Malawi, higher level of care in the closest facility was not associated with higher facility use unlike in Zambia where higher level of care at the closest facility increased facility use (Gabrysch et al., 2011a).

To understand these surprising findings, the role of delivery facilities was further investigated by stratifying births by the average proportion of facility deliveries in the cluster, by average proportion of caesarean sections in the cluster and by average proportion of hospital deliveries in the cluster. In addition, the association between proportion of facility delivery in the cluster and early neonatal mortality was studied.

Caesarean sections and hospital deliveries were more common in clusters with a low percentage of facility deliveries, suggesting that health facility deliveries are more likely to be complicated among women from clusters with low facility use. In these clusters, care is mainly sought when complications arise whereas in clusters with high facility use, facility delivery is the norm and a large proportion of facility deliveries are thus uncomplicated. Despite this finding, proportion of facility delivery in the cluster was not associated with early neonatal mortality in Malawi or Zambia.

Wealth-related and education-related inequalities in early neonatal mortality, postneonatal infant mortality and coverage of facility delivery were quantified in 72 low- and middle-income countries. In unadjusted analyses, wealth- and education-related inequalities in early neonatal mortality were surprisingly small (2.9 per 1,000 and 3.9 per 1,000 live births, respectively) amounting to less than half of the inequalities in postneonatal infant mortality (approximately 10 per 1,000 live births for education and wealth). Adjusting for education (in wealth analyses), wealth (in education analyses) and residence (urban, rural) decreased the inequalities in mortality further.

At the same time, coverage of facility delivery (i.e. the key intervention in reducing early neonatal mortality) was 43% absolute percentage points higher among the richest compared with the poorest and 37% higher among the most educated versus the least educated mothers. Cluster-level facility delivery was associated with early neonatal mortality, but this effect disappeared when the analyses were adjusted for education, wealth and residence. In many countries, facility delivery did not convey the expected survival benefit for the newborn.

Although distance was a barrier to delivery care in rural Malawi and Zambia, longer distances did not increase early neonatal mortality in these countries. The large wealth- and education-inequalities in access to care did not translate into corresponding early neonatal mortality in most of the 72 DHS countries or in the pooled sample. Although these findings suggest that quality of care in health facilities was insufficient to save newborn lives at birth, definitive conclusions about quality cannot be made without better data sources.

6.2 Strengths and limitations

The quality of care assessment conducted in Brong Ahafo region had several strengths and limitations. The health facility assessment was the first to assess the signal functions as they were suggested by Gabrysch et al. (2012a). Although the newborn signal functions or clinical vignettes used in this study have not been validated against a health outcome, they are widely accepted as the main interventions to prevent mortality related to childbirth (Moxon et al., 2015; WHO et al., 2006; WHO & Unicef, 2014). Therefore, all of them, including manually assisted delivery, should be taught and performed.

It is important to keep in mind that signal functions are not intended to cover the whole range of actions needed to manage complications, but to 'signal' a certain level of health facility functioning (WHO et al., 2009). The signal functions will only save lives if they are conducted in an appropriate manner (e.g. avoiding their over-use and performing them only when indicated), by skilful professionals and at the right time (Miller et al., 2016). All medical procedures possess a complication risk that needs to be weighed against their potential benefit. Therefore, I cannot be sure whether even the highest quality in the assessment based on signal functions would indeed lead to improved health outcomes.

One major limitation of the quality assessment relates to the generalizability of its results. The 64 health facilities are located in central rural Ghana and these results do not necessarily apply to the rest of Ghana or other low- and middle-income countries. However, the study area in Ghana was fairly large including seven districts and had a maternal mortality ratio and coverage of facility births close to average Ghanaian estimates (Unicef, 2016). Therefore, I would argue that the study area is a fairly typical rural area of Ghana. Further, the multidimensional approach has been adapted to and used in several other contexts and countries (Allen et al., 2017; Wichaidit et al., 2016; Winter et al., 2017).

The health facility assessment in this study was based on theoretical performance of signal functions as I did not check whether they have been performed within the past three months as required by the UN handbook (WHO et al., 2009). This was due to two reasons. First, these data were generally not available as medical records in most facilities were poor. Second, measuring true rather than theoretical performance may underestimate functioning of small facilities due to lower numbers of deliveries and emergencies in these facilities despite their capacity to perform a function. Therefore, the assessment is more likely to overestimate than underestimate the true capacity of facilities to perform the interventions.

In addition, availability of some items may have been overestimated as I observed availability of tracer items only, instead of checking availability of all drugs and equipment included in the assessment. For example, although oxytocin was reportedly available in one facility, observation revealed that the only available oxytocin ampoule was frozen inside a large lump of ice in a freezer and therefore not usable.

Further, I did not observe clinical care, but used clinical vignettes instead as observation of obstetric complications in all facilities would require substantial resources. The major shortcoming of vignettes is that they may lead to social desirability bias, i.e. they may test knowledge rather than actual performance in practice (Peabody & Liu, 2007; Shah et al., 2010; Veloski et al., 2005). However, vignettes have been shown to reflect physician's actual practice better compared with chart abstracts in high-income settings (Peabody et al., 2000; Peabody et al., 2004a), and they have been used in multiple studies from low- and middle-income countries (Minas et al., 2011; Peabody & Liu, 2007; Peabody et al., 2014; Peabody et al., 2006; Peabody et al., 2004b; Vesel et al., 2013). If they tested knowledge only, the assessment used in this study would overestimate true performance. Therefore, the low vignette scores in this study are a major concern.

