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Interpreting the changing association between caesarean birth and neonatal death: a case study from Ethiopia

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SUMMARY BOXES

What is already known on this topic?

- Studies that assess the association between caesarean section and neonatal mortality have been conducted periodically, but the results are inconsistent.
- The majority of the studies are at the aggregate level.
- Studies based on individual-level data are more likely to report a considerably increased risk of neonatal death associated with caesarean versus vaginally born infants.
- In developing countries like Ethiopia, contextual factors such as unequal access, infrastructure, and health workforce constraints may play role in the mechanism of association between caesarean birth and neonatal death. However, previous studies lack the interpretation of the association by considering contextual factors with additional supporting evidence.

What this study adds

- This study found that the changing association between caesarean birth and neonatal death within the context of Ethiopia over time may be attributable to changes in pattern of the underlying indications for caesarean intervention which may aggravated by contextual factors such as unequal access, infrastructural, and health workforce constraints.
- The changing association between caesarean birth and neonatal death may also reflect a maturing of the health system and a shift in the characteristics of Ethiopian women undergoing caesarean section after complicated labour or severe foetal compromise in which caesarean birth may not prevent neonatal deaths because the foetus has already experienced complications that mean neonatal death is difficult to prevent.

ABSTRACT

Objective

To interpret the changing association between caesarean birth and neonatal death within the context of Ethiopia from 2000 to 2016.

Design

Secondary analysis of Ethiopian Demographic and Health Surveys (DHS).

Setting

All administrative regions of Ethiopia with surveys conducted in 2000, 2005, 2011, and 2016.

Participants

Women aged 15-49 years with a live birth during the five years preceding the survey.

Main outcome measures

We analysed the association between caesarean birth and neonatal death using log-Poisson regression models for each survey adjusted for potential confounders. We then applied the 'Three Delays Model' to provide an interpretation of the changing association between caesarean birth and neonatal death in Ethiopia.

Results

The adjusted prevalence ratios (aPR) for neonatal death among neonates born via caesarean section versus vaginal birth increased over time, from 0.95 (95% CI, 0.29, 3.19) in 2000 to 2.81 (95% CI, 1.11, 7.13) in 2016. The association between caesarean birth and neonatal death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among women from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36) in 2016. However, the aggregate-level analysis revealed that an increase in caesarean section rate is correlated with a decrease in the proportion of neonatal deaths.

Conclusions

The naïve interpretation of the changing association between caesarean birth and neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death. However, the changing association reflects improvements in health service coverage and a shift in the characteristics of Ethiopian women undergoing caesarean section after complicated labour or severe foetal compromise.

Strengths and limitations of this study

- This was the first study to examine the changing association between caesarean birth and neonatal death within the context of Ethiopia from 2000 to 2016.
- A number of analyses were conducted after adjustment for potential confounders helped develop the possible scenarios to better understand the interpretation of the changing associations.
- We have used additional supporting evidence from Ethiopian DHS data which allowed us to interpret the changing association between caesarean birth and neonatal death in view of contextual factors in Ethiopia using 'Three Delays Model'.
- We lack data on intrapartum indications for caesarean delivery.

Introduction

Globally, 2.6 million neonatal deaths occurred within the first 28 days after birth, which accounted for 46% of all under-five deaths in 2016.[1] The majority of these deaths were from low- and middle-income countries. According to the United Nation Inter-agency Group for Child Mortality Estimation, Southern Asia (39%) and sub-Saharan Africa (38%) comprised the top two regions with the highest proportion of neonatal deaths, while five countries (India, Pakistan, Nigeria, the Democratic Republic of the Congo, and Ethiopia) accounted for 50% of all newborn deaths.[1] Unlike under-five mortality, the proportion of neonatal deaths is increasing.[2] If the current trend continues, more low-and middle-income countries will fail to achieve the Sustainable Development Goal (SDG) target for neonatal mortality at 12 per 1,000 live births.[3]

In contemporary obstetric practice, caesarean section remains an important intervention in preventing neonatal mortality and other adverse birth outcomes.[4] However, caesarean section may be prone to misuse because of unequal access, social, and cultural factors.[5-7] In developing country settings, due to limited medical provisions and/or lack of skilled birth attendants, some women may not benefit from caesarean birth though they are medically eligible, while ineligible women may sometimes have increased access. In the last decades, caesarean section rates have been increasing in low-, middle, and high-income countries.[8-10] The World Health Organization (WHO) suggests a caesarean section rate of 10–15%.[11]

Previous studies conducted using aggregate- and individual-level data have yielded inconsistent results about the association between caesarean birth and neonatal mortality. For instance, two ecological studies[12,13] conducted using worldwide country-level data have found that caesarean birth was associated with lower neonatal mortality while another two ecological studies[14,15] showed no association between caesarean birth and neonatal mortality, where caesarean section rates were higher than 10%. Inconsistent results for the association between caesarean birth and neonatal mortality were also reported by different studies conducted in Africa, Latin America, and United States of America based on individual-level data.[16-21]

On the other hand, using both country-and individual-level data collected for nationally

representative Demographic and Health Surveys (DHS), Kyu et al. found an increased risk for neonatal death associated with caesarean versus vaginal births in countries with low (< 5%) and medium (5-15%) caesarean section rates.[22] However, factors associated with caesarean section that increase risk for neonatal death in countries with low and moderate caesarean section rates remain ill-defined. Previous studies are limited by either inconsistent results, which may suggest null effects (e.g. at least due to methodological/design limitations), or lack the interpretation of findings by considering the contextual factors. It is clear that in addition to the underlying indications for caesarean interventions, several contextual factors such as unequal access, infrastructural, and health workforce constraints could play a role in the association between caesarean section and neonatal death.

In low- and middle-income countries, the DHS are the most representative and widely available quality data sources for studies related to maternal and child health. We use Ethiopian DHS data from 2000, 2005, 2011, and 2016 to examine the association between caesarean birth and neonatal death. We then apply 'Three Delays Model' developed by Thadeus and Maine[23] to provide an interpretation of the changing association between caesarean birth and neonatal death in Ethiopia. The 'Three Delays Model' is a framework that describe the circumstances of pregnancy/labour-related maternal and neonatal mortality due to three delays—delay in deciding to seek care (Delay 1); delay in reaching care (Delay 2); and delay in receiving adequate health care (Delay 3).[23]

Methods

Study design and data samples

We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela, and Harari), and two city administrations (Addis Ababa and Dire Dawa). Each of the surveys involved a two-stage, stratified, clustered sampling design. The survey datasets are de-identified and made freely available online. Permission to use these data was granted by the MEASURE DHS Program. The details about the methodology and standards for protecting the privacy of study participants in all DHS can be accessed at (http://www.measuredhs.com/What-We-Do/methodology.cfm).

Exposure

The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for livebirths they have reported in the past 5 years. The self-reported data collected for caesarean birth are thought to be reliable.[24] For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally.

Outcome

Neonatal death includes children who were born alive in the 5 years before the survey, but died within the first 28 days of life. The outcome variable, neonatal death, was measured from two variables (whether the child is alive and age at death (in days)).

Confounding

The following potential confounders were identified a priori and included place of delivery (public, private, NGO, home), type of residence (urban/rural), sex of child (male/female), size of baby at birth (very large, larger than average, average, smaller than average, very small, don't know), mother's age at birth (in years), mother's education (no education, primary, secondary, higher), birth order (1, 2-3, 4+), and household wealth quintile (poorest, poorer, middle, richer, richest). Mother's age at birth was calculated as a difference (in years) between infant's date of birth and mother's date of birth. DHS computes the wealth index for each survey based on

household assets using principal components analyses[25] and categorizes households into wealth quintiles. These asset-based measures represent the wealth distribution relative to other households within the country. They are widely used and are consistent with comparisons to household expenditures and the measurement of inequalities in child mortality, education, and healthcare use in low-and middle-income countries.[26]

Statistical analysis

All analyses were weighted to be nationally representative. Associations between caesarean birth and neonatal death were analysed using log-Poisson regression using data from Ethiopian DHS in 2000, 2005, 2011, and 2016. We calculated unadjusted and adjusted prevalence ratios (aPR) and their 95%CIs.

To explore what happens among different subgroups, we conducted a series of subgroup analyses using the most recent data because the association is more pronounced in 2016 DHS. We first restricted the analysis to participants living in regions with the highest caesarean section rates to examine whether the increased access to caesarean section affected the proportion of neonatal deaths. We then estimated the effect of caesarean birth on neonatal death in rural areas where access to caesarean section is limited, by excluding women living in urban settings (Addis Ababa and Hareri). In addition, we evaluated the association by restricting the analyses to births from the lowest quintile of household wealth, births from the highest quintile of household wealth, births in public health facilities, births to rural, and urban areas separately. This allowed us to examine how contextual factors (e.g. unequal access, infrastructural, and workforce constraints) affected the association between caesarean birth and neonatal death.

As women may have had more than one birth within the five-year survey periods, we accounted for both clustering of cesarean deliveries within women as well as the complex survey design during the data analyses using unit of analysis's (children) study number and sample weights. All analyses were conducted using STATA/SE version 15.1 (Stata Corporation, College Station, TX).

Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in the design and implementation of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of the research to study participants or the relevant patient community.

Results

Of the weighted total of 11 023 children in the study (5 725 male and 5 298 female), 213 (1.9%) were born by cesarean section within 5 years preceding Ethiopian DHS 2016. The overall proportion of neonatal death was 2.9% in 2016. **Table 1** shows the characteristics of mothers and children according to mode of delivery. Additional descriptive overview of the data from Ethiopian in DHS 2000, 2005, and 2011 are presented in **Supplementary appendix.** Women who underwent caesarean delivery were more likely to live in urban areas, had a higher level of education, and were from the richest quintile of household wealth. They were also more likely to have male children. Caesarean deliveries were more frequent in women in the age category of 20-29 years, and among infants who had either very large or large size at birth. **Figure 1 & 2** shows that the proportion of institutional delivery increased from 5·0% in 2000 to 26·3% in 2016, whereas the national caesarean section rate increased from 0·7% in 2000 to 1·9% in 2016. However, the rate of caesarean delivery in Ethiopia varied widely across administrative regions. For instance, Addis Ababa had the highest (21·4%) rate, while Somali region had the lowest (0·4%) in 2016. The overall proportion of neonatal deaths decreased from 4·8% in 2000 to 2·9% in 2016, but the proportion varies among administrative regions (**Figure 1 & 3**). Our analyses based on aggregate-level data showed that an increase in caesarean section rate is correlated with a decrease in the proportion of neonatal deaths (**Supplementary Figure 1**).

Table 2 shows that the adjusted prevalence ratio (aPR) for neonatal death associated with caesarean versus vaginal births in 2000 DHS was 0·95 (95%CI, 0·29, 3·19). In 2011, the adjusted prevalence ratio (aPR) for neonatal death associated with caesarean versus vaginal births was 1·15 (95%CI, 0·45, 2·93), while the 2005 Ethiopian DHS found an aPR of 1·53 (95%CI, 0·52, 4·50). Likewise, caesarean birth was associated with a 2·81-fold higher risk of neonatal death in 2016 Ethiopian DHS (aPR, 2·81; 95%CI, 1·11, 7·13).

Table 3 summarises the findings of the subgroup analyses based on the 2016 data. When women living in urban settings, (Addis Ababa (caesarean section rate (21·4%), and Hareri (9·0%)), were excluded from the analyses, the corresponding adjusted PR for neonatal death was increased to 3·55 (95%CI, 1·31, 8·56). Similarly, when we restricted the analyses to include only rural women, the prevalence ratio for neonatal death associated with caesarean versus vaginal births was found to be 3·43 (95% CI, 1·22, 9·67). The respective risk of neonatal death increased to 7·01 (95%CI, 0·92, 53·36) when the analysis was limited to women from the lowest quintile of household wealth.

Last, when we restricted the analyses to Addis Ababa, the capital of the Ethiopia, the relative risk for neonatal death associated with caesarean versus vaginal births was 1·07 (95%CI, 0·20, 5·73). Moreover, when the analysis was confined to women from the highest quintile of the household wealth, the risk of neonatal death was 2·72 (95% CI, 0·55, 13·38).

Interpretation

The primary analyses showed that the adjusted prevalence ratios (aPR) for neonatal death associated with caesarean versus vaginal births increased from 0·95 (95% CI, 0·29, 3·19) in 2000 to 2·81 (95% CI, 1·11, 7·13) in 2016. These findings suggest that the circumstances for foetuses born in 2000 DHS are different from the foetuses in 2016. Our subgroup analyses using 2016 data suggest that the association between caesarean birth and neonatal death was stronger among rural women (aPR (95% CI) 3·43 (1·22, 9·67)) and among women from the lowest quintile of household wealth (aPR (95% CI) 7·01 (0·92, 53·36)), but not for births in areas with wider availability of caesarean such as Addis Ababa (aPR (95% CI) 1·07 (0·20, 5·73)). The changing association between caesarean birth and neonatal death over time, and the stronger association observed among different subgroup analyses may be attributable to changes in the pattern of confounding by indication due to contextual factors such as unequal access, structural health-system deficiencies (insufficient equipment, supplies, and drugs), infrastructural, and health workforce constraints. These situations may have the capacity to make women with labour problems undergo caesarean section after severe complication of labour or severe foetal compromise. Therefore, our interpretation is that caesarean section conducted after severe foetal compromise may not prevent neonatal deaths because they have already experienced such severity of complications that although live born, neonatal death is difficult to prevent.

There are two possible scenarios leading to caesarean section in Ethiopia. First, when women who have previously had a caesarean section, with breech presentation, or other risk factors such as eclampsia attend specialised health facilities, they are usually allowed to undergo caesarean section. Their caesarean section is commonly classified as "elective or scheduled caesarean section." Second, when caesarean section is performed for "emergency reasons." Full term mothers with or without signs of labour will be admitted to health facilities where their progress is monitored and labour-augmenting or inducing medications may be administered. Decisions to perform caesarean section in these facilities or decision to refer the mother to nearby hospitals for caesarean delivery or other action depends on the condition of the mother and foetus during the progress of labour. In primary health facilities (i.e., health posts and health centres), obstetric care providers use a 'Partograph', a routine labour monitoring instrument (chart) which helps the health care provider in identifying slow progress in labour and take appropriate action. In

hospitals, the decision to perform a caesarean section is reached when the labour is prolonged and/or the second stage of labour is complicated risking the life of mother and foetus.

Given these pathways to caesarean delivery in mind, our interpretation of the changing association between caesarean birth and neonatal death in Ethiopia may be explained by the 'Three Delays Model' developed by Thadeus and Maine.[23] The model comprises *delay in decision to seek care* on the part of the mother, family, or both (Delay 1); *delay in reaching care* (Delay 2); and *delay in receiving adequate health care* (Delay 3). First delay—*delay in decision to seek care*—occurs when less-educated and poorer women encounter pregnancy or labour complications. Poorer and less-educated women are more likely to select a nearby health facility, especially in rural areas, where there is limited access to caesarean section and the possibility of benefiting from caesarean section is mainly through referral to higher levels of care. Women are more likely to undergo a caesarean section if they present to specialized health facilities. However, the outcome of delivery depends on the severity of the pregnancy complications which is affected by long distance to specialized health facilities and how quick/competent the health care provider is in referring the mother or on intervening. In Ethiopia, only 1.1% of births from the lowest quintile of household wealth are attended by doctors.[27] *Delay in reaching care*, the model's second component, occurs when women with pregnancy complication live further from health facilities, and the availability and cost of transportation is problematic. Like other developing settings, these problems are especially applicable in Ethiopia, where distance to a health facilities limits access to health care for 50% of women.[27] The pregnancy complication encountered by mothers will be further worsened by delays in reaching nearby primary health facilities, and compounded by additional delays when mothers are referred to specialised health facility for caesarean section.

Moreover, the lack of facilities; inadequately trained obstetric care givers (birth attendants); and inadequate and inappropriate referral systems in conjunction with other factors in Ethiopia result in *delay in receiving adequate health care* (Delay 3) among mothers with pregnancy and labour complications in both primary and specialised health facilities. For example, in the 5 years before Ethiopian DHS 2016,[27] only 28·0% of births were delivered by 'skilled providers' (includes doctor, nurse, midwife, health officer, and health extension worker). The majority of births in

Ethiopia are attended by traditional birth attendant (42·0%), nurses or midwives (20·0%) followed by doctors (6·0%), health extension workers (2·0%), and health officers (0·4%).

Lastly, delay in caesarean intervention may even happen if mothers with less severe labour complications were referred and presented to specialised health facilities in a timely manner. This is because a trial of labour is usually attempted before a decision to have caesarean section. For instance, some women who are referred from primary health facilities undergo induction and augmentation of labour because these interventions are only provided in health facilities with the capacity to provide caesarean section in Ethiopia. These practices, in turn, will result in delay in receiving caesarean section leading to worsening of the already existing pregnancy complication. Thus, any delays to caesarean intervention have a higher chance of aggravating the already existing complications and increase the risk of neonatal death.

Discussion

Our study examined the changing association between caesarean birth and neonatal death within the context of Ethiopia from 2000-2016. The association between caesarean section and neonatal death increased over time and variable among population sub-groups. These changes over time, and variation across population sub-groups may be attributable to changes in the pattern of confounding by indication due to contextual factors such as improvement in health service coverage, unequal access (e.g. due to a range of geographic, social, and economic barriers), and structural, and health workforce constraints.

In Ethiopia, the proportion of women aged 15-49 who received any antenatal care from a skilled provider has increased from 27% in 2000 to 62% in 2016.[27] Health facility-based deliveries have increased from 5% in 2000 to 26% in 2016 (increased from 2% in 2000 to 20% in 2016 for rural women, and increased from 32% in 2000 to 79% in 2016 for urban women).[27] The proportion of births in health facilities assisted by a skilled birth attendants increased from 6% in 2000 to 28% in 2016.[27] These figures reflect improvement in health service coverage in Ethiopia.

Moreover, since 2004, with the implementation of the Health Extension Programme—a community-based primary healthcare programme—the Ethiopian government has increased the number of health posts from 4,211 in 2005 to 16,447 in 2015.[28,29] Likewise, the number of health centres were increased from 600 in 2005 to 3,586 in 2015.[28,29] However, due to limitations in proper monitoring of labour for making timely decisions, especially on whether or not to initiate a referral from primary health facilities to higher level facilities, and due to poor transport and road networks which are still the common problems in low income countries,[30] the underlying medical indications for caesarean intervention will be worsened by these 'delay factors.' Delay in receiving adequate and appropriate care is still a common problem in low income countries due to deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, blood transfusion capacity, and a shortage of skilled birth attendants.[31-33] These situations often result in poor quality care, and the caesarean section conducted after complicated labour may be associated with increased neonatal mortality due to confounding by indication.

Unlike previous studies, the present study takes into account the interpretation of the changing

association between caesarean birth and neonatal death within the context of Ethiopia using DHS data. The change in the strength of effect estimates across DHS waves, and the different subgroup analyses suggest that neonatal mortality can be reduced by increasing timely access to caesarean section and timely decision for caesarean delivery via increasing health service coverage, improving infrastructure, increasing the number of skilled birth attendants, improving quality of care, and increasing awareness about antenatal care and health facility delivery among women. Moreover, provision of training to skilled birth attendants on close monitoring of labour and early detection of complications, equipping the primary health facilities (e.g. health centres) to the level of caesarean capacity, and continuous financial investment in primary health facilities will be an important strategy to reduce neonatal mortality.

It appears that previous studies which used individual-level data are more likely to report an increased risk of neonatal death among infants born by caesarean section than the ecological studies. This may be due to the indications for the caesarean delivery (e.g. the severity of the underlying causes) was involved in causing both caesarean delivery and neonatal death in studies which used individual-level data, suggesting the role of confounding by indication in the association between caesarean birth and neonatal death because an intended effect of caesarean birth is prevention of neonatal death. Therefore, the increased risk for neonatal death associated with caesarean birth, compared with vaginal birth, would appear to be intuitive given the fact that neonatal death rates after emergency caesarean section is strongly dependent upon the underlying indication (e.g. antenatally diagnosed foetal malformation or foetal growth restriction) for caesarean intervention.

In Ethiopia, the national rate of caesarean section increased from 0·7% in 2000 to 1·9% in 2016. On the other hand, neonatal mortality rate declined from 49 deaths per 1,000 live births in 2000 to 29 deaths per 1,000 births in 2016.[27] Our analyses based on aggregate-level data from Ethiopian DHS showed that an increase in caesarean section rate is correlated with a decrease in the proportion of neonatal deaths. Even though similar context-specific interpretation is applicable to ecological studies, additional explanation may also be necessary to interpret the association. For example, a change in neonatal mortality rate may be attributable to changes acting on the population as a whole (e.g. changes in health coverage indicators, such as an

increase in births attended by skilled birth attendants (increased from 6% in 2000 to 28% in 2016)).[27] The findings of our analyses of DHS data aggregated to different DHS waves and administrative regions are presented in **Supplementary appendix**

The most important limitation of our study is that we lack data on intrapartum indications for caesarean delivery. For example, information on foetal intolerance of labour and arrest of labour[34] which are thought to affect both caesarean section and neonatal health are not available in DHS. However, we believe that our interpretation of the changing association between caesarean birth and neonatal death may not be biased even in the presence of confounding by indication because emergency caesarean section conducted after complicated labour aggravated by any 'delay factors' leads to neonatal death. Another limitation is the mother's recall of the child's size at birth was used as a substitute for the child's birth weight in this study because the data for birth weight was not collected for more than 50% of the neonates in DHS.

Conclusions

The naïve interpretation of the changing association between caesarean birth and neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death. However, the changing association reflects improvements in health service coverage and a shift in the characteristics of Ethiopian women undergoing caesarean section after complicated labour or severe foetal compromise.

Contributors: All authors (EY, BWM, JWL and LGS) contributed to the design of the study and the interpretation of data. EY performed the data analysis and drafted the manuscript. All other authors critically revised the draft manuscript. All authors read and approved the final manuscript. EY is the guarantor of the paper.

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Data sharing: Datasets used for this study are freely available online at http://dhsprogram.com/.

Transparency declaration: The corresponding author (EY) affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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LIST OF TABLES AND FIGURES

SUPPLEMENTARY FIGURES AND TABLES

Supplementary Figure 2. The relationship between caesarean section rate and neonatal death by survey years.