Competence of health workers was evaluated using clinical vignettes that described two obstetric emergencies – pre-eclampsia and ante-partum haemorrhage. Ideally, more vignettes describing all dimensions of care would have been used to form a more comprehensive picture of competence. We needed to balance the time taken to conduct the assessment and being as comprehensive as possible. Further, we did not want to spend too much of the health providers' time during their working day. However, the vignettes described two key life-threatening emergencies for the mother and the unborn baby, and all facilities providing delivery care should have the means to recognize and start treatment for these emergencies.

We visited each health facility only once meaning that we assessed items and interviewed the most experienced provider present at the time of that one visit. This might lead to underestimation of quality or competence particularly in small facilities if the most competent provider happened to be absent or equipment was temporarily unavailable. However, the quality captured in the quality assessment would have been the quality available to a labouring woman presenting at the facility that day. Further, it is likely that there are fewer and possibly less experienced providers available during night time or weekends compared with daytime on a working day when we visited the facilities. Therefore, we will rather have overestimated quality for women presenting outside working hours. Although the HFA and the surveillance were conducted one year apart (in 2010 and 2009, respectively), it is unlikely that any major changes in health facilities have occurred between the surveillance and the HFA.

The major strength of the quality and competence assessments was that the HFA included all facilities and the surveillance included all deliveries in the study area. The delivery location for 98% of deliveries was known enabling us to link these deliveries with information on quality of care collected in the HFA and to estimate average workload. The workload estimates include uncertainty as not necessarily all skilled birth attendants managed patients and some patients may have been managed by staff without training. Some facilities (particularly one big regional hospital) might have managed patients coming from areas other than the study area but excluding this hospital from the analysis did not affect the overall results.

While the analyses related to geographic access to care at birth in rural Malawi and Zambia were controlled for numerous confounders at the individual and community level, residual confounding caused by unmeasured variables (discussed later in this paragraph) is still possible. The main limitations of these analyses arise from the distance measurement, level of care classification and the mortality data.

The distance measurements in Malawi and Zambia are approximations of distance due to various potential sources of error, such as scrambling of geo-referenced data (see 4.3.6) (Burgert et al., 2013), erroneous geographic coordinates of facilities or clusters, using straight-line distance instead of true travel times and distance measurements from the centre of clusters to approximate measurement from households. These factors would likely be non-differential with respect to mortality and result in a decreased distance effect.

Time taken to get to a health facility is more important than distance in case of an obstetric complication. Time could be modified by several factors, such as maternity waiting homes or alternative pre-delivery locations (other than home) and transport options. These factors could be differential in terms of distance, i.e. more commonly used by remote populations that need to overcome long distances. This would lead to diluted or even disappearing distance effects on facility use and mortality. However, a strong association of facility use with distance was detected, which somewhat validates the distance measure.

Details on newborn care were not included in the dataset which limited the assessment of newborn care. For example, the newborn signal functions had not been defined at the time the data were collected. In Zambia, this study assessed emergency obstetric care that plays an important role in newborn survival but is not comprehensive regarding newborns. The 2002 Malawi Health Facility Census did not contain information on emergency obstetric signal functions, and therefore fewer details were used in the classification of facilities in Malawi. Nevertheless, this study remains one of the few that have considered level of care (Leslie et al., 2016; McKinnon et al., 2014a).

Level of care may have changed in health facilities over the Demographic and Health Survey recall periods (1999-2004 in Malawi and 2002-2007 in Zambia) whereas the health facility censuses were cross-sectional assessments conducted in 2002 in Malawi and in 2005 in Zambia. However, big changes in the level of care are unlikely as quality of care tends to change slowly and the censuses seem a decent approximation as they were carried out in the middle of the Demographic and Health Survey recall periods.

The analyses on socioeconomic inequalities in early neonatal mortality benefitted from a large sample size with data from 72 low- and middle-income countries. Using relative socioeconomic position in each country enabled me to compare mortality differences between the most and least advantaged groups in each country. The entire wealth-and education-distributions were accounted for by using the slope index of inequality (Barros & Victora, 2013). Further, several sensitivity analyses were performed comparing the richest and poorest wealth quintiles and education levels instead of years, and results from these analyses were consistent with the main findings.

Previous multicountry studies have focused on inequalities in neonatal or later child mortality (see 2.3.6) whereas this study reported inequalities in *early* neonatal mortality – which is more closely related to care at birth. To my knowledge, this is the first nationally representative multicountry analysis reporting wealth-related and education-related inequalities in early neonatal mortality. I additionally reported inequalities in coverage of facility delivery and skilled birth attendant and compared inequalities in early neonatal mortality with postneonatal infant mortality.

Limitations of the DHS data influenced the studies related to geographic and socioeconomic access to care. Although the surveys are very well-standardized, the data relies on retrospectively reported deaths by mothers and misclassification, heaping, and underreporting of deaths can cause uncertainties (Boerma et al., 1994; Footman et al., 2015; Macro International Inc., 1994; Pullum, 2006). According to the Malawi 2004 DHS final report, specifically early neonatal deaths were underreported in the Malawi 2004 DHS (National Statistical Office - NSO/Malawi & ORC Macro, 2004), however, this was not reported for Zambia 2007 where the counter-intuitive association was found. If underreporting of deaths was differential with distance, lower or even reverse associations between distance and early neonatal mortality would be found. The differential underreporting could be due to higher workload triggered by a death for the DHS interviewers, and longer travel distances for the interviewers might lead to an incentive to reduce their workload particularly in remote locations.

There are very few factors that would act the other way and increase neonatal mortality among those living close to health facilities or among the rich and educated. One factor might be unnecessary medical procedures among those having better geographic or socioeconomic access to delivery care (Miller et al., 2016; ten Hoope-Bender et al., 2014). An alternative explanation is that there was an unknown negative confounder that was not controlled for, for example, obesity is more common among the wealthy and associated with early neonatal mortality (Cresswell et al., 2012). However, well-functioning health facilities should be able to manage obese patients as they do in high-income settings where mortality is low and obesity rates are high.

Early neonatal deaths can easily be misclassified as stillbirths particularly among home deliveries (Lawn et al., 2009b), and this misclassification could also be differential in terms of distance or socioeconomic position as home deliveries are more common among remote and deprived populations. Ideally, I would have included stillbirths and studied perinatal mortality as an outcome, however, the DHS surveys only contain information on the latest stillbirth and many important variables, such as place of delivery, are missing for stillbirths.

To find out whether having perinatal mortality as an outcome would have affected the main results, the mortality analyses were conducted using perinatal mortality (including the latest stillbirth) as an outcome and identical odds ratios of mortality were found in Malawi while the association weakened slightly in Zambia (from OR of 0.55 to 0.66).

In the analyses on socioeconomic inequalities, the latest stillbirth was stratified by wealth and education and found that stillbirths were actually more common among the richest wealth quintile and among the most educated compared with the poorest and among those who had no education, respectively. Therefore, using perinatal mortality as an outcome to study the association between distance and mortality would have most likely had only a minimal effect, whereas the wealth-and education-inequalities may have probably reduced even further.

I need to be careful when drawing conclusions about causality with cross-sectional data. For example, I cannot rule out reverse effect of newborn death on socioeconomic position that could be a risk particularly in poor households (Houweling & Kunst, 2010). Despite these limitations of the DHS, these data remain one of the most reliable sources of information from low- and middle-income countries and have been used in a plethora of health studies for decades (DHS Program, 2018; Pullum, 2008).

6.3 Quality of care at birth

Ever since the EmNC functions were suggested, more studies measuring them have emerged and similar to the quality assessment presented in this thesis, many of them report low availability of emergency newborn care. For example, in a study from Bangladesh, high-level EmNC was provided in only 2% of 875 randomly selected urban and rural health facilities (Wichaidit et al., 2016). Another nationally representative study from Kenya found that only 3% of facilities provided EmNC (Allen et al., 2017). The low availability of EmNC functions illustrate that newborn care has been a neglected area of care at birth.

In the quality assessment presented in this thesis, EmNC was available in 8% of facilities (5 out of 64), however, 20% of deliveries took place in these facilities. These findings are consistent with, for example, the above-mentioned Kenyan study in which 12% of deliveries took place in facilities offering EmNC despite the lower overall availability of EmNC (2%) (Allen et al., 2017). This is explained by large volume of deliveries taking place in hospitals that typically offer higher quality of care (Figure 9). Hospitals attract deliveries as they generally have a large capacity, they function as referral institutions and are usually located in or close to cities or bigger towns (Allen et al., 2017; Gabrysch et al., 2012b).

An alternative explanation would be that women are aware of quality and by-pass facilities offering poorer quality of care and seek care in better facilities. An analysis using the same data showed that having a hospital or higher-quality facility as the closest health facility was not associated with higher facility use when adjusted for distance (Nesbitt et al., 2016). This finding suggests that the higher proportion of deliveries taking place in hospitals and in high-quality facilities was at least partly explained by their location close to densely populated areas.

Some authors have suggested that the signal function approach overestimates readiness to manage emergencies and called for a more comprehensive approach to assessing emergency preparedness (Banke-Thomas et al., 2016; Cranmer et al., 2018). Indeed, high coverage with indicated key signal functions (e.g. magnesium sulphate for eclampsia) among women with a severe maternal outcome (i.e. death or near-miss) was not associated with lower maternal mortality in a study including 357 large delivery hospitals in 29 low- and middle-income countries (Souza et al., 2013). Further, mortality was not increased among women who did not receive an indicated intervention compared with those who did (Souza et al., 2013). The authors suggested this unexpected finding was due to delayed or lack of comprehensive patient management. For example, 'injectable antibiotics for sepsis' is a signal function that may often be available (Kanyangarara et al., 2018), but treatment of septic shock requires *fast* diagnosis and *fast* start of an appropriate antimicrobial regimen as well as comprehensive shock management (Ferrer et al., 2014; Rhodes et al., 2017; Seymour et al., 2017).

Assessing competence using clinical vignettes in addition to signal functions might be a more comprehensive way to evaluate quality of care. Two separate studies from nine sub-Saharan African countries (Adegoke et al., 2012) and four South Asian countries (Utz et al., 2013) investigated definitions and roles of skilled birth attendants and found that cadre names, length of training and the ability and permission of different cadres to provide signal functions varied substantially between cadres and countries. Using clinical vignettes to assess staff competence might provide insight into whether quality of care is constrained by staff skills or due to other reasons, such as limited equipment and infrastructure.