Table 1. Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2016

	Mode of delivery	
	Caesarean (n=213) %	Vaginal (n= 10,810) %
Neonatal death		
Yes	8·28	2·74
No	91·72	97·26
Types of residence		
Urban	60·43	10·06
Rural	39·57	89·94
Region		
Tigray	6·81	6·49
Afar	0·37	1·05
Amhara	22·10	18·74
Oromia	21·22	44·46
Somali	1·02	4·68
Benishangul-Gumuz	0·56	1·11
SNNP	20·98	20·83
Gambela	0·17	0·25
Harari	1·09	0·22
Addis Ababa	24·53	1·77
Dire Dawa	1·16	0·41
Mother's age at birth		
<20	6·42	9·99
20-29	58·43	54·64
30-39	31·74	30·88
40-49	3·40	4·50
Mother's education		
No education	22·80	66·93
Primary	35·14	26·60
Secondary	15·31	4·45
Higher	26·76	2·01
Place of delivery		
Public	83·95	23·64
Private	13·69	0·90
NGO	2·36	0·24
Home	0·00	75·22
Birth order		
1	41·36	18·23
2-3	43·76	30·21
4+	14·88	51·56
Sex of child		
Male	53·97	51·90
Female	46·03	48·10
Size of baby at birth*		
Very large	26·53	17·58
Larger than average	16·00	13·82

Average	36·12	41·66
Smaller than average	7·02	10·09
Very small	12·65	16·04
Don't know	1·68	0·82
Wealth quantile		
Poorest	7·23	24·25
Poorer	12·25	23·07
Middle	10·81	20·88
Richer	9·27	18·31
Richest	60·44	13·50

NB: ***n***=weighted; * mother's estimate of baby's size at birth

Table 2. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean vs vaginal delivery, Ethiopia DHS**, 2016, 2011, 2005 and 2000**

	Prevalence Ratio (95% CI) for neonatal death
Ethiopia DHS 2016	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,641)	3·02 (1·37, 6·66)
Caesarean delivery, model 1[a] (n=10,641)	2·81 (1·11, 7·13)
Ethiopia DHS 2011	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n=11,654)	1·49 (0·62, 3·61)
Caesarean delivery, model 1[a] (n= 11,654)	1·15 (0·45, 2·93)
Ethiopia DHS 2005	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 9,861)	1·74 (0·67, 4·51)
Caesarean delivery, model 1[a] (n= 9, 861)	1·53 (0·52, 4·50)
Ethiopia DHS 2000	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,873)	0·93 (0·38, 2·30)
Caesarean delivery, model 1[a] (n= 10,853)	0·95 (0·29, 3·19)

[a]Adjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

Table 3. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean vs vaginal delivery, Ethiopia **DHS 2016**

	Prevalence Ratio (95% CI) for neonatal death
Main analysis	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,641)	3·02 (1·37, 6·66)
Caesarean delivery, model 1[a] (n=10,641)	2·81 (1·11, 7·13)
Sensitivity analyses	
Restricted to Addis Ababa region[a] (n=461)	1·07 (0·20, 5·73)
Excluded Addis Ababa and Hareri regions[a] (n= 9,575)	3·35 (1·31, 8·56)
Restricted to births in public facility[a] (n=3,023)	2·78 (1·16, 6·63)
Restricted to rural mothers[a] (n= 8,636)	3·43 (1·22, 9·67)
Restricted to women from lowest quintile of household wealth (n=3958)	7·01 (0·92, 53·36)
Restricted to women from highest quintile of household wealth (n=2092)	2·72 (0·55, 13·38)

[a]Adjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

1

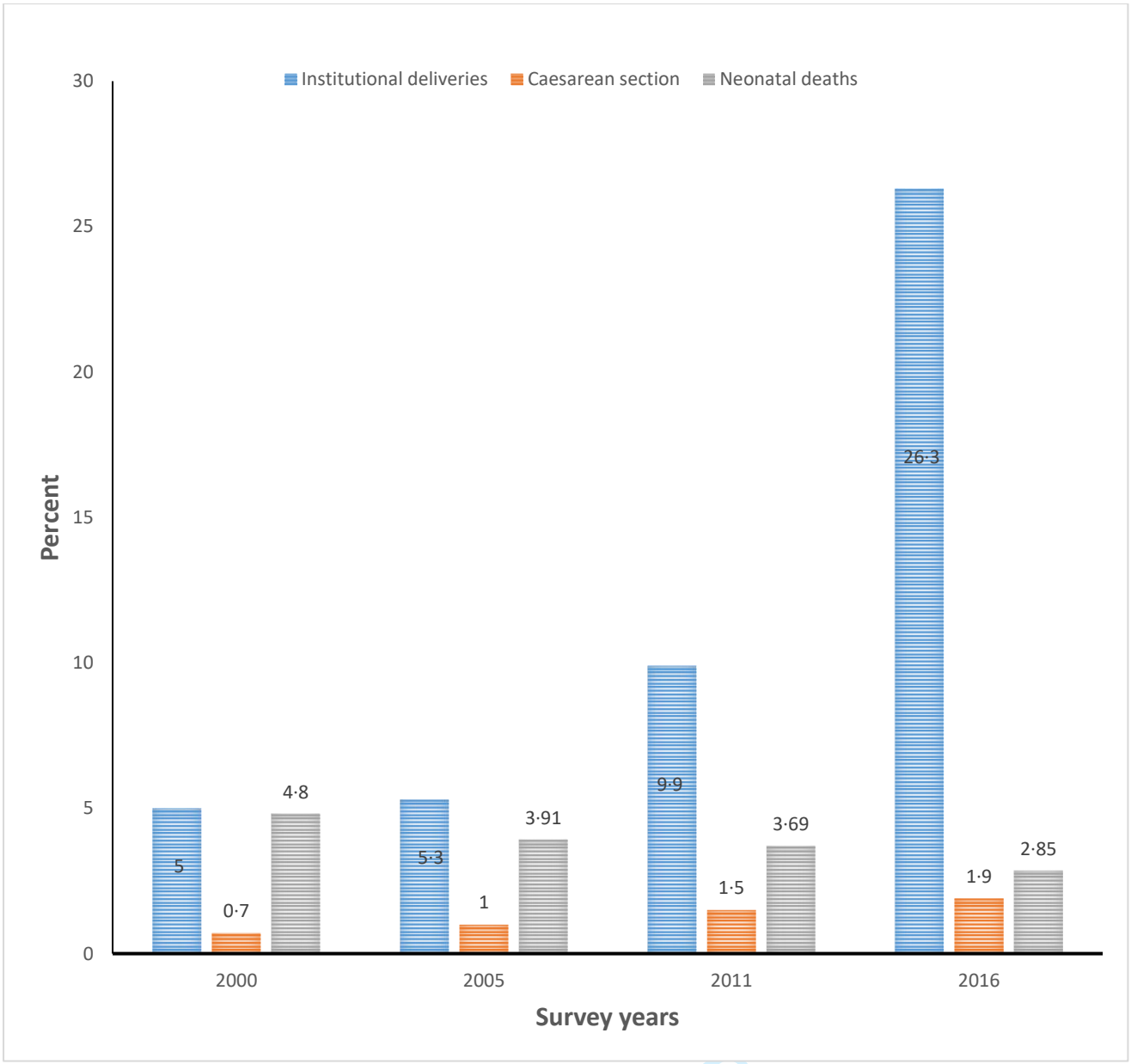


Figure 1. Trends in proportion of institutional deliveries, caesarean section and neonatal deaths in the 5 years before each of the surveys, Ethiopia DHS 2000, 2005, 2011 and 2016.

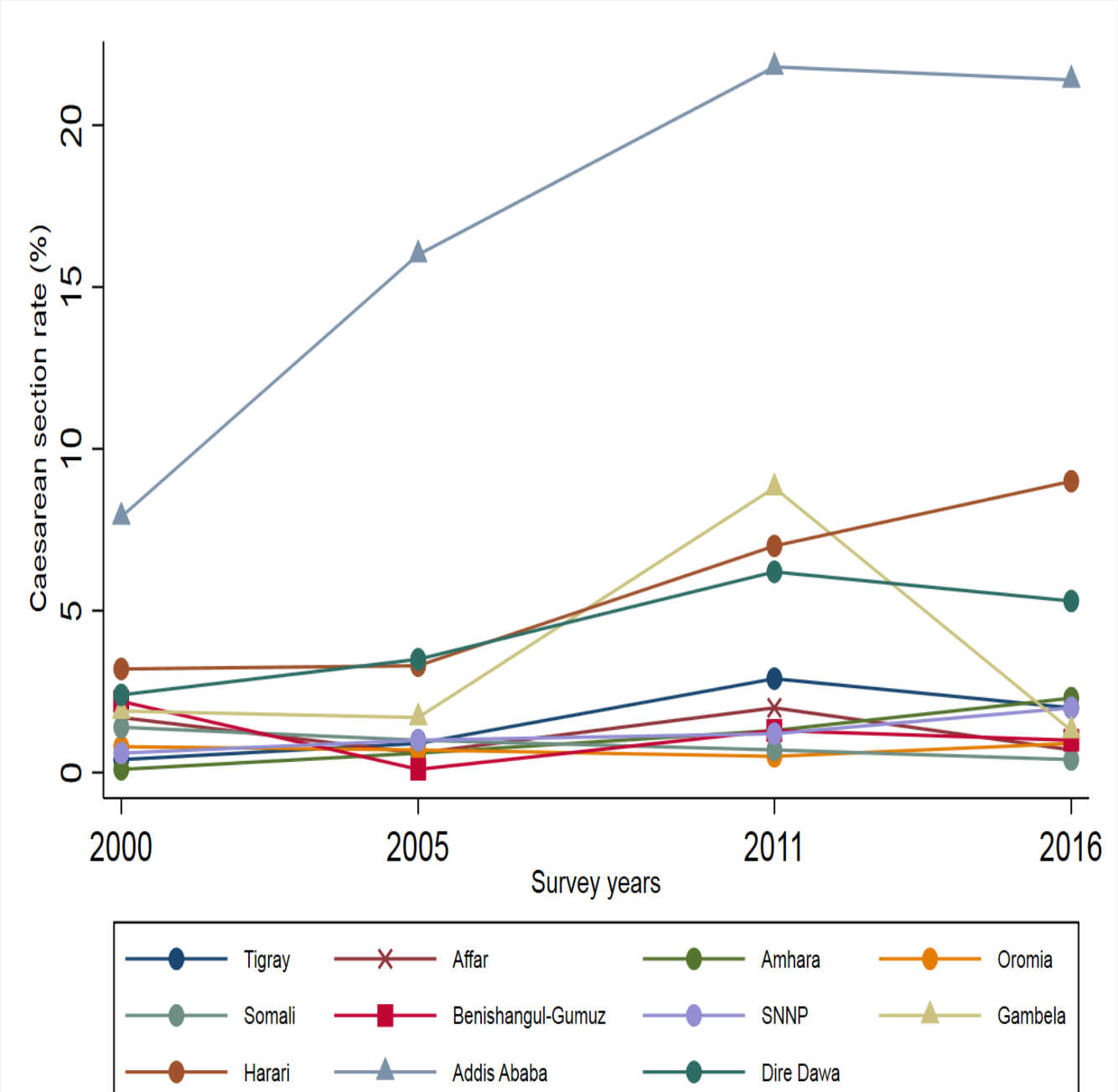


Figure 2. Trends in caesarean section rates in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016.

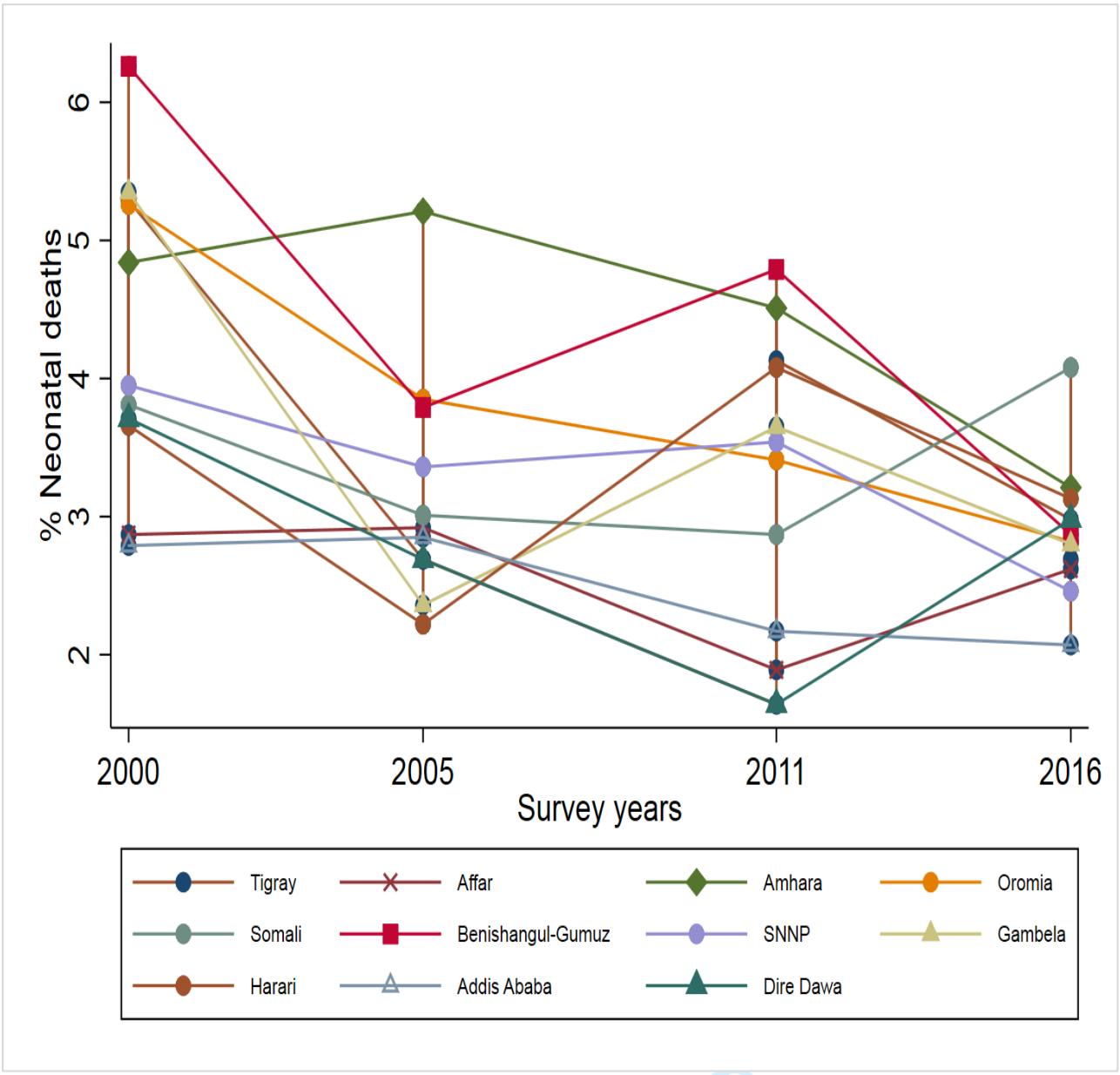


Figure 3. Trends in proportion of neonatal deaths in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016.

Supplementary Table 1. Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2000.

	Mode of delivery	
	Caesarean (n=86) **%**	Vaginal (n=12,174) **%**
Neonatal death		
Yes	4·48	4·80
No	95·52	95·20
Types of residence		
Urban	76·16	9·95
Rural	23·84	90·05
Region		
Tigray	3·98	6·44
Afar	2·46	1·02
Amhara	3·71	26·27
Oromia	46·31	40·74
Somali	2·29	1·15
Benishangul-Gumuz	3·15	0·99
SNNP	18·55	21·24
Gambela	0·63	0·23
Harari	0·95	0·20
Addis Ababa	16·87	1·38
Dire Dawa	1·11	0·32
Mother's age at birth		
<20	19·37	12·02
20-29	70·83	51·27
30-39	9·81	30·05
40-49	0·00	6·66
Mother's education		
No education	15·66	82·54
Primary	21·76	12·96
Secondary	56·41	4·31
Higher	6·17	0·19
Place of delivery		
Public	96·31	4·04
Private	1·29	0·13
NGO	2·40	0·18
Home	0·00	95·65
Birth order		
1	75·47	18·64
2-3	19·76	30·18
4+	4·77	51·18
Sex of child		
Male	61.80	51.21
Female	38.20	48.79
Size of baby at birth*		
Very large	9·76	5·26
Larger than average	31·96	25·44
Average	34·62	35·73
Smaller than average	19·73	27·56
Very small	3·75	5·86
Don't know	0·19	0·15
Wealth quantile		
Poorest	1·86	21·06
Poorer	4·93	20·98
Middle	4·09	21·96

Richer	6·13	20·54
Richest	82·98	15·46

NB: ***n***=weighted; * mother's estimate of baby's size at birth

Supplementary Table 2. Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2005.

	Mode of delivery	
	Caesarean (n=111) %	Vaginal (n= 11,052) %
Neonatal death		
Yes	6·74	3·89
No	93·26	96·11
Types of residence		
Urban	68·84	6·68
Rural	31·16	93·32
Region		
Tigray	5·38	6·26
Afar	0·58	0·97
Amhara	15·21	23·56
Oromia	28·45	39·62
Somali	4·23	4·28
Benishangul-Gumuz	0·14	0·95
SNNP	21·61	22·40
Gambela	0·46	0·28
Harari	0·66	0·20
Addis Ababa	22·09	1·17
Dire Dawa	1·17	0·33
Mother's age at birth		
<20	13·27	13·39
20-29	59·76	51·18
30-39	24·07	29·28
40-49	2·90	6·16
Mother's education		
No education	30·09	79·67
Primary	14·48	16·64
Secondary	46·54	3·40
Higher	8·88	0·30
Place of delivery		
Public	90·23	3·92
Private	5·93	0·27
NGO	3·84	0·13
Home	0·00	95·67
Birth order		
1	53·19	16·95
2-3	31·69	30·00
4+	15·12	53·04
Sex of child		
Male	51.29	51.27
Female	48.71	48.73
Size of baby at birth*		
Very large	30·74	22·31
Larger than average	11·45	9·45
Average	37·81	39·99
Smaller than average	9·41	7·25
Very small	9·54	20·57
Don't know	1·05	0·42
Wealth quantile		
Poorest	0·58	22·07
Poorer	5·87	21·25
Middle	3·94	22·45

Richer	9·74	20·00
Richest	79·87	14·22

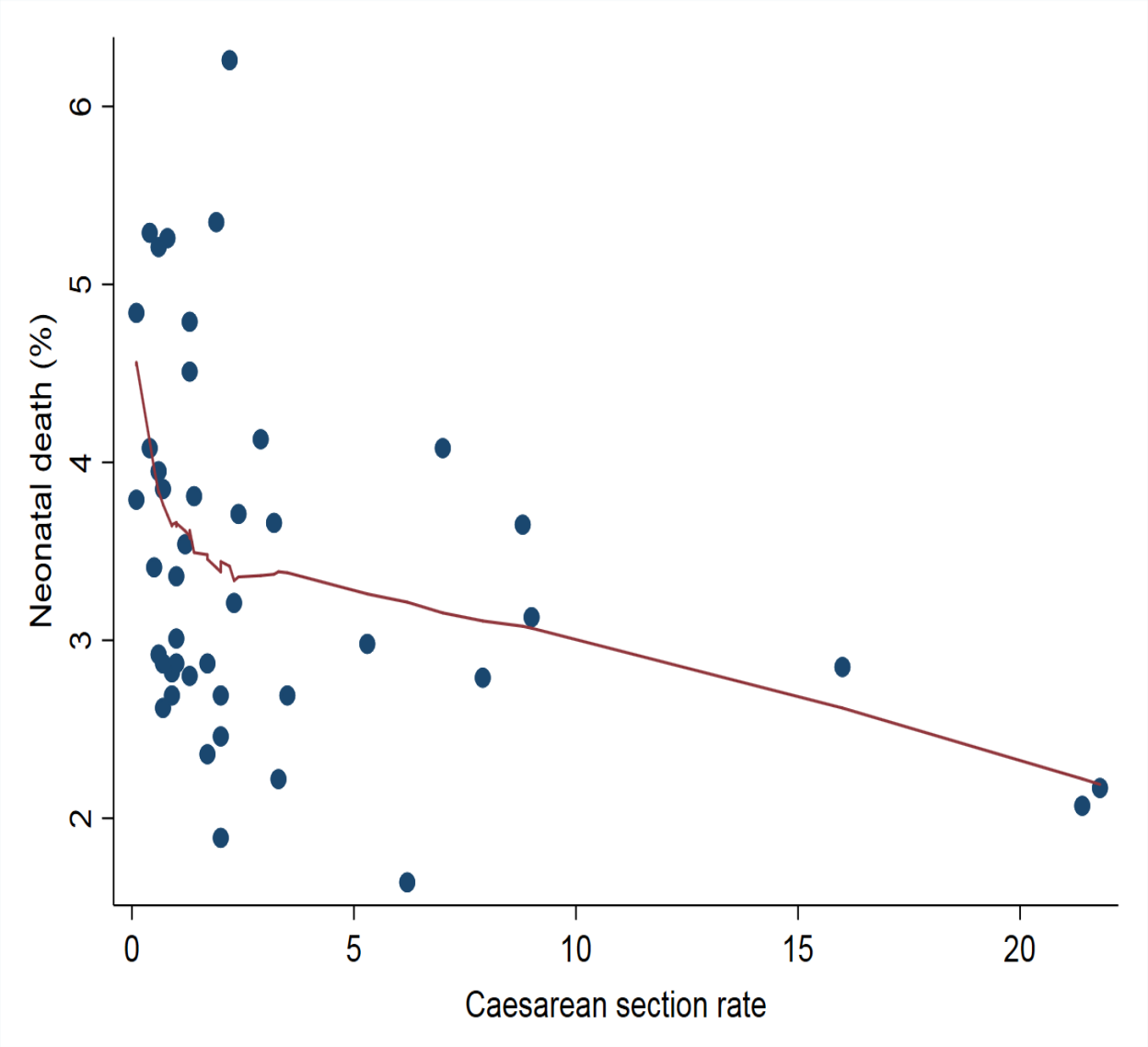
NB: ***n***=weighted; * mother's estimate of baby's size at birth

Supplementary Table 3. Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2011.

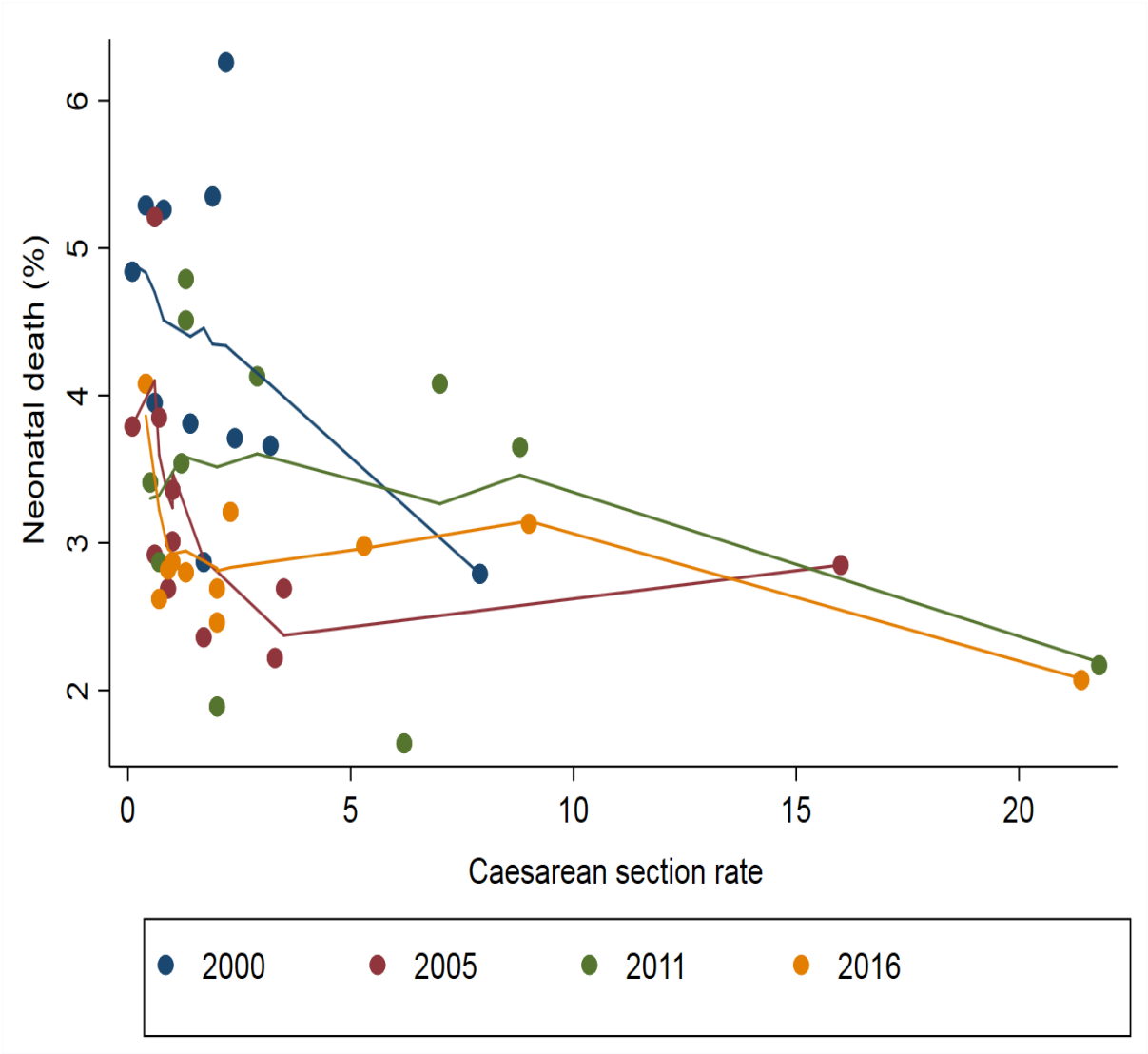
	Mode of delivery	
	Caesarean (n=175) %	Vaginal (n= 11,697) %
Neonatal death		
Yes	5·47	3·66
No	94·53	96·34
Types of residence		
Urban	70·92	12·00
Rural	29·08	88·00
Region		
Tigray	12·52	6·25
Afar	1·41	1·02
Amhara	19·38	22·42
Oromia	14·63	42·64
Somali	1·44	3·09
Benishangul-Gumuz	1·04	1·18
SNNP	17·45	21·06
Gambela	2·01	0·32
Harari	1·15	0·23
Addis Ababa	27·57	1·48
Dire Dawa	1·38	0·31
Mother's age at birth		
<20	10·49	10·86
20-29	62·84	55·69
30-39	23·66	28·71
40-49	3·00	4·74
Mother's education		
No education	19·92	70·04
Primary	44·73	26·78
Secondary	22·17	1·94
Higher	13·18	1·24
Place of delivery		
Public	83·49	7·61
Private	13·55	0·81
NGO	2·96	0·18
Home	0·00	91·41
Birth order		
1	53·54	18·53
2-3	27·37	31·17
4+	19·09	50·29
Sex of child		
Male	57·24	51·87
Female	42·76	48·13
Size of baby at birth*		
Very large	25·82	19·22
Larger than average	11·66	12·75
Average	42·31	38·25
Smaller than average	4·86	8·74
Very small	14·78	20·61
Don't know	0·58	0·42
Wealth quantile		
Poorest	2·05	23·13
Poorer	8·37	22·60
Middle	8·99	20·70

Richer	6·51	19·32
Richest	74·09	14·24

NB: ***n***=weighted; * mother's estimate of baby's size at birth



Supplementary Figure 1. The relationship between caesarean section rate and neonatal death**.**



Supplementary Figure 2. The relationship between caesarean section rate and neonatal death by survey years.

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The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys

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The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys

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ABSTRACT

Objective

To interpret the changing temporal association between caesarean birth and neonatal death within the context of Ethiopia from 2000 to 2016.

Design

Secondary analysis of Ethiopian Demographic and Health Surveys (DHS).

Setting

All administrative regions of Ethiopia with surveys conducted in 2000, 2005, 2011, and 2016.

Participants

Women aged 15-49 years with a live birth during the five years preceding the survey.

Main outcome measures

We analysed the association between caesarean birth and neonatal death using log-Poisson regression models for each survey adjusted for potential confounders. We then applied the 'Three Delays Model' to provide an interpretation of the changing association between caesarean birth and neonatal death in Ethiopia.

Results

The adjusted prevalence ratios (aPR) for neonatal death among neonates born via caesarean section versus vaginal birth increased over time, from 0.95 (95% CI, 0.29, 3.19) in 2000 to 2.81 (95% CI, 1.11, 7.13) in 2016. The association between caesarean birth and neonatal death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among women from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36)) in 2016. Aggregate-level analysis revealed that an increased caesarean section rates were correlated with decreased proportion of neonatal deaths.

Conclusions

A naïve interpretation of the changing temporal association between caesarean birth and neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death. However, the changing temporal association reflects improvements in health service coverage and secular shifts in the characteristics of Ethiopian women undergoing caesarean section after complicated labour or severe foetal compromise.

Strengths and limitations of this study

- This was the first study to examine the temporal association between caesarean birth and neonatal death within the context of Ethiopia from 2000 to 2016.
- A number of analyses were conducted after adjustment for potential confounders helped develop the possible scenarios to better understand the interpretation of the changing associations.
- We have used additional supporting evidence from Ethiopian DHS data which allowed us to interpret the changing association between caesarean birth and neonatal death in view of contextual factors in Ethiopia using the 'Three Delays Model'.
- Given the very low base rates of caesarean delivery in Ethiopia, the interpretation of our findings may not reflect the context of other low-and middle-income countries.

Introduction

Globally, 2.6 million neonatal deaths occurred within the first 28 days after birth, which accounted for 46% of all under-five deaths in 2016.[1] The majority of these deaths were from low- and middle-income countries. According to the United Nations Inter-agency Group for Child Mortality Estimation, Southern Asia (39%) and sub-Saharan Africa (38%) comprised the top two regions with the highest proportion of neonatal deaths, while five countries (India, Pakistan, Nigeria, the Democratic Republic of the Congo, and Ethiopia) accounted for 50% of all newborn deaths.[1] Unlike under-five mortality, the proportion of neonatal deaths is increasing.[2] If the current trend continues, more low-and middle-income countries will fail to achieve the Sustainable Development Goal (SDG) target for neonatal mortality at 12 per 1,000 live births.[3]

In contemporary obstetric practice, caesarean section remains an important intervention in preventing neonatal mortality and other adverse birth outcomes.[4] However, caesarean section may be prone to misuse because of unequal access, social, and cultural factors.[5-7] In developing country settings, due to limited medical provisions and/or lack of skilled birth attendants, some women may not benefit from caesarean birth though they are medically eligible, while ineligible women may sometimes have increased access. In the last decades, caesarean section rates have been increasing in low-, middle, and high-income countries.[8-10] The World Health Organization (WHO) suggests, "every effort should be made to provide caesarean sections to women in need, rather than striving to achieve a specific rate."[11]

Previous studies conducted using aggregate- and individual-level data have yielded inconsistent results about the association between caesarean birth and neonatal mortality. For instance, two ecological studies[12,13] conducted using worldwide country-level data have found that caesarean birth was associated with lower neonatal mortality while another two ecological studies[14,15] showed no association between caesarean birth and neonatal mortality, where caesarean section rates were higher than 10%. Inconsistent results for the association between caesarean birth and neonatal mortality were also reported by different studies conducted in Africa, Latin America, Asia, and United States of America based on individual-level data.[16-21] For example, a large study conducted by Villar et al. in 410 health facilities in 24 areas in eight Latin American countries found that, with cephalic presentation, both intrapartum and elective caesarean was associated with 1.66 (95% Confidence Interval (CI):

1.26, 2.20) and 1.99 (95%CI: 1.51, 2.63) times higher odds of neonatal mortality up to hospital discharge, respectively.[17] However, another study based on WHO global survey completed in nine countries in Asia found that both pre-labour (Adjusted Odds Ratio (aOR) 0.2, (95% CI: 0.1, 0.3)) and intrapartum caesarean sections (aOR 0.3, 95% CI: 0.2, 0.4) were associated with improved perinatal outcomes following breech presentation[16].

On the other hand, using both country-and individual-level data collected for nationally representative Demographic and Health Surveys (DHS), Kyu et al. found an increased risk for neonatal death associated with caesarean versus vaginal births in countries with low (< 5%) and medium (5-15%) caesarean section rates.[22] However, factors associated with caesarean section that increase risk for neonatal death in countries with low and moderate caesarean section rates remain ill-defined. Previous studies are limited by either inconsistent results or lack the interpretation of findings by considering the contextual factors.[12-22] In addition to the underlying indications for caesarean interventions like 'fetal distress', 'cord prolapse', 'prolonged and obstructed labour', 'fetal mal-presentation', 'major antepartum haemorrhage', and 'placenta praevia';[23,24] several contextual factors such as unequal access, infrastructural, and health workforce constraints could play a role in the association between caesarean section and neonatal death.

In low- and middle-income countries, the DHS are the most representative and widely available quality data sources for studies related to maternal and child health. In a recent study using DHS data in Ethiopia, it was shown that the proportion of institutional deliveries and caesarean section rates are still low, especially for rural births though increases from 2000 to 2016 surveys are notable.[25]We use Ethiopian DHS data from 2000, 2005, 2011, and 2016 to examine the association between caesarean birth and neonatal death. We then apply the 'Three Delays Model' developed by Thadeus and Maine[26] to provide an interpretation of the changing association between caesarean birth and neonatal death in Ethiopia.

Methods

Study design and data samples

We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela, and Harari), and two city administrations (Addis Ababa and Dire Dawa). Each of the surveys involved a two-stage, stratified, clustered sampling design. The survey datasets are de-identified and made freely available online. Permission to use these data was granted by the MEASURE DHS Program. The details about the methodology and standards for protecting the privacy of study participants in all DHS can be accessed at (http://www.measuredhs.com/What-We-Do/methodology.cfm).

Exposure

The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for livebirths they have reported in the past 5 years. The self-reported data on caesarean section rates collected for DHS, compared with facility-based records of caesarean sections, are found to be reliable in developing countries.[27] For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally.

Outcome

Neonatal death includes children who were born alive in the 5 years before the survey, but died within the first 28 days of life. The outcome variable, neonatal death, was measured from two variables (whether the child is alive and age at death (in days)).

Confounding

The following potential confounders were identified based on a priori subject-matter and expert knowledge. They included place of delivery (public, private, NGO, home), type of residence (urban/rural), sex of child (male/female), size of baby at birth (very large, larger than average, average, smaller than average, very small, don't know), mother's age at birth (in years), mother's education (no education, primary, secondary, higher), birth order (1, 2-3, 4+), and household wealth quintile (poorest, poorer, middle, richer, richest). Mother's age at

birth was calculated as a difference (in years) between infant's date of birth and mother's date of birth. DHS computes the wealth index for each survey based on household assets using principal components analyses[28] and categorizes households into wealth quintiles. These asset-based measures represent the wealth distribution relative to other households within the country. They are widely used and are consistent with comparisons to household expenditures and the measurement of inequalities in child mortality, education, and healthcare use in low-and middle-income countries.[29]

Statistical analysis

All analyses were weighted to be nationally representative. As women may have had more than one birth within the five-year survey periods, we also accounted for both clustering of cesarean deliveries within women as well as the complex survey design during the data analyses using the unit of analysis (children) study number and sample weights. We then conducted both individual- and aggregate-levels analyses. Our analysis was also supplemented by an application of the 'Three Delays Model' to interpret the changing association between caesarean birth and neonatal death both empirically and theoretically. All analyses were conducted using STATA/SE version 15.1 (Stata Corporation, College Station, TX).

Individual-level analysis

Associations between caesarean birth and neonatal death at the individual level were analysed using log-Poisson regression using data from Ethiopian DHS in 2000, 2005, 2011, and 2016. We calculated unadjusted and adjusted prevalence ratios (aPR) and their 95% Confidence Intervals (CIs) for each survey. We have then compared the strength of association between caesarean birth and neonatal death across all surveys analysed.

After noting the increasing association between caesarean birth and neonatal death over time, we conducted a series of analyses to explore what was during the change. We used the 2016 data because the association was more pronounced. We first restricted the analysis to participants living in regions with the highest caesarean section rates to examine whether the increased access to caesarean section affected the proportion of neonatal deaths. We then

estimated the effect of caesarean birth on neonatal death in regions with low caesarean section rate (ranged: 0.4-5.3%) or where access to caesarean section is limited, by excluding births in relatively high caesarean section rate regions—Addis Ababa (21.4%) and Hareri (9.0%).[25] Both low-and high-level of caesarean use has risks exceeding the risks of spontaneous vaginal deliveries.[16,30] It was demonstrated that low levels of caesarean are related to lack of access and can contribute to maternal and newborn deaths.[22,31]

Given the very large rural-urban differences in caesarean section in Ethiopia,[25,32] we also conducted similar analyses separately for rural women. In addition, we evaluated the association by restricting the analyses to births from the lowest quintile of household wealth, births from the highest quintile of household wealth, and births in public health facilities separately. These alternative analyses were exploratory in nature and helped us to understand contextual factors leading to inequalities in caesarean use that may occur not only due to inadequate access among the poorest women, but also overuse of caesarean section among the richest population subgroups.[33,34] However, as the caesarean section rate in Ethiopia is low (about 2%), the number of neonatal deaths following caesarean birth is low and resulted in wide confidence intervals for the estimates. The subgroup analyses allowed us to explain how contextual factors such as unequal access, infrastructural, and workforce constraints could play role in the association between caesarean section and neonatal death because these factors will result in delay in accessing emergency caesarean section, which is usually accessible at specialized health facilities.

The 2016 DHS data included an additional question regarding 'timing of decision to conduct caesarean section (i.e., whether it was before or after the onset of labour pains).' We used this variable as a proxy to type of caesarean birth (indicative of intrapartum or pre-labour caesarean section) and conducted analysis to examine the association between types of caesarean section and neonatal death. As this is confined only to 2016 data, we have provided the results in the **Supplementary Table A1**.

Aggregate-level analysis

Data on the caesarean section rate and proportion of neonatal deaths were disaggregated by urban-rural areas for each of the nine regions and two city administrations in Ethiopia for each of DHS surveys in 2000, 2005, 2011, and 2016. However, the urban-rural stratification

for Addis Ababa is only available for the 2005 survey. These results in a total of 85 data points (observations). In order to assess the correlation between caesarean section and neonatal death at aggregate-level, we conducted simple linear regression for overall surveys together and for individual surveys separately.

The 'Three Delays Model'

The 'Three Delays Model' is a conceptual framework developed by Thadeus and Maine to examine factors contributing to maternal mortality with specific focus on those that affect the "interval between the onset of obstetric complication and its outcome."[26] The 'Three Delays Model' summarises the various factors that affect this interval into three phases of delay—delay in deciding to seek care (*Phase I delay*); delay in identifying and reaching medical facility (*Phase II delay*); and delay in receiving adequate and appropriate treatment (*Phase III delay*). Some of the key factors that shape the model include: the status of women; distance from the health facility; availability and cost of transportation; condition of roads; distribution of health facilities; shortage of supplies, equipment, and skilled birth attendants; and adequacy of referral system.[26] The pictorial presentation of the 'Three Delays Model' is provided in the **Supplementary Figure A1-A4.**

As maternal and neonatal mortality share many risk factors, we adopted the 'Three Delays Model' as a framework to help interpret the changing association between caesarean birth and neonatal mortality within the context of Ethiopia because factors contributing to the 'three delays" aggravate the underlying medical indications for caesarean intervention that make neonatal death difficult to prevent. Previous studies conducted in India,[35] Tanzania[36] and Uganda[37] have applied the 'Three Delays Model' to their analyses of perinatal deaths.

We have identified some contributing factors underlying the 'Three Delays Model' from the 2016 survey. For example, information regarding problems faced by women of reproductive age (15-49 years) in accessing health care to obtain medical advice or treatment for themselves when they are sick were gathered. It consisted of four questions: distance to health facility (big problem/not big problem); getting money for treatment (big problem/not big problem); getting permission to go for treatment (big problem/not big problem); and not

wanting to go alone (big problem/not big problem). Furthermore, data on attendance by skilled birth attendants during delivery and women's socioeconomic and demographic status are also available in the DHS. This information can particularly be important to understand and address the barriers that women face in seeking care during pregnancy and delivery.[32] We have, therefore, analysed the DHS data to describe these factors empirically in the context of Ethiopia.

Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in the design and implementation of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of the research to study participants or the relevant patient community.

Results

Table 1 shows the characteristics of mothers and children according to mode of delivery for each of the surveys conducted in 2000, 2005, 2011, and 2016. Across the four DHS survey waves, women who underwent caesarean delivery were more likely to live in urban areas, had a higher level of education, and were from the richest quintile of household wealth. They were also more likely to have male children. Caesarean deliveries were more frequent in women in the age category of 20-29 years, and among infants who had either very large or large size at birth. **Figure 1** shows that the proportion of institutional deliveries increased from 5.0% in 2000 to 26.3% in 2016, whereas the national caesarean section rate increased from 0.7% in 2000 to 1.9% in 2016. However, the rate of caesarean delivery in Ethiopia varied widely across administrative regions (**Figure 2**). For instance, Addis Ababa had the highest (21.4%) rate, while Somali region had the lowest (0.4%) in 2016. The national proportion of neonatal deaths decreased from 4.8% in 2000 to 2.9% in 2016, but the proportion varies among administrative regions (**Figure 1 & Supplementary Table A2**).

Table 2 shows that the adjusted prevalence ratio (aPR) for neonatal death associated with caesarean versus vaginal births in 2000 DHS was 0.95 (95%CI, 0.29, 3.19), in 2005 it was 1.53 (95%CI, 0.52, 4.50). In 2011, the adjusted prevalence ratio (aPR) for neonatal death associated with caesarean versus vaginal births was 1.15 (95%CI, 0.45, 2.93), while in 2016 it was 2.81-fold higher risk of neonatal death (aPR, 2.81; 95%CI, 1.11, 7.13).

Table 3 summarises the findings of the subgroup analyses based on the 2016 data. When women living in urban settings, (Addis Ababa (caesarean section rate (21.4%), and Hareri (9·0%)), were excluded from the analyses, the corresponding adjusted PR for neonatal death was increased to 3.55 (95%CI, 1.31, 8.56). Similarly, when we restricted the analyses to include only rural women, the prevalence ratio for neonatal death associated with caesarean versus vaginal births was found to be 3.43 (95% CI, 1.22, 9.67). The respective risk of neonatal death increased to 7.01 (95%CI, 0.92, 53.36) when the analysis was limited to women from the lowest quintile of household wealth.

When we restricted the analyses to Addis Ababa, the capital of Ethiopia, the relative risk for neonatal death associated with caesarean versus vaginal births was 1.07 (95%CI, 0.20, 5.73).

Moreover, when the analysis was confined to women from the highest quintile of the household wealth, the risk of neonatal death was 2.72 (95% CI, 0.55, 13.38).

Lastly, **Figure 3** shows that an increase in caesarean section rate is weakly correlated with a decrease in the proportion of neonatal deaths (correlation coefficient (r) = -0.1839) when aggregate-level data for all surveys together was analyzed. However, the relationship between caesarean birth and neonatal death is variable when the analysis is restricted to each survey year separately (see **Figure 4**).

Interpretation

The primary individual level analyses showed that the adjusted prevalence ratios (aPR) for neonatal death associated with caesarean versus vaginal births increased from 0.95 (95% CI, 0.29, 3.19) in 2000 to 2.81 (95% CI, 1.11, 7.13) in 2016. These findings suggest that the circumstances for foetuses born in 2000 DHS are different from the foetuses in 2016. Our subgroup analyses using 2016 data suggest that the association between caesarean birth and neonatal death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among women from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36)), but not for births in areas with wider availability of caesarean such as Addis Ababa (aPR (95% CI) 1.07 (0.20, 5.73)). The changing association between caesarean birth and neonatal death over time, and the stronger association observed among different subgroup analyses may be attributable to changes in the pattern of confounding by indication due to contextual factors such as unequal access, structural health-system deficiencies (insufficient equipment, supplies, and drugs), infrastructural, and health workforce constraints.

The national caesarean section and institutional delivery rates in Ethiopia are still low though increases in the past decade are notable. There is also substantial disparity in caesarean section rates, with very low rates in rural areas and among the poorest women,[25] suggesting unequal access which may be as a consequence of a range of geographic, social, and economic barriers. The low caesarean rates may also be due to lack of skilled birth attendants, and poor health infrastructure (e.g., shortage of medical care institutions, deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, and blood transfusion capacity).[38-40] In Ethiopia, there are only 820 Obstetricians, 10,846 General practitioners, 996 Emergency obstetric surgeons, 6,345 Health officers, 41,009 Nurses, 8,635 Midwives, 233 Anaesthesiologists, and 33,320 Health extension workers for the population of over 90 million in 2015.[41] Similarly, there are only 3,547 functional Health centres, 16, 447 functional Health posts, and 189 functional Hospitals in 2015.[42]

We know from previous research that inadequate access to timely caesarean section may result in perinatal asphyxia, uterine rupture, obstructed labour, and these can contribute to maternal and newborn deaths.[43] Conversely, it was demonstrated that maternal and neonatal mortality due to obstetric complications can be prevented with timely access to caesarean section.[43,44] Delay, therefore, emerges as relevant factor in worsening the underlying medical

indications for caesarean intervention thereby contributing to neonatal death. Context specific factors that delay access to caesarean section may have the capacity to make women with labour problems undergo caesarean section after severe complication of labour or severe foetal compromise. Therefore, our interpretation is that caesarean section conducted after severe foetal compromise may not prevent neonatal deaths because they have already experienced such severity of complications that although live born, neonatal death is difficult to prevent.