In the two real-life situations described in the vignettes and used in this thesis, clinical practice would have been limited by both lack of equipment and lack of health provider competence to diagnose and treat these emergencies. The major limiting factor was competence, reflecting a missed opportunity. One striking example of lack of competence was the low use of oxygen for a woman presenting with antepartum bleeding shock (5% of respondents) although supplemental oxygen was available in half of all health facilities (Figure 12).

Other studies have reported similar findings to ours. A paper on quality of newborn care in the same 64 health facilities in Brong Ahafo region reported poor recognition of newborn danger signs in clinical vignettes among respondents of 11 focus facilities in that study (Vesel et al., 2013). Another study using clinical vignettes reported low competence in care for diarrhoea, tuberculosis and prenatal care among 300 doctors in five middle-income countries, and competence rather than resources was reported to be the limiting factor of care (Peabody & Liu, 2007).

In the workload analysis presented in this thesis, the average workload per skilled birth attendant was 39 deliveries in 2009. Although this seems a small number compared with the UN recommendation of 175 annual deliveries per skilled birth attendant (WHO 2005), human resource shortage affects Ghana alongside other sub-Saharan countries (UNFPA et al., 2014). In fact, 39 deliveries per skilled birth attendant is a typical sub-Saharan African workload (ten Hoope-Bender et al., 2014). In this thesis, particularly the small and remote clinics employed very few staff in total, and it can be questioned whether a true 24-hour functionality could be maintained in these facilities. The workload was unevenly distributed between facilities, leading to possibly overburdening workloads in some health facilities and too few deliveries to maintain competence in other facilities.

The findings of this thesis raise important questions on whether small facilities can save lives, given that 88% of these provided poor care in all four dimensions in the study setting. In addition to being poorly equipped, these facilities employed the least numbers and the least competent delivery attendants and managed too few deliveries to maintain competence.

One major benefit of smaller health facilities is that they are typically located in more rural environments and are more accessible to remote populations who generally have poor access to care. Indeed, an analysis using the same data from Brong Ahafo region that was used in this thesis found that rural women had to travel a median distance of 3.3 kilometres to the closest delivery facility while the closest facility providing emergency newborn care was a median of 24 kilometres away (Nesbitt et al., 2016).

Particularly in low- and middle-income countries, the trade-off between distance to care and quality of care has to be made carefully, and their effects need to be analysed in the light of health outcomes. This leads to the next section, in which I discuss whether geographic and socioeconomic inequalities in access to care at birth are associated with early neonatal mortality.

6.4 Access to care at birth

Similar to the findings presented in this thesis, many previous studies report either missing, very small or inconsistent effects with increasing distance on neonatal mortality (Table 8). Although previous studies have mainly measured Euclidean distances, studies cannot be easily compared as distances have been measured to different types of health facilities and to facilities providing varying levels of care. In some studies, distance has been measured to the closest health facility, in others to the closest hospital or to the closest facility providing EmONC.

A study from Malawi published in 2016 reported a neonatal mortality difference of 23 per 1,000 between births in higher-quality and low-quality delivery facilities (Leslie et al., 2016). The authors linked data from the 2013-14 Millennium Development Goals survey (including 6,668 births and 115 neonatal deaths) with the 2013 Malawi Service Provision Assessment (SPA) data from 467 delivery facilities. In this study, coverage of health facility deliveries was very high at 91.5% and only facility deliveries were included in the study (Leslie et al., 2016). Quality was assessed based on a predefined 25-item quality index including maternal and newborn indicators. Facilities belonging to the top 25% based on this index were defined as higher-quality and other delivery facilities as low-quality. To account for adverse selection of high-risk deliveries into higher-level facilities, differential distance to the closest and higher-level care was used as an instrumental variable in the regression analyses (Leslie et al., 2016). In this study, the majority of hospitals, but only 16% of health centres provided higher-level care (Leslie et al., 2016).

The absence of an effect of level of care on neonatal mortality in this thesis is likely partly explained by the limited quality assessment in Malawi, but it is also probable that quality of care has actually improved after the Malawi 2002 HFC. For example, the Malawian government has implemented the Every Newborn Action Plan (WHO & Unicef, 2015), and coverage of facility delivery has increased to over 89% (Unicef, 2016) whereas it was 57% in the Malawi 2004 DHS (National Statistical Office - NSO/Malawi & ORC Macro, 2004). Despite these improvements, neonatal mortality remains high at 22 per 1,000 live births suggesting that a large number of deliveries occur in health facilities that cannot deliver a sufficiently high quality to reduce neonatal deaths (WHO & Unicef, 2015).

Reduction of mortality with distance in Zambia is more difficult to explain. One explanation could be that care in health facilities was harmful, for example through spread of infections (Campbell et al., 2015; Velleman et al., 2014), harmful care practices (Miller et al., 2016) or inappropriate medical care such as over-medicalization (Brownlee et al., 2017; Miller et al., 2016; ten Hoope-Bender et al., 2014). Alternative explanations are that there was a strong unknown negative confounder that was not controlled for or differential reporting of deaths in terms of distance (discussed in 6.2.2).

This thesis found evidence of higher emergency care-seeking in communities with low proportions of facility delivery which should result in higher mortality as not all women will arrive in time for the baby to be saved. However, cluster-level facility delivery was not associated with early neonatal mortality in Malawi or Zambia raising further concern of the quality of newborn care.

The optimal rate of caesarean delivery is not well-defined, however, a caesarean rate ranging from 5 to 15% is often considered acceptable (WHO et al., 2009). The low share of caesarean sections in the samples from rural Malawi (2.5%) and rural Zambia (1.5%) suggest that not enough caesarean deliveries were performed to save newborns as a caesarean rate between 1% to 2% is considered too low to save even mothers' lives (Cavallaro et al., 2013; De Brouwere et al., 2002; Ronsmans et al., 2004). It is therefore likely that most caesareans in the study samples were performed due to maternal rather than foetal indications.

The difference in proportions of facility deliveries among populations living farthest from a facility compared with the closest populations was 40% in Malawi and less than 20% in Zambia. These are thus the proportion of births that the beneficial effect of facility delivery could act upon.

In 2009, a review article estimated that comprehensive emergency obstetric care and newborn resuscitation could reduce (mainly intrapartum-related) neonatal deaths among facility deliveries by 36% (Lawn et al., 2009a). The same analysis estimated that with higher than 90% coverage, CEmONC could reduce these deaths by 68% (Lawn et al., 2009a). Currently facility delivery is believed to be even more beneficial when life-saving interventions are increasingly being performed. A Countdown analysis estimated that high quality care at birth of deliveries with higher than 90% coverage could reduce neonatal deaths by 77% in 75 countries with high mortality (Bhutta et al., 2014).

Distance may be a barrier to care in high income countries too. In Finland, a high-income country with very low maternal and newborn mortalities (Unicef, 2016), the current policy is to close delivery hospitals with less than thousand yearly deliveries to ensure high quality (Nieminen, 2015). This policy has been criticized as it may lead to higher numbers of unintentional out-of-hospital deliveries in some populations due to long distances to delivery hospitals (Hemminki et al., 2011). The question is definitely more complicated in low-resource settings without high-quality referral systems, bad road networks, lack of transport vehicles, emergency services or hospital capacity.

The small wealth- and education-related inequalities in early neonatal mortality found in the 72 DHS countries were surprising as there are multiple ways in addition to facility delivery in which wealth and education could improve newborn survival as suggested by Mosley and Chen in 1984 (see 2.1.2 and Figure 3). Inequalities in early neonatal mortality did not correspond to the large inequalities in coverage of delivery care, suggesting care at birth was not effective in saving newborn lives.

In the pooled sample, facility delivery was 43% and 37% (absolute percentage points) higher among the richest and the most educated compared with the poorest and the least educated, respectively. If facility delivery was as effective as estimated by the Countdown analysis and reduced 77% of early neonatal deaths (Bhutta et al., 2014) in the study sample presented in this thesis, the pooled inequalities in early neonatal mortality due to differences in coverage of delivery care alone would amount to 6.6 per 1,000 live births for wealth and 5.8 per 1,000 live births for education[†] instead of 2.9 per 1,000 and 3.9 per 1,000 for wealth and education, respectively. In fact, the inequalities could even be higher for early neonatal mortality as effective care at birth can potentially reduce a higher proportion of *early* deaths compared with deaths during the entire neonatal period.

Questions regarding the effectiveness of health facilities in saving lives at birth have been raised in other studies. A DHS study on 1,473,226 live births from 67 countries found no association between individual-level facility delivery and early neonatal mortality, and the authors attributed this finding to confounding by case-mix (Fink et al., 2015). In analyses conducted to overcome confounding by case-mix, the study found a slight decrease in the odds of early neonatal mortality for predicted facility delivery (based on previous facility use) (Fink et al., 2015). In another study, the Indian cash-incentive program Janani Suraksha Yojana was found to be associated with increased facility use for delivery particularly among the poor and less educated mothers, yet first-day mortality or neonatal mortality were not clearly reduced (Powell-Jackson et al., 2015). The findings were attributed to low quality of care in both studies.

As has been shown in several studies including this thesis, socioeconomically advantaged mothers have better access to care at birth, antenatal care and caesarean sections (Barros et al., 2012; Houweling & Kunst, 2010; McKinnon et al., 2016; Ronsmans et al., 2006). Advantaged mothers also have better access to higher-quality care (Das & Hammer, 2007; Fiscella et al., 2000; Gwatkin et al., 2007). In addition, higher socioeconomic groups have better sanitation, they are likely to be better nourished and in better general health and therefore have less babies that are small-for-gestational age (Curtis & Cairncross, 2003; Curtis et al., 2000; Houweling & Kunst, 2010). In some contexts, babies of poorer and less educated mothers are more likely to be exposed to indoor-pollution due to cooking fuels which have been associated with lower socioeconomic position and increased risk of perinatal and neonatal mortality (Kleimola et al., 2015; Patel et al., 2015).

Although socioeconomic inequalities in *early* neonatal mortality have not been reported previously on a large scale, multicountry studies on

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[†] Calculation for wealth: Mortality among the poorest (=19·9 / 1,000) x proportional difference in facility delivery between richest and poorest mothers (=0·429) x 0.77. Calculation for education: Mortality among the least educated (=20·3 / 1,000) x proportional difference in facility delivery between most and least educated mothers (=0·373) x 0·77.

inequalities in neonatal mortality have been conducted. A DHS analysis of 48 countries used country-level meta-regression analyses and found no association between socioeconomic inequalities in neonatal mortality and facility delivery although inequalities in facility delivery were large (McKinnon et al., 2016). Another DHS analysis of 24 countries reported pooled, unadjusted neonatal mortality differences of 8.5 and 10.9 per 1,000 live births for wealth and education, respectively (McKinnon et al., 2014b). However, the inequalities were not significant (confidence intervals crossed the null value) in nearly half of the countries analysed in that study.