There are two possible scenarios leading to caesarean section in Ethiopia. First, when women who have previously had a caesarean section, with breech presentation, or other risk factors such as eclampsia attend specialised health facilities, they are usually allowed to undergo caesarean section. Their caesarean section is commonly classified as "elective or scheduled caesarean section." Second, when caesarean section is performed for "emergency reasons." Full term mothers with or without signs of labour will be admitted to health facilities where their progress is monitored and labour-augmenting or inducing medications may be administered. Decisions to perform caesarean section in these facilities or decision to refer the mother to nearby hospitals for caesarean delivery or other action depends on the condition of the mother and foetus during the progress of labour. In primary health facilities (i.e., health posts and health centres), obstetric care providers use a 'Partograph',[45,46] a routine labour monitoring instrument (chart) which helps the health care provider in identifying slow progress in labour and take appropriate action. In hospitals, the decision to perform a caesarean section is reached when the labour is prolonged and/or the second stage of labour is complicated risking the life of mother and foetus.

Given these pathways to caesarean delivery in mind, our interpretation of the changing association between caesarean birth and neonatal death in Ethiopia may be shaped by examining factors contributing to delays in the 'Three Delays Model.' This is because delays to caesarean section aggravate the underlying medical indications for caesarean intervention. **Table 4** shows factors affecting the lengths of delays in the 'Three Delays Model', according to sociodemographic characteristics in Ethiopia.

Phase I delay: deciding to seek care

In Ethiopia, poorer and less-educated women are more likely to select a nearby health

facility, especially in rural areas, where there is limited access to caesarean section and the possibility of benefiting from caesarean section is mainly through referral to higher levels of care. Women are more likely to undergo a caesarean section if they present to specialized health facilities. However, the outcome of delivery depends on how quick/competent the health care provider is in referring the mother or on intervening, and the severity of the underlying medical complication for caesarean intervention which may be affected by the delay in women's or family's decision to seek care. Poor health decision-making depends on numerous factors such as educational status, distance to health facility, economic status, sociocultural factors (e.g., unsupportive spouse, and lack of autonomy), and quality of care.[26,47,48]

Table 4 shows that 'distance to health facility' was a big problem in accessing health care for about 60% of rural and 17% of urban women in Ethiopia. Similarly, 'getting money for treatment' is a big problem to access health care and was reported by 61% of rural and 35% of urban women in 2016 DHS. On the other hand, the status of women in a given society affects the decision to seek care. For instance, efforts to seek timely care is influenced by women's limited mobility because they need permission to travel from spouse and/or mother-in-law.[26] In Ethiopia, about 37% of rural and 15% of urban women reported 'getting permission to go for treatment' is a big problem to access health care.

Phase II delay: identifying and reaching a medical facility

Delay in reaching health care may occurs when women who encounter obstetric complication live further from health facilities, where the availability and cost of transportation is problematic. In one study conducted in rural India, Kumar *et al*.[47] found that health facility births occur less likely among women living farther away from the health facilities, suggesting distance as an important barrier to in-facility births for rural women. In addition to the travel distance, the scarcity of transportation which may be accompanied by poor roads is also another obstacle for women with labour complications to timely reach even the closest health facility. As a result of this, women who arrive at the nearby facility following labour complications probably will travel further to specialised hospital due to emergency referral. It is clear that the obstetric complications encountered by mothers reaching nearby primary health facilities will be compounded by additional delays when they are referred for

caesarean section. These scenarios highlight the likelihood of adverse delivery outcome followed by aggravated obstetric complications due to delays in reaching medical facility as high.

In Ethiopia, about 50% of women of reproductive age (15-49 years) reported 'distance to health facility' as a big problem to access health care (see **Table 4**). Moreover, access to caesarean situation in Ethiopia is worse than in most other settings.

Phase III delay: receiving adequate and appropriate treatment

Phase III delays occur within any health facilities and are indicators of inadequate care due to lack of facilities; inadequately trained obstetric care givers (skilled birth attendants); and deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, and blood transfusion as well as inadequate and inappropriate referral systems. These deficiencies will limit women's access to lifesaving procedures such as caesarean section. In Ethiopia, only 28.0% of all births were delivered by 'skilled providers' (includes doctor, nurse, midwife, health officer, and health extension worker) in 2016 DHS. **Table 4** also shows that there are disparities in the proportion of births attended by skilled birth attendants by urban-rural place of residence, region, level of mother's education, and household wealth. It is clear that an insufficient number of skilled birth attendants at any health facility will lead to delay in receiving appropriate treatment among women with obstetric complications. Although health posts and health centres (primary health care unit) are the most accessible to the general population in Ethiopia, they are not fully equipped to deal with obstetric complications.[41,42] As a result of this, women with complications will have to travel on to better equipped institution (secondary and tertiary level health care) with caesarean section capacity (e.g. general hospitals and specialized hospitals) through referral. By the time the women reach these well-equipped health facility, the delays will have further aggravated the obstetric complication on the way. A schematic representation of Ethiopian health system structure is provided in **Supplementary Figure A5.**

On the other hand, delay in caesarean intervention may even happen if mothers with less severe labour complications were referred and presented to specialised health facilities in a timely manner. This is because a trial of labour is usually attempted before a decision to have caesarean section. For instance, some women who are referred from primary health facilities

undergo induction and augmentation of labour because these interventions are only provided in health facilities with the capacity to provide caesarean section in Ethiopia. These practices, in turn, will result in delay in receiving caesarean section leading to worsening of the already existing obstetric complications. Thus, any delays to caesarean intervention have a higher chance of aggravating the already existing complications and increase the risk of neonatal death.

Discussion

Our study examined the changing temporal association between caesarean birth and neonatal death within the context of Ethiopia from 2000 to 2016. The association between caesarean section and neonatal death increased over time and was variable among population subgroups. These changes over time, and variation across population sub-groups may be attributable to changes in the pattern of confounding by indication due to contextual factors such as improvement in health service coverage, unequal access (e.g. due to a range of geographic, social, and economic barriers), and structural, and health workforce constraints.

In Ethiopia, the proportion of women aged 15-49 who received any antenatal care from a skilled provider has increased from 27% in 2000 to 62% in 2016.[32] Health facility-based deliveries have increased from 5% in 2000 to 26% in 2016 (increased from 2% in 2000 to 20% in 2016 for rural women, and increased from 32% in 2000 to 79% in 2016 for urban women).[32] The proportion of births in health facilities assisted by a skilled birth attendants increased from 6% in 2000 to 28% in 2016.[32] These figures reflect improvement in health service coverage in Ethiopia.

Moreover, since 2004, with the implementation of the Health Extension Programme—a community-based primary healthcare programme—the Ethiopian government has increased the number of health posts from 4,211 in 2005 to 16,447 in 2015.[42,49] Likewise, the number of health centres were increased from 600 in 2005 to 3,586 in 2015.[42,49] However, due to limitations in proper monitoring of labour for making timely decisions, especially on whether or not to initiate a referral from primary health facilities to higher level facilities, and due to poor transport and road networks which are still the common problems in low income countries,[50] the underlying medical indications for caesarean intervention will be worsened by factors contributing to 'delays.' Delay in receiving adequate and appropriate care is still a common problem in low income countries due to deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, blood transfusion capacity, and a shortage of skilled birth attendants.[51-53] There is also an inequitable distibution of the health workforce across urban and rural areas. For example, the majority of specialist doctors in Ethiopia serve in urban areas, where the total population distribution is only 19.4%.[41,42] These situations often result in poor quality care to rural women, and the caesarean section conducted after a complicated labour may be associated with increased neonatal mortality due to confounding

by indication.

Unlike previous studies, the present study takes into account the interpretation of the changing association between caesarean birth and neonatal death within the context of Ethiopia using DHS data. The change in the strength of effect estimates across DHS waves, and the different subgroup analyses suggest that neonatal mortality can be reduced by increasing timely access to caesarean section and timely decision for caesarean delivery via increasing health service coverage, improving infrastructure (e.g. increasing number of health facilities), increasing the number of skilled birth attendants, improving quality of care, and increasing awareness about antenatal care and health facility delivery among women. Moreover, provision of training to skilled birth attendants on close monitoring of labour and early detection of complications, equipping the primary health facilities (e.g. health centres) to the level of caesarean capacity, and continuous financial investment in primary health facilities will be an important strategy to reduce neonatal mortality.

It appears that previous studies which used individual-level data are more likely to report an increased risk of neonatal death among infants born by caesarean section than the ecological studies. This may be due to the indications for the caesarean delivery (e.g. the severity of the underlying causes) was involved in causing both caesarean delivery and neonatal death in studies which used individual-level data, suggesting the role of confounding by indication in the association between caesarean birth and neonatal death because an intended effect of caesarean birth is prevention of neonatal death. Therefore, the increased risk for neonatal death associated with caesarean birth, compared with vaginal birth, would appear to be intuitive given the fact that neonatal death rates after emergency caesarean section is strongly dependent upon the underlying medical indication (e.g. antenatally diagnosed foetal malformation or foetal growth restriction) for caesarean intervention.

In Ethiopia, the national rate of caesarean section increased from 0.7% in 2000 to 1.9% in 2016. On the other hand, neonatal mortality rate declined from 49 deaths per 1,000 live births in 2000 to 29 deaths per 1,000 births in 2016.[32] Similarly, the pregnancy-related mortality ratio decreased from 871 pregnancy-related deaths per 100,000 live births in 2000 to 412 pregnancy-related deaths per 100,000 live birth in 2016 DHS.[32] Our analyses based on aggregate-level data from Ethiopian DHS showed that an increase in caesarean section rate is

correlated with a decrease in the proportion of neonatal deaths. Even though similar context-specific interpretation is applicable to ecological studies, additional explanation may also be necessary to interpret the association. For example, a change in neonatal mortality rate may be attributable to changes acting on the population as a whole—e.g. changes in health coverage indicators, such as an increase in births attended by skilled birth attendants (increased from 6% in 2000 to 28% in 2016)[32] and immunization coverage (was 86.4% in 2015).[42]

We acknowledge the following limitations of this study. Firstly, as both the proportion of institutional deliveries and caesarean section rate is low in Ethiopia, especially rural area, the number of neonatal deaths following caesarean section may be low. However, since our analyses are weighted, we believe that the weight improves the representativeness of the data in terms of size, distribution and characteristics of the Ethiopian population. The weight may also ensure that our estimates are unbiased though the confidence interval for some subgroup analyses are somewhat wide. Secondly, the interpretation of our study is specific to the context of Ethiopia and may not be generalizable to other developing countries in Africa or elsewhere. Another limitation is the mother's recall of the child's size at birth was used as a substitute for the child's birth weight in this study because the data for birth weight was not collected for more than 50% of the neonates in DHS.

Conclusions

A naïve interpretation of the changing association between caesarean birth and neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death. However, the changing temporal association likely reflects improvements in health service coverage and a shift in the characteristics of Ethiopian women undergoing caesarean section after complicated labour or severe foetal compromise.

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have been explained.

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LIST OF TABLES AND FIGURES

Table 1. Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2000, 2005, 2011 and 2016

	Mode of delivery							
	DHS 2000		DHS 2005		DHS 2011		DHS 2016	
	Caesarean (n=86) %	Vaginal (n=12,174) %	Caesarean (n=111) %	Vaginal (n= 11,052) %	Caesarean (n=175) %	Vaginal (n=11,697) %	Caesarean (n=213) %	Vaginal (n= 10,810) %
Neonatal death								
Yes	4.5	4.8	6.7	3.9	5.5	3.7	8.3	2.7
No	95.5	95.2	93.3	96.1	94.5	96.3	91.7	97.3
Types of residence								
Urban	76.2	9.9	68.8	6.7	70.9	12.0	60.4	10.1
Rural	23.8	90.1	31.2	93.3	29.1	88.0	39.6	89.9
Region								
Tigray	4.0	6.4	5.4	6.3	12.5	6.2	6.8	6.5
Afar	2.5	1.0	0.6	1.0	1.4	1.0	0.4	1.0
Amhara	3.7	26.3	15.2	23.6	19.4	22.4	22.1	18.7
Oromia	46.3	40.7	28.5	39.6	14.6	42.6	21.2	44.5
Somali	2.3	1.2	4.2	4.3	1.4	3.1	1.0	4.7
Benishangul-Gumuz	3.1	1.0	0.1	0.9	1.0	1.2	0.6	1.1
SNNP	18.5	21.2	21.6	22.4	17.4	21.1	21.0	20.8
Gambela	0.6	0.2	0.5	0.3	2.0	0.3	0.2	0.2
Harari	0.9	0.2	0.7	0.2	1.2	0.2	1.1	0.2
Addis Ababa	16.9	1.4	22.1	1.2	27.6	1.5	24.5	1.8
Dire Dawa	1.1	0.3	1.2	0.3	1.4	0.3	1.2	0.4
Mother's age at birth								
<20	19.4	12.0	13.3	13.4	10.5	10.9	6.4	10.0
20-29	70.8	51.3	59.8	51.2	62.8	55.7	58.4	54.6
30-39	9.8	30.0	24.1	29.3	23.7	28.7	31.7	30.9
40-49	0.0	6.7	2.9	6.2	3.3	4.7	3.4	4.5
Mother's education								
No education	15.7	82.5	30.1	79.7	19.9	70.0	22.8	66.9
Primary	21.8	13.0	14.5	16.6	44.7	26.8	35.1	26.6

Secondary	56.4	4.3	46.5	3.4	22.2	21.9	15.3	4.5
Higher	6.2	0.2	8.9	0.3	13.2	1.2	26.8	2.0
Place of delivery§								
Public	96.3	4.0	90.2	3.9	83.5	7.6	84.0	23.6
Private	1.3	0.1	5.9	0.3	13.6	0.8	13.7	0.9
NGO	2.4	0.2	3.8	0.1	3.0	0.2	2.4	0.2
Home	0.0	95.6	0.0	95.7	0·00	91.4	0·00	75.2
Birth order								
1	75.5	18.6	53.2	17.0	53.5	18.5	41.4	18.2
2	17.5	16.5	26.0	15.5	17.0	17.0	25.6	16.0
3	2.2	13.7	5.7	14.5	10.3	14.2	18.2	14.2
4	1.0	11.3	1.5	12.9	6.0	12.6	3.3	12.5
5	0.6	10.4	2.2	10.8	8.4	10.5	5.3	11.4
6+	3.2	29.5	11.4	29.4	4.7	27.2	6.3	27.6
Sex of child								
Male	61.8	51.2	51.3	51.3	57.2	51.9	54.0	51.9
Female	38.2	48.8	48.7	48.7	42.8	48.1	46.0	48.1
Size of baby at birth*								
Very large	9.8	5.3	30.7	22.3	25.8	19.2	26.5	17.6
Larger than average	32.0	25.4	11.4	9.5	11.7	12.7	16.0	13.8
Average	34.6	35.7	37.4	40.0	42.3	38.2	36.1	41.7
Smaller than average	19.7	27.5	9.4	7.3	4.9	8.7	7.0	10.1
Very small	3.7	5.9	9.5	20.6	14.8	20.6	12.7	16.0
Don't know	0.2	0.2	1.1	0.4	0.6	0.4	1.7	0.8
Wealth quantile								
Poorest	1.9	21.1	0.6	22.1	2.0	23.1	7.2	24.2
Poorer	4.9	21.0	5.9	21.3	8.4	22.6	12.2	23.1
Middle	4.1	22.0	3.9	22.5	9.0	20.7	10.8	20.9
Richer	6.1	20.5	9.7	20.0	6.5	19.3	9.3	18.3
Richest	83.0	15.5	79.9	14.2	74.1	14.2	60.4	13.5

NB: ***n***=weighted; §Missing for 2000 (n = 9); * mother's estimate of baby's size at birth; **DHS**, Demographic and Health Survey

Table 2. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean versus vaginal delivery, Ethiopia DHS **2000, 2005, 2011, and 2016**

	Prevalence Ratio (95% CI) for neonatal death
Ethiopia DHS 2000	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,873)	0.93 (0.38, 2.30)
Caesarean delivery, model 1[a] (n=10,853)	0.95 (0.29, 3.19)
Ethiopia DHS 2005	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 9,861)	1.74 (0.67, 4.51)
Caesarean delivery, model 1[a] (n= 9,861)	1.53 (0.52, 4.50)
Ethiopia DHS 2011	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n=11,654)	1.49 (0.62, 3.61)
Caesarean delivery, model 1[a] (n= 11,654	1.15 (0.45, 2.93)
Ethiopia DHS 2016	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,641)	3.02 (1.37, 6.66)
Caesarean delivery, model 1[a] (n= 10,641)	2.81 (1.11, 7.13)

[a]Adjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

Table 3. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean versus vaginal delivery, Ethiopia **DHS 2016**

	Prevalence Ratio (95% CI) for neonatal death
Main analysis	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,641)	3.02 (1.37, 6.66)
Caesarean delivery, model 1[a] (n=10,641)	2.81 (1.11, 7.13)
Subgroup analyses	
Restricted to Addis Ababa[b] (n=461)	1.07 (0.20, 5.73)
Excluded Addis Ababa and Hareri region[a] (n= 9,575)	3.35 (1.31, 8.56)
Restricted to births in public facility[a] (n=3,023)	2.78 (1.16, 6.63)
Restricted to rural mothers[b] (n= 8,636)	3.43 (1.22, 9.67)
Restricted to women from lowest quintile of household wealth[c] (n=3,958)	7.01 (0.92, 53.36)
Restricted to women from highest quintile of household wealth[c] (n=2,092)	2.72 (0.55, 13.38)

[a]Adjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.
[b]Adjusted for place of delivery, sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.
[c]Adjusted for place of delivery, sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order.

Table 4. Factors contributing to the 'Three Delays Model', according to sociodemographic characteristics, Ethiopia DHS 2016

	Delivery by skilled provider§	Number of births	Problems in accessing health care by women aged 15-49 years*					
			Distance to health facility	Getting money for treatment	Getting permission to go for treatment	Not wanting to go alone	At least one problem accessing health care	Number of women
Types of residence								
Urban	80.1	1216	17.0	34.7	15.1	21.4	45.6	3476
Rural	21.2	9807	59.8	60.5	37.0	47.9	76.9	12207
Region								
Tigray	59.3	716	37.4	46.1	15.3	24.6	60.7	1129
Afar	16.4	114	54.3	51.7	28.2	41.8	66.6	128
Amhara	27.7	2072	33.7	35.3	15.4	34.6	55.7	3714
Oromia	19.7	4851	68.9	70.1	58.3	57.0	82.9	5701
Somali	20.0	508	47.3	63.0	25.7	32.2	72.6	459
Benishangul-Gumuz	28.6	122	57.4	62.4	36.5	43.8	76.8	160
SNNPR	28.6	2296	52.7	59.1	18.4	39.5	75.4	3288
Gambela	46.9	27	41.0	44.3	24.3	33.7	61.2	44
Harari	51.2	26	18.1	28.2	16.3	13.8	30.8	38
Addis Ababa	96.8	244	10.8	29.2	8.7	14.5	40.0	930
Dire Dawa	56.7	47	57.4	64.5	58.7	55.2	71.4	90
Mother's education								
No education	17.2	7284	59.2	62.9	37.6	47.1	78.0	7498
Primary	38.6	2951	50.3	55.7	31.9	43.2	71.1	5490
Secondary	78.4	514	27.8	33.2	18.2	27.8	48.1	1817
More than secondary	93.2	274	20.6	23.8	15.9	20.4	39.8	877
Wealth quintile								
Poorest	11.0	2636	67.7	70.9	40.0	54.5	85.3	2633

Poorer	20.8	2520	66.8	67.0	42.1	52.7	82.9	2809
Middle	24.2	2280	59.4	61.0	35.2	47.6	77.3	2978
Richer	28.5	1999	49.8	50.2	33.8	41.2	68.2	3100
Richest	70.3	1588	22.1	35.2	17.0	23.4	47.7	4163
Total	27.7	11023	50.3	54.8	32.1	42.0	70.0	15683

§Percentage delivered by a skilled provider (includes doctor, nurse, midwife, health officer, and health extension worker)

*Percentage of women age 15-49 who reported that they have serious problems in accessing health care for themselves when they are sick, by type of problem, according to sociodemographic characteristics, Ethiopia DHS 2016

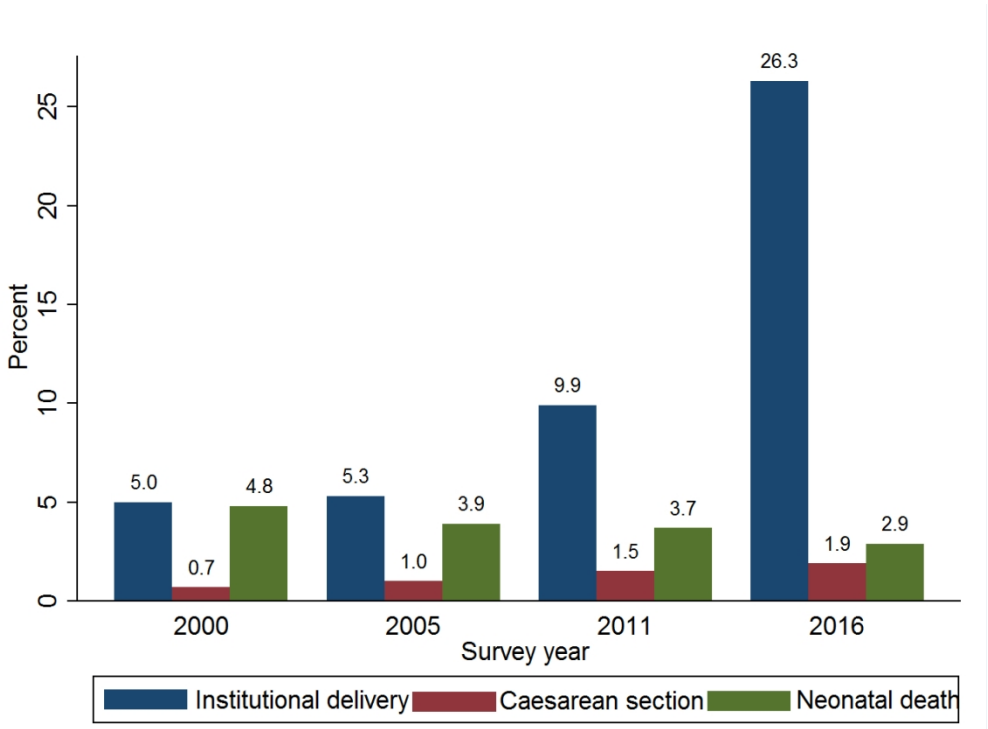

Figure 1. Trends in proportion of institutional deliveries, caesarean section and neonatal death in the 5 years before each of the surveys, Ethiopia DHS 2000, 2005, 2011 and 2016

457x333mm (72 x 72 DPI)