There are three main conclusions that arise from previous literature and the analysis on postneonatal infant mortality. First, the socioeconomic inequalities in postneonatal infant mortality seem to be larger compared with inequalities in early neonatal mortality, however, not as large as those reported in under-five mortality (Gakidou et al., 2010; O'Hare et al., 2013; Rutstein, 2000; Wang et al., 2014; Wang, 2003). Second, the large inequalities in postneonatal infant mortality presented in this thesis indicate that survival benefit often arises when better care and living conditions are available to the advantaged groups. Third, future studies should study deaths associated with childbirth separate from later infant mortality as their biological and socioeconomic determinants differ.

The findings of small inequalities in early neonatal mortality and large inequalities in postneonatal infant mortality are surprising given that DHS analyses have demonstrated much larger socioeconomic inequalities in skilled delivery attendance compared with inequalities in interventions that reduce infant mortality in low- and middle-income countries (i.e. immunization coverage, oral rehydration therapy or medical treatment for childhood illnesses) (Gwatkin et al., 2007; Houweling et al., 2007). These higher inequalities in care at birth should translate into higher inequalities in early neonatal mortality if care at birth was effective in saving newborn lives. The findings from 72 countries presented in this thesis suggest that high-quality care at birth is not available to anyone, not even the most advantaged groups, and babies of the rich and educated mothers die regardless of receiving delivery care.

6.5 Implications for future research and policy

There are three main areas of study questions and policy recommendations that arise from this thesis: A) improving quality and how quality is measured, B) increasing coverage of high-quality care and C) improving data sources (Table

21). Although these suggestions and recommendations only concern the study contexts, they may be applicable in other regions or countries experiencing similar challenges of poor quality and high mortality.

Improving quality and how quality is measured

Measuring process indicators, such as signal functions, may lead to a false assumption that these interventions are necessary in their own right and therefore they may be performed too much, too late or by personnel who are not trained and experienced enough to perform them (Miller et al., 2016). Future studies should, therefore, focus on validating measured signal functions with health outcomes and if they cannot be validated, they should be revised to have a larger discriminatory power in terms of health outcomes.

Signal functions are important in drawing attention to key interventions, however, they are not meant to describe all aspects of care. This is the benefit and disadvantage of the signal function approach; they can be measured relatively easily and rapidly, but important aspects of clinical care may be missed. For example, caesarean section saves mothers and babies, yet the procedure may be unsafe as many low-resource settings suffer from a severe shortage of anaesthesiologists and anaesthesia-related drugs, equipment, infrastructure and transportation (Anderson et al., 2014; Epiu et al., 2017a; Epiu et al., 2017b). Further, an obstetric emergency often leaves one or more patients in critical condition requiring intensive care that is often not available (Epiu et al., 2017a). Indeed, a caesarean section may tick a box in a facility assessment but fail to save any lives due to intra- and perioperative risks.

The slow global reduction in birth-related mortality has raised concern that 'phrases such as skilled birth attendant and emergency obstetric care can mask poor quality care' (Campbell et al., 2016). A recent paper suggested that the signal functions overestimate quality and recommended replacing them by a clinical cascade method that models the readiness to respond to obstetric emergencies as a three-step cascade: 1) identification of emergency, 2) treatment and 3) monitoring-modifying therapy (Cranmer et al., 2018). While a more comprehensive and detailed approach to evaluating quality may be needed, the coverage of even signal functions remains poor in many countries.

Table 21A. Recommendations for research and policy: Improving quality and how quality is measured	

Research implications	• Link quality measures with health outcomes (collect better data on complications, come up with ways to overcome confounding by case-mix)
	• If a link cannot be established, develop and test new methods of measuring quality that have larger discriminatory power, e.g. the clinical cascade approach (Cranmer et al., 2018) or clinical vignettes
	• Develop new quantitative methods and use existing methods, e.g. the Robson score (Robson, 2001), for monitoring and comparison of interventions at birth
	• Review the safety and effectiveness of key interventions, including
	    o indications
	    o timing
	    o staff skills to perform them
	    o safety
	    o anaesthesia and intensive care
	    o follow-up of patients
	    o provider training and competence needed for performing the procedures
	• Establish the staffing and workload needs per skilled birth attendant and per health facility
	• Establish the minimum number of staff per facility for maintenance of true 24-hour functionality
	• Develop new methods for training skilled delivery attendants and maintaining their competence
	• Frequently collect and analyse data to monitor key indicators and inform policy makers

Policy implications	• Prioritize training, maintenance of staff competence and retaining skilled birth attendants • Ensure that all signal functions are taught to and performed by skilled birth attendants • Ensure that only skilled birth attendants manage deliveries • Ensure availability of essential drugs, equipment and infrastructure • Ensure that quality of care is high in all dimensions in a health facility offering delivery care • Ensure that all health facilities that manage deliveries function at least at high level and that they have a referral facility functioning at highest level • Ensure minimum staff needs to ensure a true 24-hour availability of key interventions and all dimensions of care • Improve quality when and where needed based on evidence

Table 21B. Recommendations for research and policy: **Improving coverage with high-quality care**	