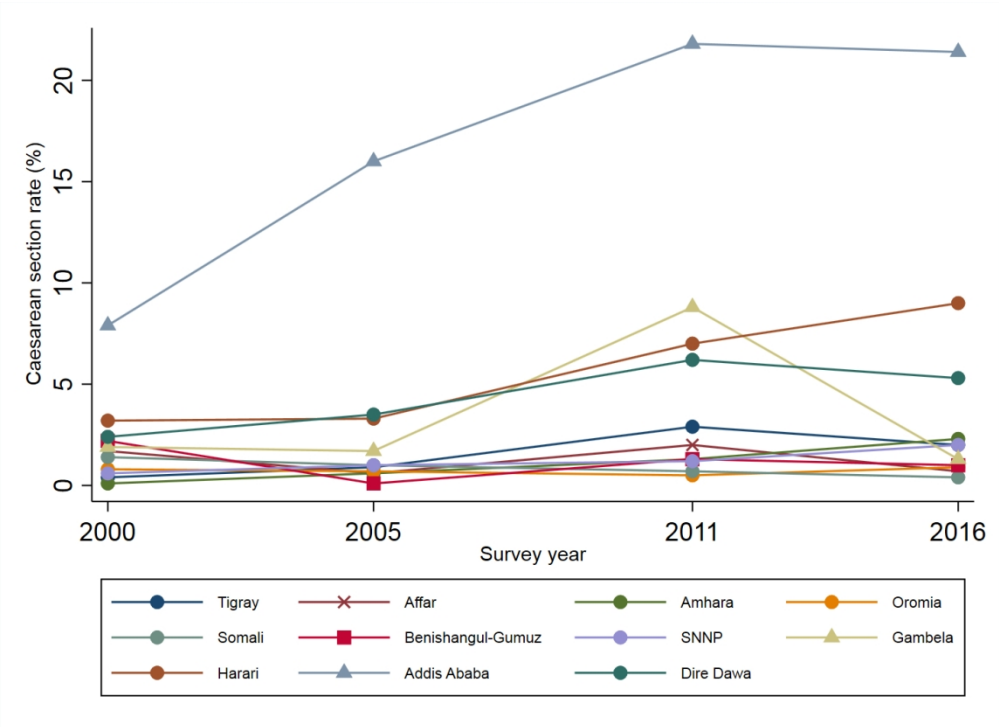

Figure 2. Trends in caesarean section rates in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016

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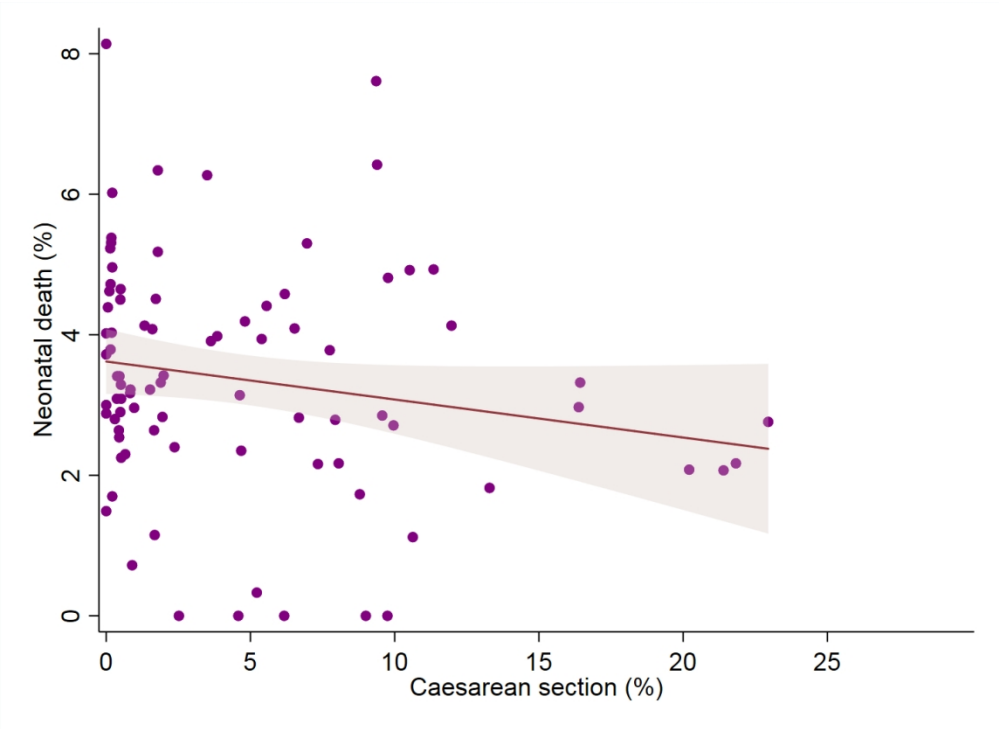

Figure 3. The relationship between caesarean section rate and neonatal death in Ethiopia

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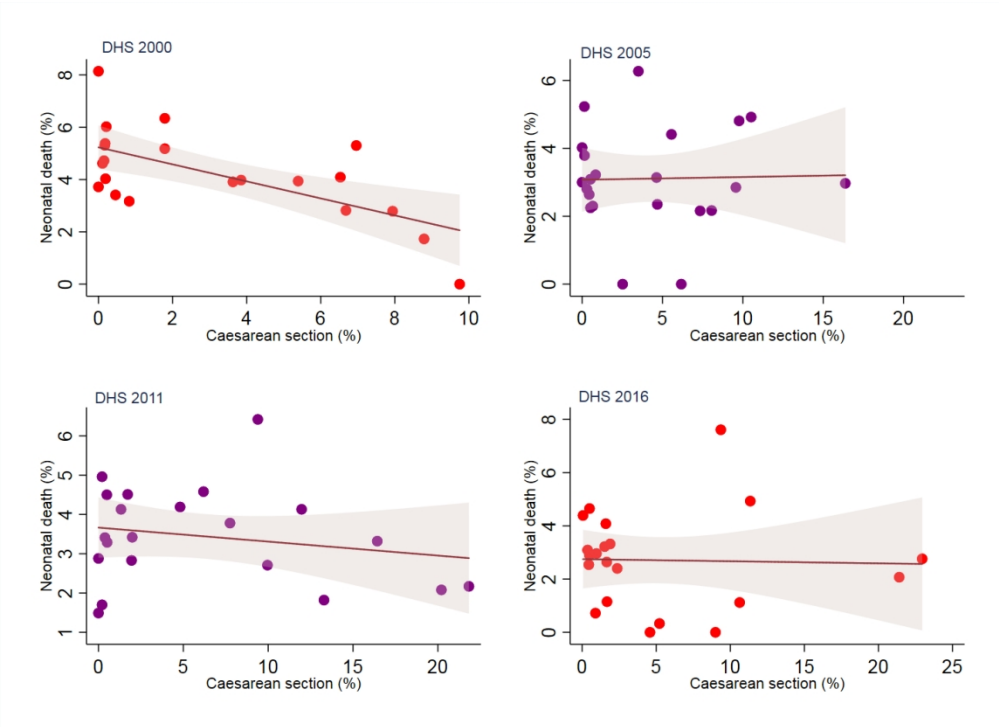


Figure 4. The relationship between caesarean section rate and neonatal death by survey years

509x370mm (72 x 72 DPI)

SUPPLEMENTARY MATERIAL

This file includes supplementary analyses that complement the main findings and pictures that describe the 'Three Delays Model' and the Ethiopian health system structure cited in the full text of the article.

Table A1. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with 'timing of decision to conduct caesarean section' versus vaginal delivery, Ethiopian DHS**, 2016**

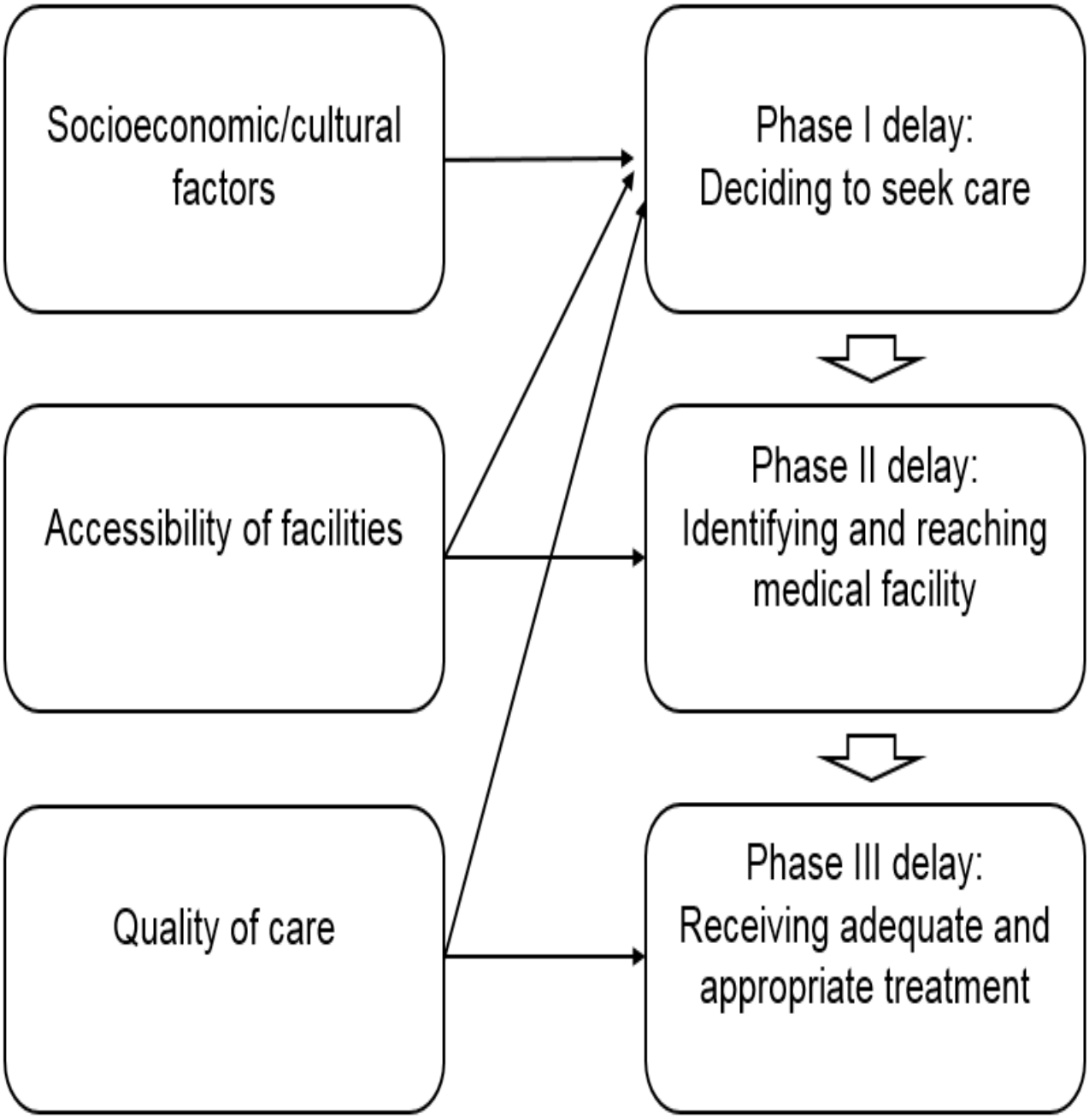
	Prevalence Ratio (95%CI) for neonatal death
Unadjusted (n= 10 641)	
Vaginal delivery	1 [*Ref.*]
Caesarean section decided before onset of labour	4.21 (1.34, 13.19)
Caesarean section decided after onset of labour	2.31 (0.84, 6.41)
Adjusted[a] (n=10 641)	
Vaginal delivery	1 [*Ref.*]
Caesarean section decided before onset of labour	3.79 (1.03, 13.93)
Caesarean section decided after onset of labour	2.26 (0.75, 6.82)

[a]Adjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth

NB: 'Timing of decision to conduct caesarean section'—caesarean section that was planned before the onset of labor pains and caesarean section that was decided after the onset of labor pains—was used as a proxy to pre-labour caesarean section and emergency caesarean section.

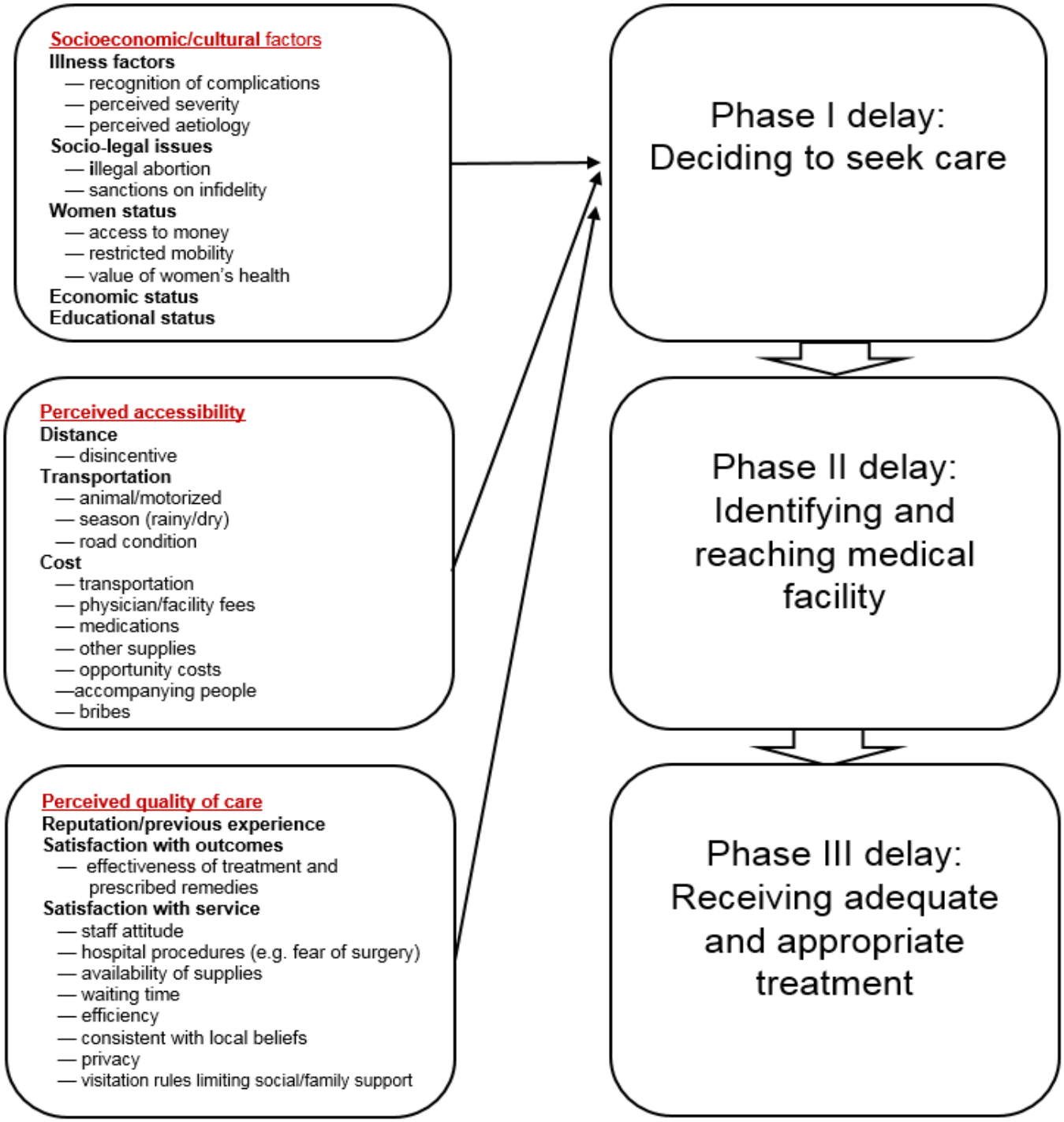
Table A2. Trends in proportion of neonatal deaths in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016

	Survey year								
	2000 %	Number of births	2005 %	Number of births	2011 %	Number of births	2016 %	Number of births	Absolute change %
Types of residence									
Urban	4.4	1277	4.4	815	3.9	1528	3.4	1216	-1.0
Rural	4.8	10983	3.9	10348	3.7	10344	2.8	9807	-2.0
Region									
Tigray	5.3	788	2.7	698	4.1	753	2.7	716	-2.6
Afar	2.9	126	2.9	107	1.9	121	2.6	114	-0.3
Amhara	4.8	3202	5.2	2621	4.5	2656	3.2	2072	-1.6
Oromia	5.3	4999	3.8	4411	3.4	5014	2.8	4851	-2.5
Somali	3.8	142	3.0	477	2.9	364	4.1	508	+0.3
Benishangul-Gumuz	6.3	124	3.8	105	4.8	140	2.9	122	-3.4
SNNP	4.0	2602	3.4	2500	3.5	2494	2.5	2296	-1.5
Gambela	5.3	29	2.4	31	3.6	40	2.8	27	-2.5
Harari	3.7	25	2.2	22	4.1	29	3.1	26	-0.6
Addis Ababa	2.8	182	2.9	153	2.2	222	2.1	244	-0.7
Dire Dawa	3.7	40	2.7	37	1.6	39	3.0	47	-0.7
Total	4.8	12260	3.9	11163	3.7	11872	2.9	11023	-2.0



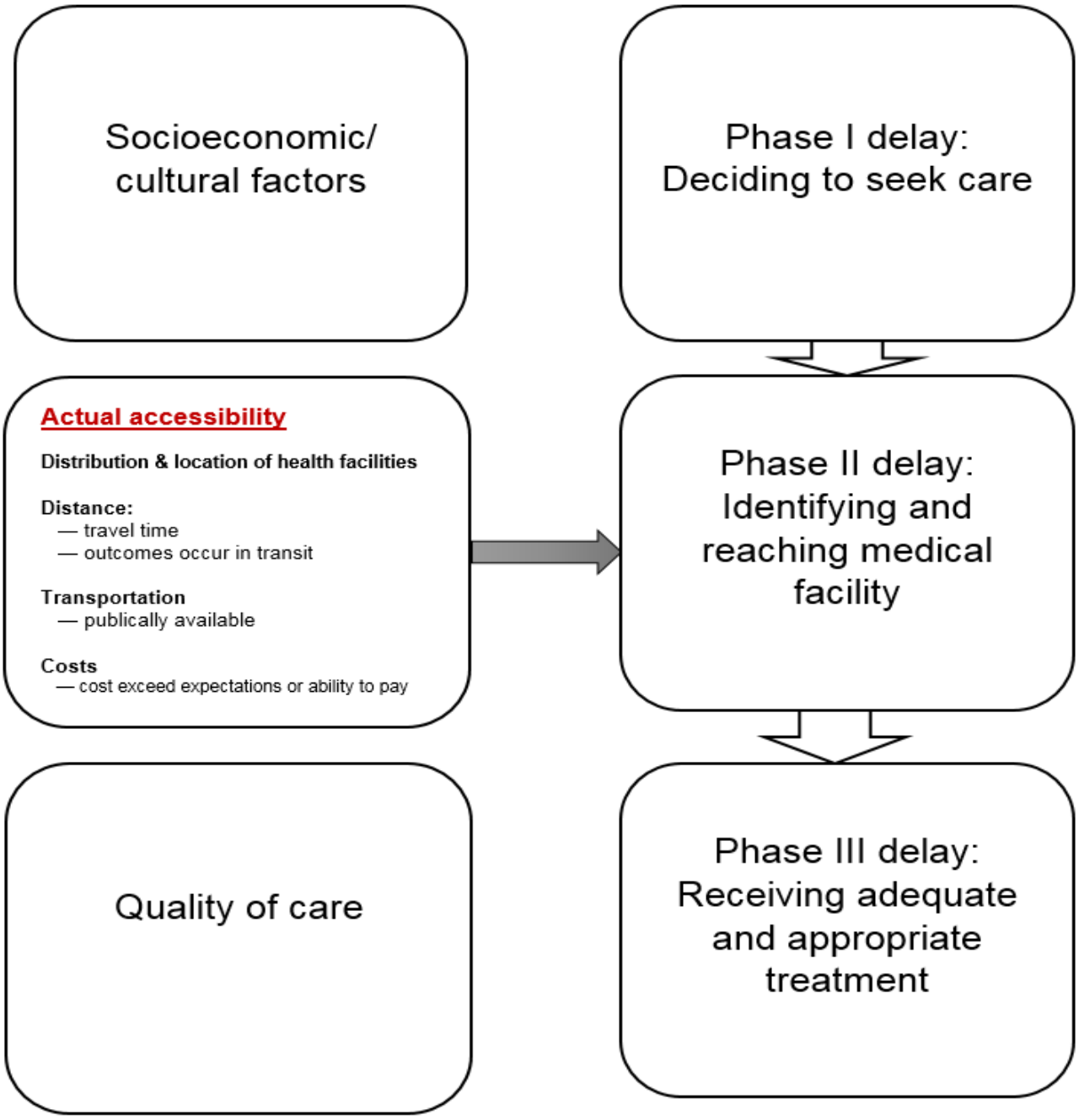
Source: Social science & medicine, 1994; **38**(8): 1091-110.[1]

Figure A1. The 'Three Delays Model'