Research implications	• Carefully plan a health facility network considering population needs with the help of geographic information systems
	• Test mobile geographic information applications to locate a patient, healthcare provider or emergency transport vehicle
	• Develop and test ways of bringing the most remote and deprived populations to high-quality care or bringing care to them
	    ○ maternity waiting homes
	    ○ means of emergency transport
	    ○ mobile clinics with skilled team for areas that are hard to reach

Policy implications	• Prioritize quality over coverage of care
	• Ensure that all health facilities have an adequate capacity and adequate capture area to maintain staff competence
	    ○ Consider discontinuing delivery care in the smallest units that provide poor quality
	• Once quality is ensured, improve access particularly for the remote and deprived populations
	• Ensure maintenance of good-quality road networks, particularly between BEmONC and CEmONC facilities
	• Ensure availability and maintenance of routine and emergency transport
	    ○ Improve mobile phone coverage and employ mobile technology in health
	    ○ establish applications for requesting emergency and routine transport

BEmONC, Basic Emergency Obstetric Care; CEmONC, Comprehensive Emergency Obstetric Care	

Table 21C. Recommendations for research and policy:
Improving data sources

Research implications	• Develop ways of establishing vital registration in low- and middle-income countries
	• Develop and test electronical medical records, including simple ways of monitoring health facility performance by collecting data on:
	    o normal deliveries
	    o complications at birth
	    o immediate follow-up of mothers and babies
	    o sick newborns
	    o antenatal and postnatal care
	    o well child checks
	    o chronic diseases
	    o physical resources, including staffing, equipment and drugs
	• Develop automatized systems for collection of comparable key indicators
	• Link data from health facilities, vital registries and users to analyse quality of care
	    o Employ mobile devices to collect data from providers and users, e.g. data of complications, and travel routes of users
	• Develop ways to gather reliable data, but ensuring patient confidentiality

Policy implications	• Prioritize establishing vital registration
	• Establish electronic medical records with careful patient confidentiality protection
	• Monitor quality of care periodically and correct when needed
	    o Make quality of care indicators and results available and transparent
	• Improve mobile phone coverage and employ mobile phone technology in health
	    o Work together with scientists to establish mobile applications for collecting facility level and user data
	• Ensure that reliable data are available for research

In addition to increasing coverage with signal functions, quality and safety of the interventions that are already being performed should be reviewed. Are the procedures done when indicated and at the right timing? Are the staff skilled to perform the procedures? Are safety precautions followed? Is anaesthesia safe and adequately resourced? Is the follow-up of the patients adequate? Simple comparison and monitoring methods for key interventions, such as the Robson score for caesarean sections (Robson, 2001), should be developed.

Research should establish the minimum annual workload for skilled birth attendants and for health facilities offering delivery care. The recommendations of the WHR 2005 (175 births per midwife per year) and WHR 2006 (2.28 staff per 1,000 population) have been criticised as they are based on district birth loads and ecological analyses, respectively (Gabrysch et al., 2012b). It is probable that one workload recommendation is not applicable for all situations as a suitable workload is likely to depend on the context, i.e. the consultation possibilities, proximity to higher level care and number of other skilled staff present.

Policy-makers need to prioritize training enough staff in all necessary skills, including manually assisted delivery and removal of placenta, that are not taught in all countries (Adegoke et al., 2012; Ameh & Weeks, 2009; Paxton et al., 2003). Gaps in education result in delivery attendants who are devoid of some life-saving midwifery skills but who are still referred to as skilled (Campbell et al., 2016; Footman et al., 2015). All facilities should provide high quality on all dimensions as a facility that provides high quality in one dimension (e.g. EmONC), but substandard care in other dimension (e.g. routine care), is unlikely to improve health outcomes.

Increasing coverage of high-quality care

The smallest health facilities may not improve health outcomes and it requires careful consideration whether these should be upgraded to high-quality facilities (i.e. facilities offering at least BEmONC, high-quality routine and high-quality non-medical care) or whether delivery care should no longer be provided in these health facilities. Indeed, the network of hospitals and smaller delivery units should be carefully planned for every context using geographic information and linking these with population needs (i.e. birth loads) as has been suggested in previous studies (Gabrysch et al., 2012b; Gabrysch et al., 2011c).

Distance and socioeconomical deprivation are barriers to accessing care and ways of improving access to high-quality care should be found. Possible solutions include organizing free transportation and maternity waiting homes. Despite being recommended by the World Health Organization, evidence of even maternity home use is scarce (Campbell et al., 2016; WHO, 2015) and more research is needed on how to best implement maternity waiting homes.

Even if long distances to routine care can be overcome with maternity waiting homes or similar solutions, emergency transport needs to be established in a coordinated way. Research should address how to best organize and coordinate transport as in many low- and middle-income countries even emergency transport is either facility-based or relies on private providers (Campbell et al., 2016). Emergency transport saves lives (Austin et al., 2015; Campbell et al., 2016; Dogba et al., 2011; Fournier et al., 2009), but routine transportation to preventive care should be made available too as it shortens travel times and costs and increases facility use (Banu et al., 2014; Campbell et al., 2016; Gabrysch et al., 2011a; Richard et al., 2007).

Organising emergency medical services and transport needs considerable resources as these services require specialized staff, they need to be functional 24 hours per day every day and they need to be coordinated, for instance, by a call centre (Campbell et al., 2016). In addition, they require road networks that need to be maintained. New methods, such as mobile clinics, could be experimented with, particularly in areas that are hard to reach, but these are likely to require substantial resources too.

Increasing coverage of mobile phones in low- and middle-income countries (World Bank, 2018) enable mobile geographic information applications to be used in healthcare, for example, for locating a patient, a healthcare provider, an emergency transport vehicle or closest hospital offering comprehensive emergency obstetric care. These options should be explored more particularly among remote populations that are hard to reach.

Policy-makers should prioritize quality over coverage of care. Building more small facilities in remote areas is not a viable solution if quality cannot be guaranteed. Increasing coverage without quality is unethical due to various reasons. For example, facility-based delivery can harmful to the mother or the baby as has been previously discussed in this thesis. Further, accessing delivery care is expensive in some settings and may plunge a family deeper into poverty. Finally, poor care undermines the credibility of the entire health system which may influence later decisions to seek care and health behaviour in general. In contrast, a good delivery experience may recur in future health gains of the mother, her children and the entire community. Once quality of care is ensured, particularly the remote and socioeconomically deprived populations should be targeted to improve their access to care.

Improving data sources

A prerequisite for assessing quality of care is that data sources are improved. Outcome data, including stillbirths, should preferably be collected through vital registration rather than questionnaire-based surveys and research should address how to best set up vital registries in low- and middle-income settings. Further, policy-makers should ensure that reliable data are available for research and that patient confidentiality is maintained in ways that do not interfere with reliability of data (such as scrambling geo-referenced data).

Simple electronic medical records should be made increasingly available and data should be analysed at the facility, regional and country levels using existing technology. For example, the District Health Information System 2 is an open source, web-based health information system developed by a south-south-north collaborative network referred to as Health Information Systems Program (DHIS2, 2018). The network aims to develop, improve and implement health information systems in low-resource countries (DHIS2, 2018). Increasing coverage of mobile phones in low- and middle-income countries enables surveys to be conducted through mobile phones saving time and resources. User-end data can be linked with facility level data and population data to analyse quality of care.

This thesis is an example on how to use geographic information in health studies. Improving geographic information technologies that are integrated into mobile devices and increasing coverage of mobile phones in low- and middle-income countries enable much more detailed geographic information to be collected. These data can be used to understand and improve functioning of the health system at birth.

7 CONCLUSIONS

The findings of this thesis point to insufficient quality of care at birth in the seven districts of Brong Ahafo region in Ghana, in Malawi and Zambia and in the 72 DHS countries. Quality of childbirth care was studied at three levels (facility level, country level and multicountry level) and in three dimensions (structure, processes and outcomes). The Donabedian *structure* of care (Donabedian, 1988) was evaluated through a sub-regional health facility assessment in Brong Ahafo region in Ghana. The *process* of clinical emergency obstetric care was studied using vignettes in the same setting. Early neonatal death is one of the main *outcomes* of childbirth care (Bhutta et al., 2014), and distance to care and socioeconomic position were investigated as distal determinants that act through high-quality care to influence early neonatal mortality.

Mortality around childbirth has frequently been called a litmus test of health system performance (Darmstadt et al., 2014; Lawn et al., 2014; Lawn et al., 2009a; Shankar et al., 2008). Indeed, childbirth comprises of multiple aspects of clinical care, including routine and emergency care for the mother and the baby. In addition, patient-provider interactions may be particularly important in delivery care. Complications and emergency care are a pressure test of health providers' competence to rapidly diagnose and manage or refer complicated cases further. In addition to clinical skills, functioning equipment, drugs and communication channels are needed (Campbell et al., 2016). A functioning referral system is furthermore crucial and requires well-maintained roads and transport vehicles. Early neonatal survival is thus a public health goal that also indicates a functioning health system.

Early neonatal mortality remains a global health problem that has not been solved by increasing coverage with institutional deliveries. As only high-quality care saves lives, quality instead of coverage needs to be prioritized to meet the goal of reducing neonatal mortality. In addition, improved data sources for measuring quality and health outcomes are needed.

The conclusions for the specific aims set for this study (chapter 3) are as follows:

I. Hospitals and large health centres provided the highest quality of care among the 64 delivery facilities in Brong Ahafo region. Although coverage of facility delivery was fairly high at 68%, coverage of high-quality care at birth was only 18% indicating a large quality gap. The smallest delivery facilities providing poor-quality care should be either upgraded or they should discontinue providing delivery care as care in these facilities is unlikely to improve health outcomes.

II. Large health facilities that provided the highest quality of care also employed the most competent staff among the 64 delivery facilities in Brong Ahafo region. Doctors, midwives and nurses working in larger facilities achieved moderate competence scores in vignettes describing two obstetric emergencies. Competence was low among other cadres and trainings need to be targeted to particularly these health workers. Although there were shortages in equipment and drugs, lack of health providers' competence may limit quality of care more than shortages of these items. Delivery workload needs to be sufficiently high to maintain staff competence.

III. Delivery in a health facility did not save the lives of rural newborns in Malawi or Zambia. Although distance to a health facility was a strong barrier to delivery care, improving quality of care in delivery facilities should be prioritized over improving geographic access in both countries. Offering higher quality of care may increase facility use in some settings, such as Zambia.

IV. Large socioeconomic inequalities in access to care at birth existed in most of the 72 study countries and in the pooled sample. Despite this, the socioeconomically advantaged newborns did not possess a corresponding survival advantage over the poorest and least educated suggesting that health facilities often failed to save newborn lives at birth. Coverage of care at birth should be increased, and the socioeconomically disadvantaged mothers should only be targeted after sufficiently high quality of care has been ensured.

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