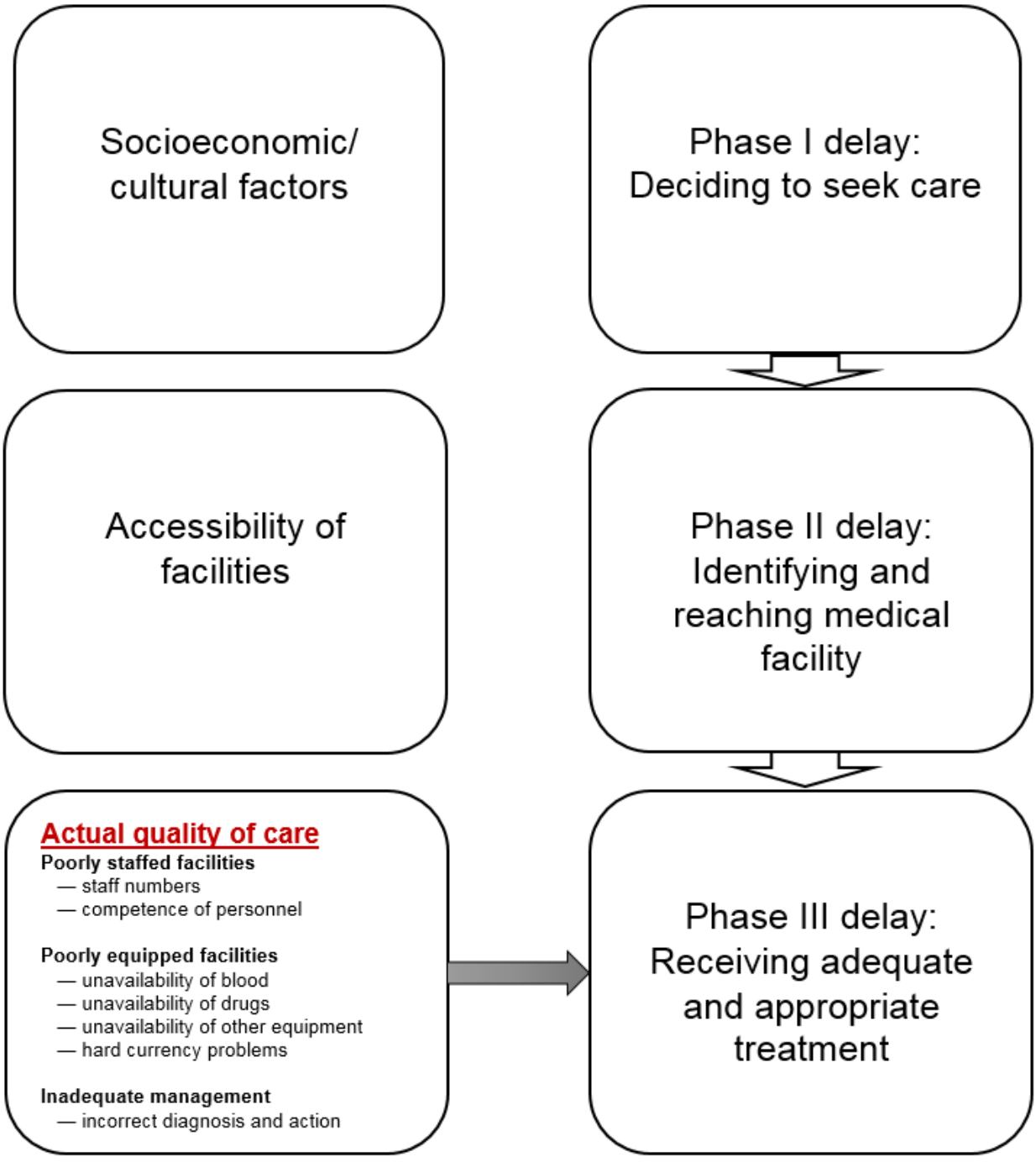
Source: Social science & medicine, *1994; **38**(8): 1091-110.*[1]

Figure A2. Phase I delay, detail



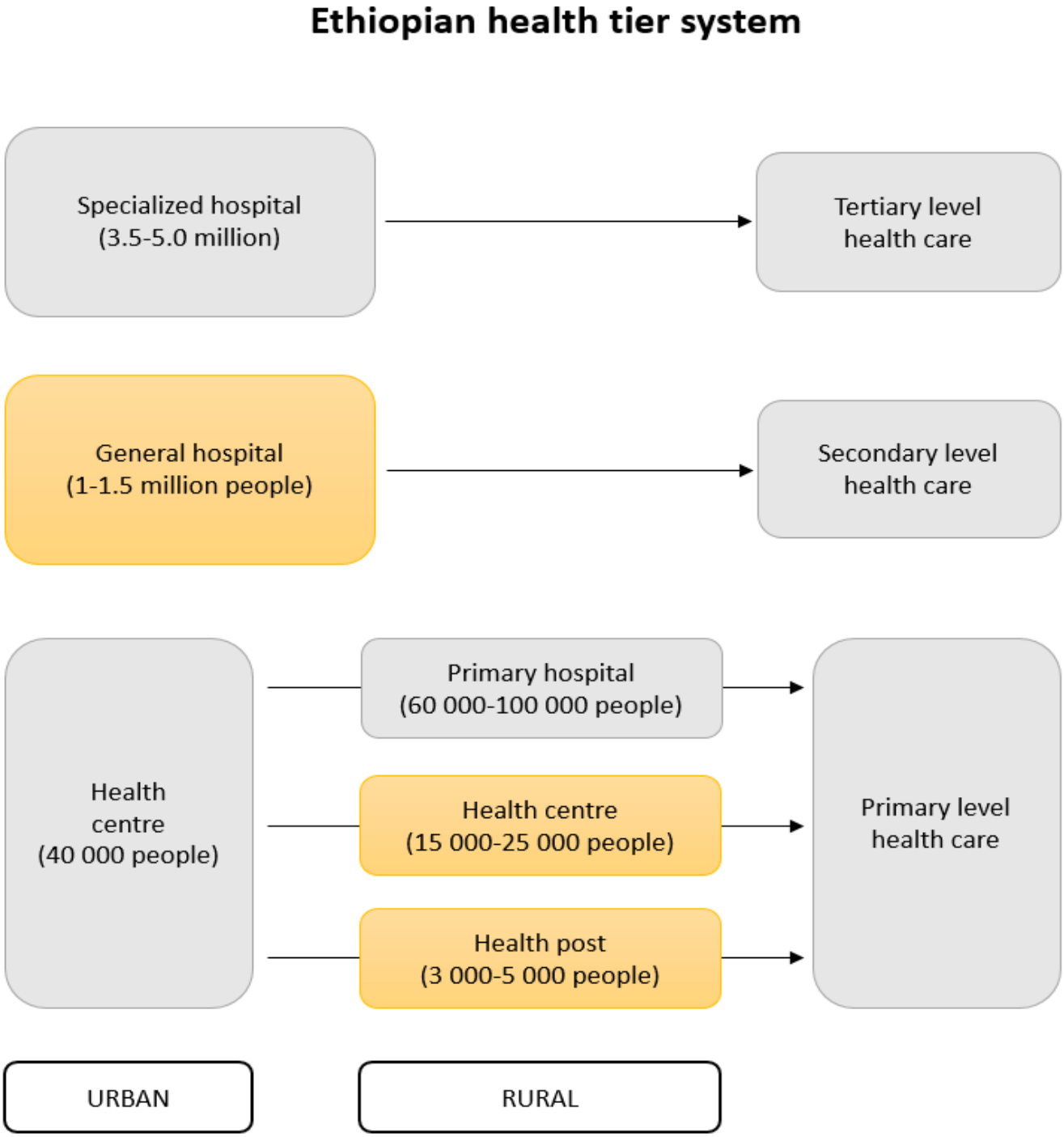
Source: Social science & medicine, 1994; **38**(8): 1091-110.[1]

Figure A3. Phase II delay, detail



Source: Social science & medicine, 1994; **38**(8): 1091-110.[1]

Figure A4. Phase III delay, detail



Source: Ethiopian Health Sector Transformation Plan, 2015,[2] and World Health Organization, 2017. [3]

Figure A5. Ethiopian health system structure

References

1. Thaddeus S, Maine D. Too far to walk: maternal mortality in context. *Social science & medicine* 1994; **38**(8): 1091-110.

2. Ministry of Health. Health Sector Transformation Plan. Addis Ababa: Federal Democratic Republic of Ethiopia; 2015.

3. WHO. Primary health care systems (PRIMASYS): case study from Ethiopia, abridged version. Geneva: World Health Organization; 2017.Licence: CC BY-NC-SA 3.0 IGO.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 1-3	(See Title and Abstract): "The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys"
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2	(see Abstract: Main outcome measures; Results)
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 4-5	(see Introduction)
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5	"We use Ethiopian DHS data from 2000, 2005, 2011, and 2016 to examine the association between caesarean birth and neonatal death. We then apply the 'Three Delays Model' developed by Thadeus and Maine[26] to provide an interpretation of the changing association between caesarean birth and neonatal death in Ethiopia."
Methods				
Study design	4	Present key elements of study design early in the paper	Page 6	(see Methods—Study design and data samples)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 6	(see Methods—Study design and data samples)
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Page 6	"The DHS questionnaire asks women about pregnancy, antenatal,

				and delivery care for livebirths they have reported in the past 5 years. For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally."
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 6-9	(see Methods—Exposure, Outcome and Confounding)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 6	**"Exposure** The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for livebirths they have reported in the past 5 years. The self-reported data on caesarean section rates collected for DHS, compared with facility-based records of caesarean sections, are found to be reliable in developing countries.[27] For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally. **Outcome** Neonatal death includes children who were born alive in the 5 years before the survey, but died within the first 28 days of life. The outcome variable, neonatal death,

				was measured from two variables (whether the child is alive and age at death (in days)).”
Bias	9	Describe any efforts to address potential sources of bias	Page 7-10	(see Methods—Statistical analysis)
Study size	10	Explain how the study size was arrived at	Page 6	(see Methods—Study design and data samples): “We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela, and Harari), and two city administrations (Addis Ababa and Dire Dawa).”
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 6-9	(see Methods— Confounding)
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Page 7-10	(see Methods—Statistical analysis)
		(*b*) Describe any methods used to examine subgroups and interactions	Page 7-9	(see Methods—Statistical analysis)
		(*c*) Explain how missing data were addressed		Not applicable
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	Page 7	“All analyses were weighted to be nationally representative. As women may have had more than one birth within the five-year survey periods, we also accounted for both clustering of cesarean deliveries within women as well as the complex survey design during the data analyses using the unit of

				analysis (children) study number and sample weights."
		(*e*) Describe any sensitivity analyses		Not applicable
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 11	(see Results): "Table 1"
		(b) Give reasons for non-participation at each stage		Not applicable
		(c) Consider use of a flow diagram		Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 11	(see Results)
		(b) Indicate number of participants with missing data for each variable of interest		Not applicable
Outcome data	15*	Report numbers of outcome events or summary measures	Page 11-12	(see Results)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	page 11-12	(see Results)
		(*b*) Report category boundaries when continuous variables were categorized	Page 11-12	(see Results)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period		Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 11-12	(see Results)
Discussion				
Key results	18	Summarise key results with reference to study objectives	Page 13 & page 18	(See Interpretation and Discussion sections)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 20	(See Discussion: "We acknowledge the following limitations of this study. Firstly, as both the proportion of institutional deliveries and caesarean section rate is low in Ethiopia, especially rural area, the number of neonatal deaths

				following caesarean section may be low. However, since our analyses are weighted, we believe that the weight improves the representativeness of the data in terms of size, distribution and characteristics of the Ethiopian population. The weight may also ensure that our estimates are unbiased though the confidence interval for some subgroup analyses are somewhat wide. Secondly, the interpretation of our study is specific to the context of Ethiopia and may not be generalizable to other developing countries in Africa or elsewhere. Another limitation is the mother's recall of the child's size at birth was used as a substitute for the child's birth weight in this study because the data for birth weight was not collected for more than 50% of the neonates in DHS")
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13-20	(See Interpretation and Discussion sections)
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 20	(See Discussion)
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 21	(See Funding—The first author is fully supported by an Australian Government Research Training Programme (RTP) Scholarship. The

funder does not have role in the design of the study.)

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys

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The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys

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ABSTRACT

Objective

To examine the changing temporal association between caesarean birth and neonatal death within the context of Ethiopia from 2000 to 2016.

Design

Secondary analysis of Ethiopian Demographic and Health Surveys (DHS).

Setting

All administrative regions of Ethiopia with surveys conducted in 2000, 2005, 2011, and 2016.

Participants

Women aged 15-49 years with a live birth during the five years preceding the survey.

Main outcome measures

We analysed the association between caesarean birth and neonatal death using log-Poisson regression models for each survey adjusted for potential confounders. We then applied the 'Three Delays Model' to 2016 survey to provide an interpretation of the association between caesarean birth and neonatal death in Ethiopia.

Results

The adjusted prevalence ratios (aPR) for neonatal death among neonates born via caesarean section versus vaginal birth increased over time, from 0.95 (95% CI, 0.29, 3.19) in 2000 to 2.81 (95% CI, 1.11, 7.13) in 2016. The association between caesarean birth and neonatal death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among women from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36)) in 2016. Aggregate-level analysis revealed that an increased caesarean section rates were correlated with a decreased proportion of neonatal deaths.

Conclusions

A naïve interpretation of the changing temporal association between caesarean birth and neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death. However, the changing temporal association reflects improvements in health service coverage and secular shifts in the characteristics of Ethiopian women undergoing caesarean section after complicated labour or severe foetal compromise.

Strengths and limitations of this study

- This was the first study to examine the temporal association between caesarean birth and neonatal death within the context of Ethiopia from 2000 to 2016.
- A number of analyses conducted after adjustment for potential confounders helped develop the possible scenarios to better understand the interpretation of the changing associations.
- We have used additional supporting evidence from the 2016 Ethiopian Demographic and Health Survey data which allowed us interpret the association between caesarean birth and neonatal death in view of contextual factors in Ethiopia using the 'Three Delays Model'.
- Given the very low base rates of caesarean delivery in Ethiopia, the interpretation of our findings may not reflect the context of other low-and middle-income countries.

Introduction

Globally, 2.6 million neonatal deaths occurred within the first 28 days after birth, which accounted for 46% of all under-five deaths in 2016.[1] The majority of these deaths were from low- and middle-income countries. According to the United Nations Inter-agency Group for Child Mortality Estimation, Southern Asia (39%) and sub-Saharan Africa (38%) comprised the top two regions with the highest proportion of newborn deaths, while five countries (India, Pakistan, Nigeria, the Democratic Republic of the Congo, and Ethiopia) accounted for 50% of all newborn deaths.[1] Evidence show that, compared to mortality among children aged 1-59 months, neonatal mortality is decreasing more slowly.[1] If the current trend continues, more low-and middle-income countries will fail to achieve the Sustainable Development Goal (SDG) target for neonatal mortality at least as low as 12 per 1,000 live births.[2]

In contemporary obstetric practice, caesarean section remains an important intervention in preventing neonatal mortality and other adverse birth outcomes.[3] However, caesarean section may be prone to misuse because of unequal access, social, and cultural factors.[4-6] In developing country settings, due to limited medical provisions and/or lack of skilled birth attendants, some women may not benefit from caesarean birth though they are medically eligible, while ineligible women may sometimes have increased access. In the last decades, caesarean section rates have been increasing in low-, middle, and high-income countries.[7-9] The World Health Organization (WHO) suggests, "every effort should be made to provide caesarean sections to women in need, rather than striving to achieve a specific rate."[10]

Previous studies conducted using aggregate- and individual-level data have yielded inconsistent results about the association between caesarean birth and neonatal mortality. For instance, two ecological studies[11,12] conducted using worldwide country-level data have found that caesarean birth was associated with lower neonatal mortality while another two ecological studies[13,14] showed no association between caesarean birth and neonatal mortality, where caesarean section rates were higher than 10%. Inconsistent results for the association between caesarean birth and neonatal mortality were also reported by different studies based on individual-level data conducted in Africa, Latin America, Asia, and United States of America.[15-20] For example, a large study conducted by Villar *et al.* in 410 health facilities in 24 areas in eight Latin American countries found that, with cephalic presentation, both intrapartum and elective caesarean was associated with 1.66 (95% Confidence Interval (CI):

1.26, 2.20) and 1.99 (95%CI: 1.51, 2.63) times higher odds of neonatal mortality up to hospital discharge, respectively.[16] However, another study based on WHO global survey completed in nine countries in Asia found that both pre-labour (Adjusted Odds Ratio (aOR) 0.2, (95% CI: 0.1, 0.3)) and intrapartum caesarean sections (aOR 0.3, 95% CI: 0.2, 0.4) were associated with improved perinatal outcomes following breech presentation.[15]

On the other hand, using both country-and individual-level data collected for nationally representative Demographic and Health Surveys (DHS), Kyu *et al.* found an increased risk for neonatal death associated with caesarean versus vaginal births in countries with low (< 5%) and medium (5-15%) caesarean section rates.[21] However, factors associated with caesarean section that increase risk for neonatal death in countries with low and moderate caesarean section rates remain ill-defined. Previous studies are limited by either inconsistent results or lack the interpretation of findings by considering the contextual factors.[11-21] In addition to the underlying indications for caesarean interventions like 'fetal distress', 'cord prolapse', 'prolonged and obstructed labour', 'fetal mal-presentation', 'major antepartum haemorrhage', and 'placenta praevia',[22,23] several contextual factors such as unequal access, infrastructural, and health workforce constraints could play a role in the association between caesarean section and neonatal death.

In low- and middle-income countries, the DHS are the most representative and widely available high quality data sources for studies related to maternal and child health. We use Ethiopian DHS data from 2000, 2005, 2011, and 2016 to examine the changing temporal association between caesarean birth and neonatal death. We then apply the 'Three Delays Model' developed by Thadeus and Maine[24] to facilitate the interpretation of the association between caesarean birth and neonatal death in Ethiopia using the 2016 data.

Methods

Study design and data samples

We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela, and Harari), and two city administrations (Addis Ababa and Dire Dawa). Each of the surveys involved a two-stage, stratified, clustered sampling design. The survey datasets are de-identified and made freely available online. Permission to use these data was granted by the MEASURE DHS Program. The details about the methodology and standards for protecting the privacy of study participants in all DHS can be accessed at (http://www.measuredhs.com/What-We-Do/methodology.cfm).

Exposure

The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for livebirths they have reported in the past 5 years. The data on caesarean section and other variables in the DHS was collected based on mothers' self-report. For example, the self-reported data on caesarean section was collected by asking mothers a question that reads, "Was (NAME) delivered by caesarean section, that is, did they cut your belly open to take the baby out?" Stanton and colleagues[25] in their study demonstrated that the DHS caesarean section rates, compared with facility-based records of caesarean section rates, are reliable for national and global monitoring in developing countries. For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally.

Outcome

Neonatal death includes children who were born alive in the 5 years before the survey, but died within the first 28 days of life. The outcome variable, neonatal death, was measured from two variables (whether the child is alive and age at death (in days)).

Confounding

The following potential confounders were identified based on a priori subject-matter and expert knowledge. They included place of delivery (public, private, NGO, home), type of

residence (urban/rural), sex of child (male/female), size of baby at birth (very large, larger than average, average, smaller than average, very small, don't know), mother's age at birth (in years), mother's education (no education, primary, secondary, higher), birth order (1, 2-3, 4+), and household wealth quintile (poorest, poorer, middle, richer, richest). The size of baby at birth was assessed based on mother's perception (estimate) of baby size at birth. It has previously been shown that in the absence of complete enumeration of birth weight, mother's perception of baby size at birth can be used as a proxy to birth weight in nationally representative surveys.[26] Mother's age at birth was calculated as a difference (in years) between infant's date of birth and mother's date of birth. DHS computes the wealth index for each survey based on household assets using principal components analyses[27] and categorizes households into wealth quintiles. These asset-based measures represent the wealth distribution relative to other households within the country. They are widely used and are consistent with comparisons to household expenditures and the measurement of inequalities in child mortality, education, and healthcare use in low-and middle-income countries.[28]

Statistical analysis

Missing information is uncommon in DHS because the data is collected by a trained interviewers at a face-to-face interview. All analyses (i.e., Ethiopian DHS 2000, 2005, 2011 and 2016) were weighted to be nationally representative. As women may have had more than one births within the five-year survey periods, we also accounted for both clustering of caesarean deliveries within women as well as the complex survey design during the data analyses using the unit of analysis (i.e., children) study number and sample weights. We then conducted both individual- and aggregate-levels analyses. Our 2016 data analysis was also supplemented by an application of the 'Three Delays Model' to interpret the association between caesarean birth and neonatal death both empirically and theoretically. All analyses were conducted using STATA/SE version 15.1 (Stata Corporation, College Station, TX).

Individual-level analysis

Associations between caesarean birth and neonatal death at individual-level were analysed using log-Poisson regression models using data from Ethiopian DHS conducted in 2000, 2005, 2011, and 2016. We calculated unadjusted and adjusted prevalence ratios (aPR) and

their 95% Confidence Intervals (CIs) for each survey. We have then compared the strength of association between caesarean birth and neonatal death across all surveys analysed.

After noting the increasing association between caesarean birth and neonatal death over time, we conducted a series of analyses to explore what was during the change. We used the 2016 data because the association was more pronounced. We first restricted the analysis to participants living in regions with the highest caesarean section rates to examine whether the increased access to caesarean section affected the proportion of neonatal deaths. We then estimated the effect of caesarean birth on neonatal death in regions with low caesarean section rate (ranged: 0.4-5.3%) or where access to caesarean section is limited, by excluding births in relatively high caesarean section rate regions—Addis Ababa (21.4%) and Harari (9.0%).[29] Both low-and high-level of caesarean use has risks exceeding the risks of spontaneous vaginal deliveries.[15,30] It was demonstrated that low levels of caesarean are related to lack of access and can contribute to maternal and newborn deaths.[21,31]

Given the very large rural-urban differences in caesarean section in Ethiopia,[29,32] we also conducted similar analyses separately for rural women. In addition, we evaluated the association by restricting the analyses to births from the lowest quintile of household wealth, births from the highest quintile of household wealth, and births in public health facilities separately. These alternative analyses were exploratory in nature and helped us understand contextual factors leading to inequalities in caesarean use that may occur not only due to inadequate access among the poorest women, but also due to overuse among the richest population subgroups.[33,34] However, as the caesarean section rate in Ethiopia is low (about 2%), the number of neonatal deaths following caesarean birth is low and resulted in wide confidence intervals for the estimates. The subgroup analyses allowed us to explain how contextual factors such as unequal access, infrastructural, and workforce constraints could play role in the association between caesarean section and neonatal death because these factors will result in delay in accessing emergency caesarean section, which is usually accessible at specialized health facilities.

The 2016 DHS included an additional question regarding 'timing of decision to conduct caesarean section (i.e., whether it was before or after the onset of labour pains)'. We used this variable as a proxy to the types of caesarean birth (indicative of intrapartum or pre-labour caesarean section) and conducted analysis to examine the association between types of caesarean section and neonatal death. As this was confined only to 2016 data, we have provided the results in the **Supplementary Table A1**.

Aggregate-level analysis

Data on the caesarean section rate and proportion of neonatal deaths were disaggregated by urban-rural areas for each of the nine regions and two city administrations in Ethiopia for each of the surveys completed in 2000, 2005, 2011, and 2016. However, the urban-rural stratification for Addis Ababa is only available for the 2005 survey. These results in a total of 85 data points (observations). In order to assess the correlation between caesarean section and neonatal death at aggregate-level, we conducted simple linear regression for overall surveys together and for individual surveys separately.

Application of the 'Three Delays Model'

The 'Three Delays Model' is a conceptual framework developed by Thadeus and Maine to examine factors contributing to maternal mortality with specific focus on those that affect the "interval between the onset of obstetric complication and its outcome".[24] The 'Three Delays Model' summarises the various factors that affect *this interval* into three phases of delay—delay in deciding to seek care (*Phase I delay*); delay in identifying and reaching medical facility (*Phase II delay*); and delay in receiving adequate and appropriate treatment (*Phase III delay*). Some of the key factors that shape the model include status of women; distance from health facility; availability and cost of transportation; condition of roads; distribution of health facilities; shortage of supplies, equipment, and skilled birth attendants; and adequacy of referral system.[24] The pictorial presentation of the 'Three Delays Model' is provided in the **Supplementary Figures A1-A4.**

As maternal and neonatal mortality share many risk factors, we adopted the 'Three Delays Model' as a framework to help interpret the association between caesarean birth and neonatal mortality within the context of Ethiopia in the 2016 survey because factors contributing to the 'three delays' aggravate the underlying medical indications for caesarean intervention that make neonatal death difficult to prevent. The 2016 survey was selected for interpretation of the association between caesarean birth and neonatal death using the 'Three Delays Model' because the association was more pronounced in 2016 data. Previous studies conducted in India,[35] Tanzania[36] and Uganda[37] have applied the 'Three Delays Model' to their analyses of perinatal deaths.

We have identified some contributing factors underlying the 'Three Delays Model' from the 2016 survey. For example, information regarding problems faced by women of reproductive age (15-49 years) in accessing health care to obtain medical advice or treatment for themselves when they are sick were gathered. It consisted of four questions: distance to health facility (big problem/not big problem); getting money for treatment (big problem/not big problem); getting permission to go for treatment (big problem/not big problem); and not wanting to go alone (big problem/not big problem). Furthermore, data on skilled assistance during delivery, and women's socioeconomic and demographic status are also available in the DHS. This information can particularly be important to understand and address the barriers that women face in seeking care during pregnancy and delivery.[32] We have, therefore, analysed the 2016 DHS data to describe these factors empirically in the context of Ethiopia.

Patient and public involvement

This research was done without patient involvement in setting the research question or the outcome measures, and in the design and implementation of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of this research to study participants or the relevant patient community.

Results

Table 1 shows the characteristics of mothers and children according to mode of delivery for each of the surveys conducted in 2000, 2005, 2011, and 2016. Across the four DHS survey waves, women who underwent caesarean delivery were more likely to live in urban areas, had a higher level of education, and were from the richest quintile of household wealth. They were also more likely to have male children. Caesarean deliveries were more frequent in women in the age category of 20-29 years, and among infants who had either very large or larger than average size of baby at birth. **Figure 1** shows that the proportion of institutional deliveries increased from 5.0% in 2000 to 26.3% in 2016, whereas the national caesarean section rate increased from 0.7% in 2000 to 1.9% in 2016. However, the rate of caesarean delivery in Ethiopia varied widely across administrative regions (**Figure 2**). For instance, Addis Ababa had the highest (21.4%) rate, while Somali region had the lowest (0.4%) in 2016. The national proportion of neonatal deaths decreased from 4.8% in 2000 to 2.9% in 2016, but the proportion varies among administrative regions of Ethiopia (**Figure 1 & Supplementary Table A2**).

Table 2 shows that the adjusted prevalence ratio (aPR) for neonatal death associated with caesarean versus vaginal births in 2000 survey was 0.95 (95%CI, 0.29, 3.19) while in 2005, it was 1.53 (95%CI, 0.52, 4.50). In 2011, the adjusted prevalence ratio (aPR) for neonatal death associated with caesarean versus vaginal births was 1.15 (95%CI, 0.45, 2.93), while it was 2.81-fold higher risk of neonatal death (aPR, 2.81; 95%CI, 1.11, 7.13) in 2016.

Table 3 summarises the findings of the subgroup analyses based on the 2016 data. When women living in urban settings—Addis Ababa (caesarean section rate (21.4%)), and Harari (9.0%)—were excluded from the analyses, the corresponding adjusted PR for neonatal death was increased to 3.55 (95%CI, 1.31, 8.56). Similarly, when we restricted the analyses to include only rural women, the prevalence ratio for neonatal death associated with caesarean versus vaginal births was found to be 3.43 (95% CI, 1.22, 9.67). The respective risk of neonatal death increased to 7.01 (95%CI, 0.92, 53.36) when the analysis was limited to women from the lowest quintile of household wealth.

When we restricted the analyses to Addis Ababa, the capital of Ethiopia, the relative risk for neonatal death associated with caesarean versus vaginal births was 1.07 (95%CI, 0.20, 5.73). Moreover, when the analysis was confined to women from the highest quintile of the household wealth, the risk of neonatal death was 2.72 (95% CI, 0.55, 13.38).

Lastly, **Figure 3** shows that an increase in caesarean section rate is weakly correlated with a decrease in the proportion of neonatal deaths (correlation coefficient (r) = -0.1839) when aggregate-level data for all surveys together was analyzed. However, the relationship between caesarean birth and neonatal death is variable when the analysis is restricted to each survey year separately (see **Figure 4**).

Interpretation

The primary individual-level analyses showed that the adjusted prevalence ratios (aPR) for neonatal death associated with caesarean versus vaginal births increased from 0.95 (95% CI, 0.29, 3.19) in 2000 to 2.81 (95% CI, 1.11, 7.13) in 2016. These findings suggest that the circumstances for foetuses born in 2000 survey were different from the foetuses in 2016. Our subgroup analyses using 2016 data suggest that the association between caesarean birth and neonatal death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among women from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36)), but not for births in areas with wider availability of caesarean such as Addis Ababa (aPR (95% CI) 1.07 (0.20, 5.73)). The changing association between caesarean birth and neonatal death over time, and the stronger association observed among different subgroup analyses may be attributable to changes in the pattern of confounding by indication due to contextual factors such as unequal access, structural health-system deficiencies (insufficient equipment, supplies, and drugs), infrastructural, and health workforce constraints.

The national caesarean section and institutional delivery rates in Ethiopia are still low though increases in the past decade are notable. There is also substantial disparity in caesarean section rates, with very low rates in rural areas and among the poorest women,[29] suggesting unequal access which may be as a consequence of a range of geographic, social, and economic barriers. The low caesarean rates may also be due to lack of skilled birth attendants, and poor health infrastructure (e.g., shortage of medical care institutions, deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, and blood transfusion capacity).[38-40] In Ethiopia, there are only 820 Obstetricians, 10,846 General practitioners, 996 Emergency obstetric surgeons, 6,345 Health officers, 41,009 Nurses, 8,635 Midwives, 233 Anaesthesiologists, and 33,320 Health extension workers for the population of over 90 million in 2015.[41] Similarly, there are only 3,547 functional Health centres, 16, 447 functional Health posts, and 189 functional Hospitals in 2015.[42]

We know from previous research that inadequate access to timely caesarean section may result in perinatal asphyxia, uterine rupture, obstructed labour, and these can contribute to maternal and newborn deaths.[43] Conversely, it was demonstrated that maternal and neonatal mortality due to obstetric complications can be prevented with timely access to caesarean section.[43,44] Delay, therefore, emerges as relevant factor in worsening the underlying

obstetric indications for caesarean intervention thereby contributing to neonatal death. Context specific factors that delay access to caesarean section may have the capacity to make women with labour problems undergo caesarean section after severe complication of labour or severe foetal compromise. Therefore, our interpretation is that caesarean section conducted after severe foetal compromise may not prevent neonatal deaths because they have already experienced such severity of complications that although live born, neonatal death is difficult to prevent.

There are two possible scenarios leading to caesarean section in Ethiopia. First, when women who have previously had a caesarean section, with breech presentation, or other risk factors such as eclampsia attend specialised health facilities, they are usually allowed to undergo caesarean section. Their caesarean section is commonly classified as 'elective or scheduled caesarean section'. Second, when caesarean section is performed for 'emergency reasons'. Full term mothers with or without signs of labour will be admitted to health facilities where their progress is monitored and labour-augmenting or inducing medications may be administered. Decisions to perform caesarean section in these facilities or decision to refer the mother to nearby hospitals for caesarean delivery or other action depends on the condition of the mother and foetus during the progress of labour. In primary health facilities (i.e., health posts and health centres), obstetric care providers usually use a 'Partograph',[45,46] a routine labour monitoring instrument (chart) which helps the health care providers to identify slow progress in labour and take appropriate action. In hospitals, the decision to perform a caesarean section is reached when the labour is prolonged and/or the second stage of labour is complicated risking the life of mother and foetus.

Given these pathways to caesarean delivery in mind, our interpretation of the association between caesarean birth and neonatal death in Ethiopia using the 2016 survey may be shaped by examining factors contributing to delays in the 'Three Delays Model'. This is because delays to caesarean section aggravate the underlying medical indications for caesarean intervention. **Table 4** shows factors affecting the length of delays in the 'Three Delays Model' according to sociodemographic characteristics in 2016 Ethiopia DHS.

Phase I delay: deciding to seek care

In Ethiopia, poorer and less-educated women are more likely to select a nearby health

facility, especially in rural areas, where there is limited access to caesarean section and the possibility of benefiting from caesarean section is mainly through referral to higher levels of care. Women are more likely to undergo a caesarean section if they present to specialized health facilities. However, the outcome of delivery depends on how quick/competent the health care provider is in referring the mother or on intervening, and the severity of the underlying obstetric complications for caesarean intervention which may be affected by the delay in women's or family's decision to seek care. Poor health decision-making depends on numerous factors such as educational status, distance to health facility, economic status, sociocultural factors (e.g., unsupportive spouse, and lack of autonomy), and quality of care.[24,47,48]

Table 4 shows that 'distance to health facility' was a big problem in accessing health care for about 60% of rural and 17% of urban women in Ethiopia. Similarly, 'getting money for treatment' is a big problem to access health care and was reported by 61% of rural and 35% of urban women in 2016. On the other hand, the status of women in a given society affects the decision to seek care. For instance, efforts to seek timely care is influenced by women's limited mobility because they need permission to travel from spouse and/or mother-in-law.[24] In Ethiopia, about 37% of rural and 15% of urban women reported 'getting permission to go for treatment' was a big problem to access health care.

Phase II delay: identifying and reaching a medical facility

Delay in reaching health care may occurs when women who encounter obstetric complication live farther from health facilities, where the availability and cost of transportation is problematic. In one study conducted in rural India, Kumar *et al*.[47] found that health facility births occur less likely among women living farther away from the health facilities, suggesting distance as an important barrier to in-facility births for rural women. In addition to the travel distance, the scarcity of transportation which may be accompanied by poor roads is also another obstacle for women with labour complications to timely reach even the closest health facility. As a result of this, women who arrive at the nearby facility following obstetric complications probably will travel further to specialised hospital due to emergency referral. It is clear that the obstetric complications encountered by mothers reaching nearby primary health facilities will be compounded by additional delays when they are referred for caesarean section. These scenarios highlight the likelihood of adverse delivery outcome

followed by aggravated obstetric complications due to delays in reaching medical facility as high.

In Ethiopia, about 50% of women of reproductive age (15-49 years) reported 'distance to health facility' as a big problem to access health care (see **Table 4**). Moreover, access to caesarean situation in Ethiopia is worse than in most other settings.

Phase III delay: receiving adequate and appropriate treatment

Phase III delays occur within any health facilities and are indicators of inadequate care due to lack of facilities; inadequately trained obstetric care givers (skilled birth attendants); and deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, and blood transfusion as well as inadequate and inappropriate referral systems. These deficiencies will limit women's access to lifesaving procedures such as caesarean section. In Ethiopia, only 28.0% of all births were delivered by 'skilled providers' (i.e., doctor, nurse, midwife, health officer, and health extension worker) in 2016 survey. **Table 4** also shows that there are disparities in the proportion of births attended by skilled birth attendants by urban-rural place of residence, region, level of mother's education, and household wealth. It is quite clear that insufficient number of skilled birth attendants at any health facility will lead to delay in receiving appropriate treatment among women with obstetric complications. Although health posts and health centres (primary health care unit) are the most accessible to the general population in Ethiopia, they are not fully equipped to deal with obstetric complications.[41,42] As a result of this, women with obstetrics complications will have to travel on to better equipped institutions (secondary and tertiary level of health care) with caesarean section capacity (e.g., general hospitals and specialized hospitals) through referral. By the time women reach these well-equipped health facility, the delays will have further aggravated the obstetric complications on the way. A schematic representation of the Ethiopian health system structure is provided in **Supplementary Figure A5.**

On the other hand, delay in caesarean intervention may even happen if mothers with less severe obstetric complications were referred and presented to specialised health facilities in a timely manner. This is because a trial of labour is usually attempted before a decision to have caesarean section. For instance, some women who are referred from primary health facilities undergo induction and augmentation of labour because these interventions are only provided

in health facilities with the capacity to provide caesarean section in Ethiopia. These practices, in turn, will result in delay in receiving caesarean section leading to worsening of the already existing obstetric complications. Thus, any delays to caesarean intervention have a higher chance of aggravating the already existing complications and increase the risk of neonatal death.

Discussion

Our study examined the changing temporal association between caesarean birth and neonatal death within the context of Ethiopia from 2000 to 2016. The association between caesarean section and neonatal death increased over time and was variable among population subgroups. These changes over time, and variation across population subgroups may be attributable to changes in the pattern of confounding by indication due to contextual factors such as improvement in health service coverage, unequal access (e.g., due to a range of geographic, social, and economic barriers), and structural, and health workforce constraints.

In Ethiopia, the proportion of women aged 15-49 years who received any antenatal care from a skilled provider has increased from 27% in 2000 to 62% in 2016.[32] Health facility-based deliveries have increased from 5% in 2000 to 26% in 2016 (increased from 2% in 2000 to 20% in 2016 for rural women, and increased from 32% in 2000 to 79% in 2016 for urban women).[32] The proportion of births in health facilities assisted by skilled birth attendants increased from 6% in 2000 to 28% in 2016.[32] These figures reflect improvement in health service coverage in Ethiopia.

Moreover, since 2003, with the implementation of the Health Extension Programme—a community-based primary health care programme—the Ethiopian government has increased the number of health posts from 4,211 in 2005 to 16,447 in 2015.[42,49] Likewise, the number of health centres were increased from 600 in 2005 to 3,586 in 2015.[42,49] However, due to limitations in proper monitoring of labour for making timely decisions, especially on whether or not to initiate a referral from primary health facilities to higher level facilities, and due to poor transport and road networks which are still the common problems in low income countries,[50] the underlying medical indications for caesarean intervention will be worsened by factors contributing to 'delays'. Delay in receiving adequate and appropriate care is still a common problem in low income countries due to deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, blood transfusion capacity, and shortage of skilled birth attendants.[51-53] There is also an inequitable distibution of the health workforce across urban and rural areas. For example, the majority of specialist doctors in Ethiopia serve in urban areas, where the total population distribution is only 19.4%.[41,42] These situations often result in poor quality care to rural women, and the caesarean section conducted after a complicated labour may be associated with increased neonatal mortality due to confounding

by indication.

Unlike previous studies, the present study takes into account the interpretation of the association between caesarean birth and neonatal death within the context of Ethiopia using DHS data. The change in the strength of effect estimates across DHS waves, and the different subgroup analyses suggest that neonatal mortality can be reduced by increasing timely access to caesarean section and timely decision for caesarean delivery via increasing health service coverage, improving infrastructure (e.g., increasing number of health facilities), increasing the number of skilled birth attendants, improving quality of care, and increasing awareness about antenatal care and health facility delivery among women. Moreover, provision of training to skilled birth attendants on close monitoring of labour and early detection of complications, equipping the primary health facilities (e.g., health centres) to the level of caesarean capacity, and continuous financial investment in primary health facilities will be an important strategy to reduce neonatal mortality.

It appears that previous studies which used individual-level data are more likely to report an increased risk of neonatal death among infants born by caesarean section than the ecological studies. This may be due to the indications for the caesarean delivery (e.g., the severity of the underlying causes) was involved in causing both caesarean delivery and neonatal death in studies which used individual-level data, suggesting the role of confounding by indication in the association between caesarean birth and neonatal death because an intended effect of caesarean birth is prevention of neonatal death. Therefore, the increased risk for neonatal death associated with caesarean birth, compared with vaginal birth, would appear to be intuitive given the fact that neonatal death rates after emergency caesarean section is strongly dependent upon the underlying medical indication (e.g., antenatally diagnosed foetal malformation or foetal growth restriction) for caesarean intervention.

In Ethiopia, the national rate of caesarean section increased from 0.7% in 2000 to 1.9% in 2016. On the other hand, neonatal mortality rate declined from 49 deaths per 1,000 live births in 2000 to 29 deaths per 1,000 births in 2016.[32] Similarly, the pregnancy-related mortality ratio decreased from 871 pregnancy-related deaths per 100,000 live births in 2000 to 412 pregnancy-related deaths per 100,000 live birth in 2016.[32] Our analyses based on aggregate-level data from Ethiopian DHS showed that an increase in caesarean section rate is correlated

with a decrease in the proportion of neonatal deaths. Even though similar context-specific interpretation is applicable to ecological studies, additional explanation may also be necessary to interpret the association. For example, a change in neonatal mortality rate may be attributable to changes acting on the population as a whole—i.e., changes in health coverage indicators, such as an increase in births attended by skilled birth attendants (increased from 6% in 2000 to 28% in 2016)[32] and immunization coverage (was 86.4% in 2015).[42]

We acknowledge the following limitations of this study. Firstly, as both the proportion of institutional deliveries and caesarean section rate is low in Ethiopia, especially in rural areas, the number of neonatal deaths following caesarean section may be low. However, since our analyses are weighted, we believe that the weight improves the representativeness of the data in terms of size, distribution and characteristics of the Ethiopian population. The weight may also ensure that our estimates are unbiased though the confidence interval for some subgroup analyses are somewhat wide. Secondly, the interpretation of our study is specific to the context of Ethiopia and may not be generalizable to other developing countries in Africa or elsewhere. Another limitation is the mother's recall of the child's size at birth was used as a substitute for the child's birth weight in this study because the data for birth weight was not collected for more than 50% of the neonates in DHS.

Conclusions

A naïve interpretation of the changing temporal association between caesarean birth and neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death. However, the changing temporal association likely reflects improvements in health service coverage and secular shifts in the characteristics of Ethiopian women undergoing caesarean section after complicated labour or severe foetal compromise.

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Table 1. Characteristics of the study participants according to the mode of delivery, Ethiopia DHS 2000, 2005, 2011, and 2016

	Mode of delivery							
	DHS 2000		DHS 2005		DHS 2011		DHS 2016	
	Caesarean (n= 86) %	Vaginal (n= 12,174) %	Caesarean (n= 111) %	Vaginal (n= 11,052) %	Caesarean (n= 175) %	Vaginal (n= 11,697) %	Caesarean (n= 213) %	Vaginal (n= 10,810) %
Neonatal death								
Yes	4.5	4.8	6.7	3.9	5.5	3.7	8.3	2.7
No	95.5	95.2	93.3	96.1	94.5	96.3	91.7	97.3
Types of residence								
Urban	76.2	9.9	68.8	6.7	70.9	12.0	60.4	10.1
Rural	23.8	90.1	31.2	93.3	29.1	88.0	39.6	89.9
Region								
Tigray	4.0	6.4	5.4	6.3	12.5	6.2	6.8	6.5
Afar	2.5	1.0	0.6	1.0	1.4	1.0	0.4	1.0
Amhara	3.7	26.3	15.2	23.6	19.4	22.4	22.1	18.7
Oromia	46.3	40.7	28.5	39.6	14.6	42.6	21.2	44.5
Somali	2.3	1.2	4.2	4.3	1.4	3.1	1.0	4.7
Benishangul-Gumuz	3.1	1.0	0.1	0.9	1.0	1.2	0.6	1.1
SNNP	18.5	21.2	21.6	22.4	17.4	21.1	21.0	20.8
Gambela	0.6	0.2	0.5	0.3	2.0	0.3	0.2	0.2
Harari	0.9	0.2	0.7	0.2	1.2	0.2	1.1	0.2
Addis Ababa	16.9	1.4	22.1	1.2	27.6	1.5	24.5	1.8
Dire Dawa	1.1	0.3	1.2	0.3	1.4	0.3	1.2	0.4
Mother's age at birth								
<20	19.4	12.0	13.3	13.4	10.5	10.9	6.4	10.0
20-29	70.8	51.3	59.8	51.2	62.8	55.7	58.4	54.6
30-39	9.8	30.0	24.1	29.3	23.7	28.7	31.7	30.9
40-49	0.0	6.7	2.9	6.2	3.3	4.7	3.4	4.5
Mother's education								
No education	15.7	82.5	30.1	79.7	19.9	70.0	22.8	66.9
Primary	21.8	13.0	14.5	16.6	44.7	26.8	35.1	26.6

Secondary	56.4	4.3	46.5	3.4	22.2	1.9	15.3	4.5
Higher	6.2	0.2	8.9	0.3	13.2	1.2	26.8	2.0
Place of delivery§								
Public	96.3	4.0	90.2	3.9	83.5	7.6	84.0	23.6
Private	1.3	0.1	5.9	0.3	13.6	0.8	13.7	0.9
NGO	2.4	0.2	3.8	0.1	3.0	0.2	2.4	0.2
Home	0.0	95.6	0.0	95.7	0.0	91.4	0.0	75.2
Birth order								
1	75.5	18.6	53.2	17.0	53.5	18.5	41.4	18.2
2	17.5	16.5	26.0	15.5	17.0	17.0	25.6	16.0
3	2.2	13.7	5.7	14.5	10.3	14.2	18.2	14.2
4	1.0	11.3	1.5	12.9	6.0	12.6	3.3	12.5
5	0.6	10.4	2.2	10.8	8.4	10.5	5.3	11.4
6+	3.2	29.5	11.4	29.4	4.7	27.2	6.3	27.6
Sex of child								
Male	61.8	51.2	51.3	51.3	57.2	51.9	54.0	51.9
Female	38.2	48.8	48.7	48.7	42.8	48.1	46.0	48.1
Size of baby at birth*								
Very large	9.8	5.3	30.7	22.3	25.8	19.2	26.5	17.6
Larger than average	32.0	25.4	11.4	9.5	11.7	12.7	16.0	13.8
Average	34.6	35.7	37.4	40.0	42.3	38.2	36.1	41.7
Smaller than average	19.7	27.5	9.4	7.3	4.9	8.7	7.0	10.1
Very small	3.7	5.9	9.5	20.6	14.8	20.6	12.7	16.0
Don't know	0.2	0.2	1.1	0.4	0.6	0.4	1.7	0.8
Wealth quantile								
Poorest	1.9	21.1	0.6	22.1	2.0	23.1	7.2	24.2
Poorer	4.9	21.0	5.9	21.3	8.4	22.6	12.2	23.1
Middle	4.1	22.0	3.9	22.5	9.0	20.7	10.8	20.9
Richer	6.1	20.5	9.7	20.0	6.5	19.3	9.3	18.3
Richest	83.0	15.5	79.9	14.2	74.1	14.2	60.4	13.5

NB: ***n***=weighted; §Missing for 2000 (n = 9); *Mother's estimate of baby's size at birth; **DHS**, Demographic and Health Survey

Table 2. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean versus vaginal delivery, Ethiopia DHS 2000, 2005, 2011, and 2016

	Prevalence Ratio (95% CI) for neonatal death
Ethiopia DHS 2000	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,873)	0.93 (0.38, 2.30)
Caesarean delivery, model 1[a] (n= 10,853)	0.95 (0.29, 3.19)
Ethiopia DHS 2005	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 9,861)	1.74 (0.67, 4.51)
Caesarean delivery, model 1[a] (n= 9,861)	1.53 (0.52, 4.50)
Ethiopia DHS 2011	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 11,654)	1.49 (0.62, 3.61)
Caesarean delivery, model 1[a] (n= 11,654)	1.15 (0.45, 2.93)
Ethiopia DHS 2016	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,641)	3.02 (1.37, 6.66)
Caesarean delivery, model 1[a] (n= 10,641)	2.81 (1.11, 7.13)

[a]Adjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

Table 3. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean versus vaginal delivery, Ethiopia DHS 2016

	Prevalence Ratio (95% CI) for neonatal death
Main analysis	
Vaginal delivery	1 [*Ref.*]
Caesarean delivery, crude (n= 10,641)	3.02 (1.37, 6.66)
Caesarean delivery, model 1[a] (n= 10,641)	2.81 (1.11, 7.13)
Subgroup analyses	
Restricted to Addis Ababa[b] (n= 461)	1.07 (0.20, 5.73)
Excluded Addis Ababa and Harari[a] (n= 9,575)	3.35 (1.31, 8.56)
Restricted to births in public facility[a] (n= 3,023)	2.78 (1.16, 6.63)
Restricted to rural mothers[b] (n= 8,636)	3.43 (1.22, 9.67)
Restricted to women from lowest quintile of household wealth[c] (n=3,958)	7.01 (0.92, 53.36)
Restricted to women from highest quintile of household wealth[c] (n=2,092)	2.72 (0.55, 13.38)

[a]Adjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.
[b]Adjusted for place of delivery, sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.
[c]Adjusted for place of delivery, sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order.

Table 4. Factors contributing to the 'Three Delays Model', according to sociodemographic characteristics, Ethiopia DHS 2016

	Delivery by skilled provider§	Number of births	Problems in accessing health care by women aged 15-49 years*					
			Distance to health facility	Getting money for treatment	Getting permission to go for treatment	Not wanting to go alone	At least one problem accessing health care	Number of women
Types of residence								
Urban	80.1	1216	17.0	34.7	15.1	21.4	45.6	3476
Rural	21.2	9807	59.8	60.5	37.0	47.9	76.9	12207
Region								
Tigray	59.3	716	37.4	46.1	15.3	24.6	60.7	1129
Afar	16.4	114	54.3	51.7	28.2	41.8	66.6	128
Amhara	27.7	2072	33.7	35.3	15.4	34.6	55.7	3714
Oromia	19.7	4851	68.9	70.1	58.3	57.0	82.9	5701
Somali	20.0	508	47.3	63.0	25.7	32.2	72.6	459
Benishangul-Gumuz	28.6	122	57.4	62.4	36.5	43.8	76.8	160
SNNPR	28.6	2296	52.7	59.1	18.4	39.5	75.4	3288
Gambela	46.9	27	41.0	44.3	24.3	33.7	61.2	44
Harari	51.2	26	18.1	28.2	16.3	13.8	30.8	38
Addis Ababa	96.8	244	10.8	29.2	8.7	14.5	40.0	930
Dire Dawa	56.7	47	57.4	64.5	58.7	55.2	71.4	90
Mother's education								
No education	17.2	7284	59.2	62.9	37.6	47.1	78.0	7498
Primary	38.6	2951	50.3	55.7	31.9	43.2	71.1	5490
Secondary	78.4	514	27.8	33.2	18.2	27.8	48.1	1817
More than secondary	93.2	274	20.6	23.8	15.9	20.4	39.8	877
Wealth quintile								
Poorest	11.0	2636	67.7	70.9	40.0	54.5	85.3	2633

Poorer	20.8	2520	66.8	67.0	42.1	52.7	82.9	2809
Middle	24.2	2280	59.4	61.0	35.2	47.6	77.3	2978
Richer	28.5	1999	49.8	50.2	33.8	41.2	68.2	3100
Richest	70.3	1588	22.1	35.2	17.0	23.4	47.7	4163
Total	27.7	11023	50.3	54.8	32.1	42.0	70.0	15683

§Percentage delivered by a skilled provider (includes doctor, nurse, midwife, health officer, and health extension worker)

*Percentage of women age 15-49 who reported that they have serious problems in accessing health care for themselves when they are sick, by type of problem, according to sociodemographic characteristics, Ethiopia DHS 2016

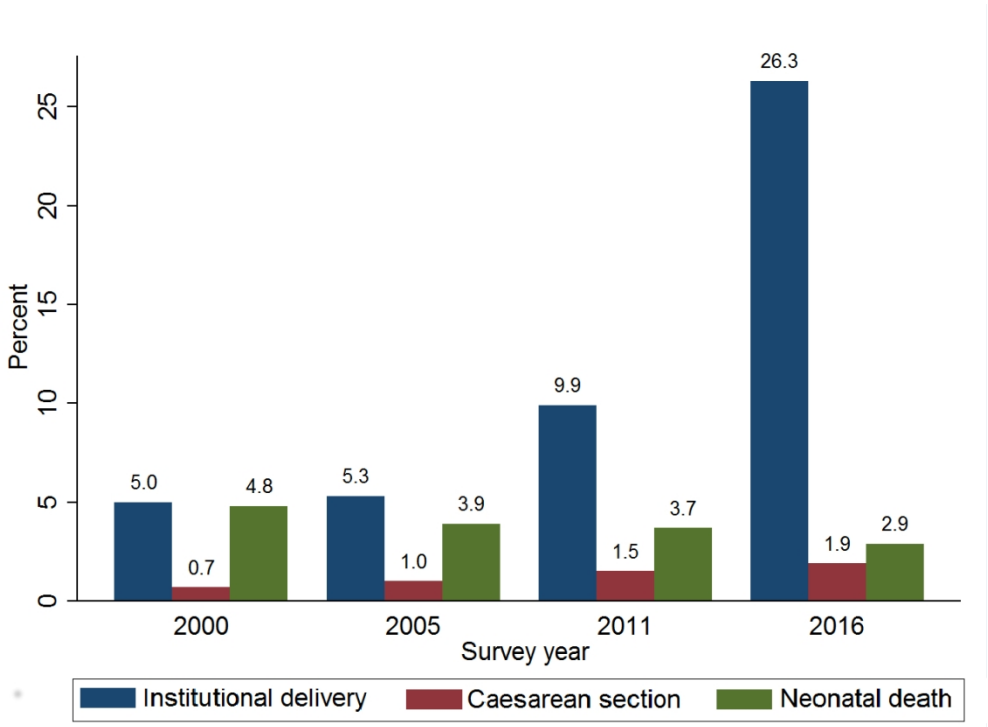


Figure 1. Trends in proportion of institutional deliveries, caesarean section and neonatal death in the 5 years before each of the surveys, Ethiopia DHS 2000, 2005, 2011 and 2016

109x79mm (300 x 300 DPI)

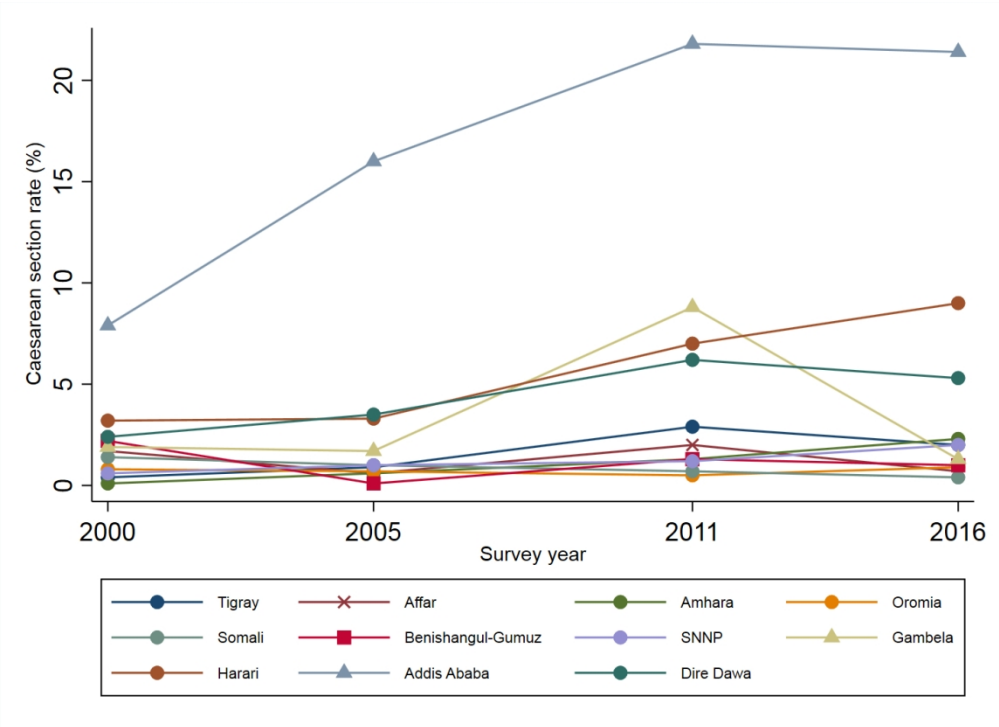


Figure 2. Trends in caesarean section rates in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016

123x89mm (300 x 300 DPI)

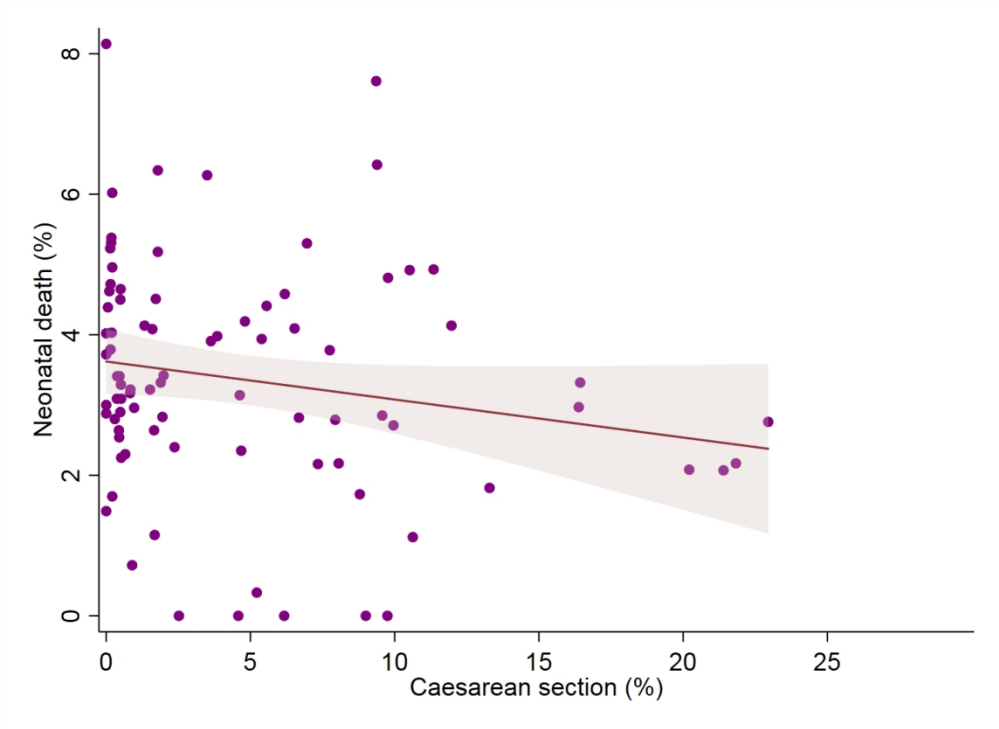


Figure 3. The relationship between caesarean section rate and neonatal death in Ethiopia

122x88mm (300 x 300 DPI)

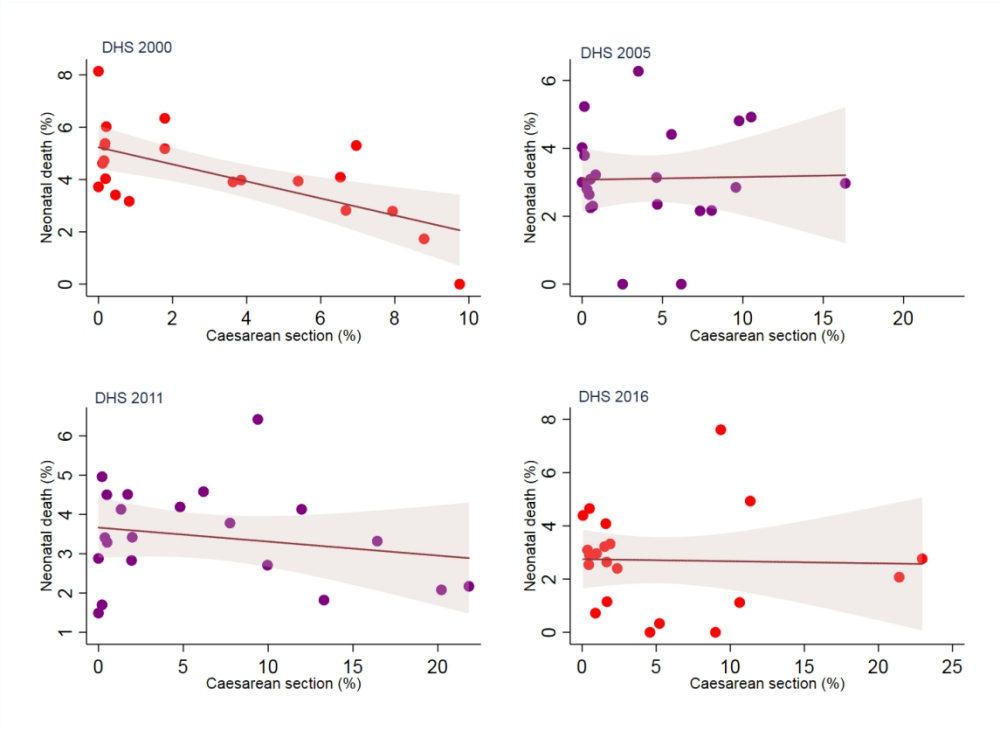


Figure 4. The relationship between caesarean section rate and neonatal death by survey years

122x88mm (300 x 300 DPI)

SUPPLEMENTARY MATERIAL

This file includes supplementary analyses that complement the main findings and pictures that describe the 'Three Delays Model' and the Ethiopian health system structure cited in the full text of the article.

Table A1. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with 'timing of decision to conduct caesarean section' versus vaginal delivery, Ethiopian DHS, 2016

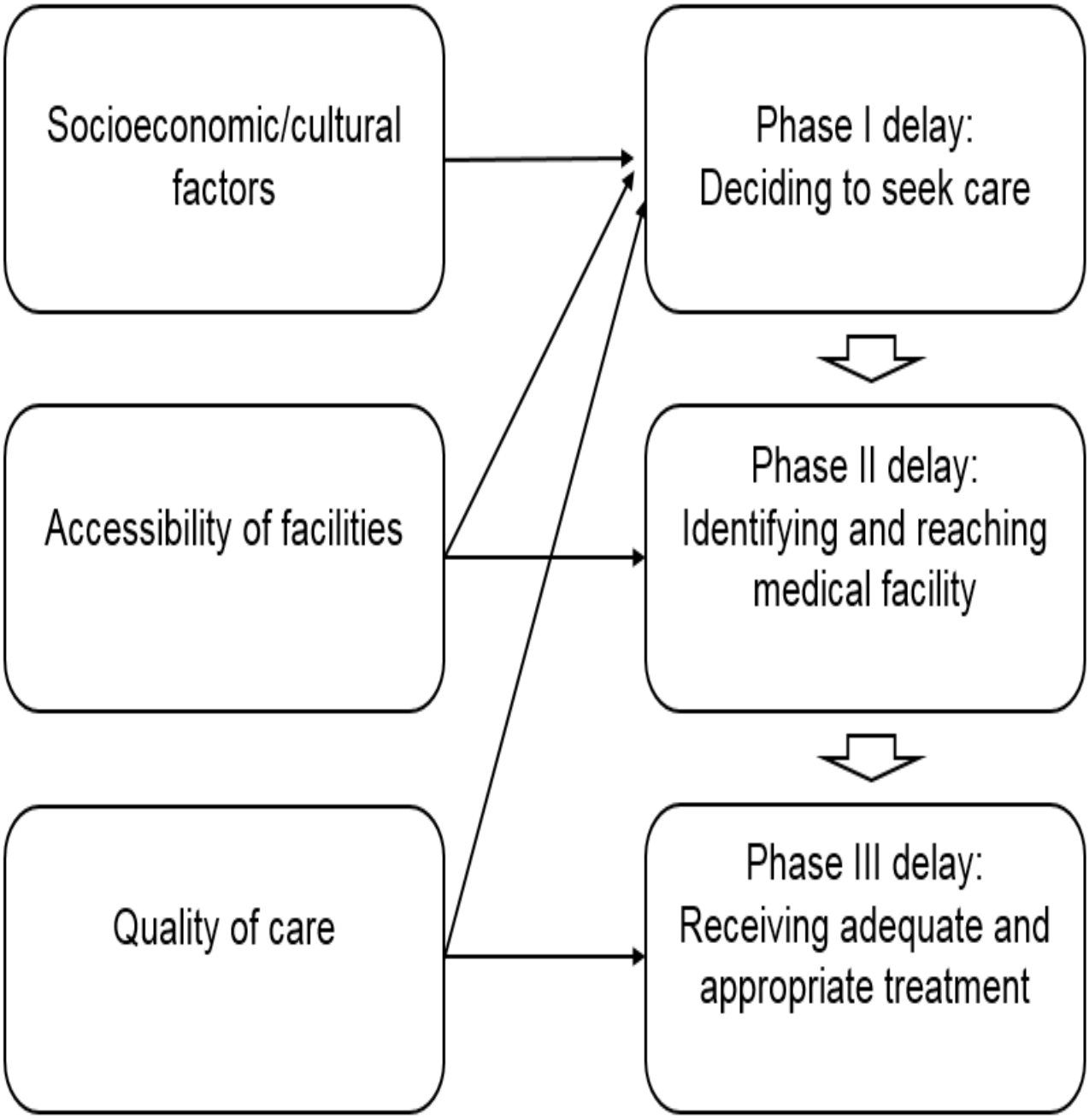
	Prevalence Ratio (95%CI) for neonatal death
Unadjusted (n= 10 641)	
Vaginal delivery	1 [*Ref.*]
Caesarean section decided before onset of labour	4.21 (1.34, 13.19)
Caesarean section decided after onset of labour	2.31 (0.84, 6.41)
Adjusted[a] (n=10 641)	
Vaginal delivery	1 [*Ref.*]
Caesarean section decided before onset of labour	3.79 (1.03, 13.93)
Caesarean section decided after onset of labour	2.26 (0.75, 6.82)

[a]Adjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth

NB: 'Timing of decision to conduct caesarean section'—caesarean section that was planned before the onset of labor pains and caesarean section that was decided after the onset of labor pains—was used as a proxy to types of caesarean section.

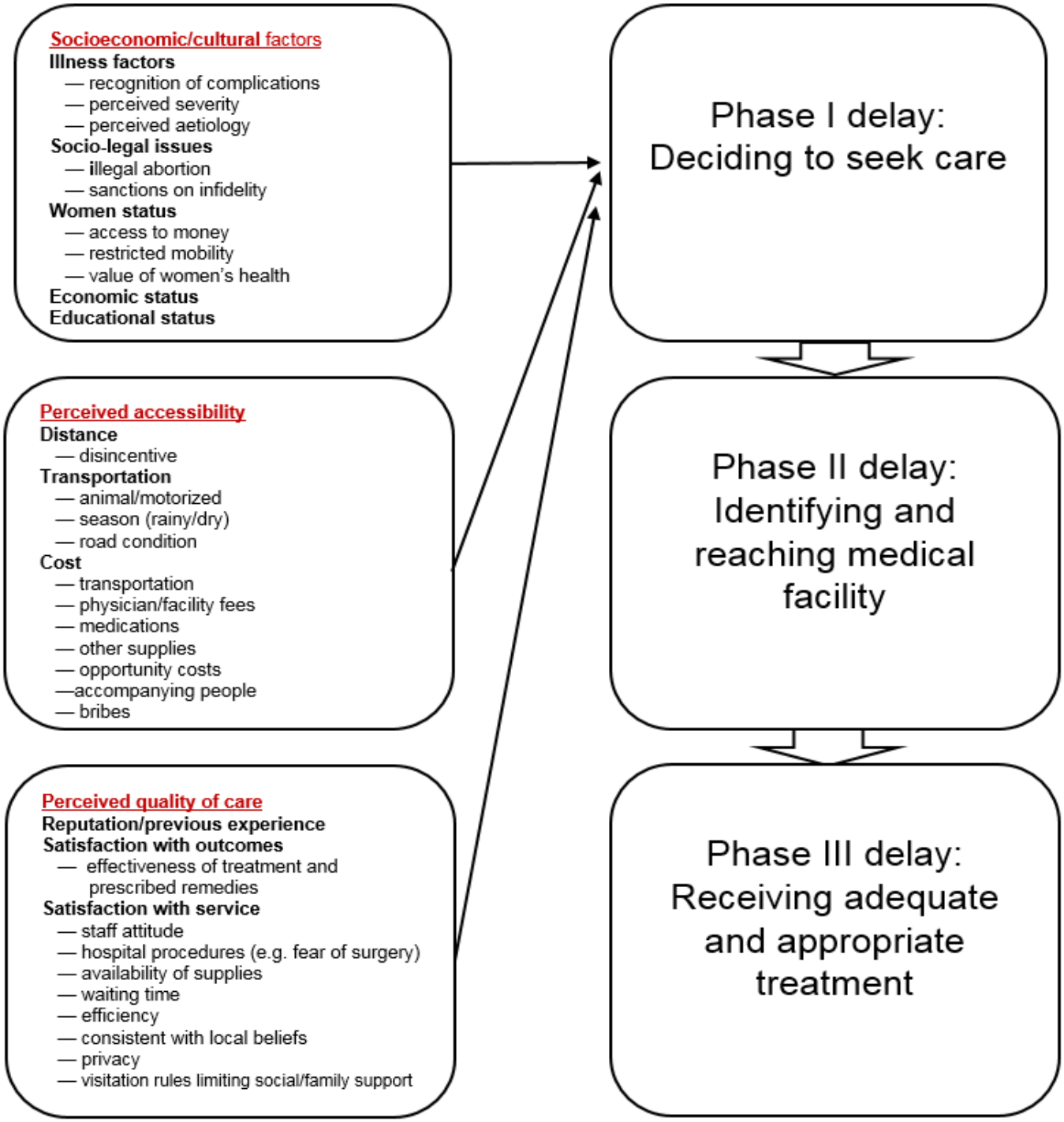
Table A2. Trends in proportion of neonatal deaths in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011, and 2016

	Survey year								
	2000 %	Number of births	2005 %	Number of births	2011 %	Number of births	2016 %	Number of births	Absolute change %
Types of residence									
Urban	4.4	1277	4.4	815	3.9	1528	3.4	1216	-1.0
Rural	4.8	10983	3.9	10348	3.7	10344	2.8	9807	-2.0
Region									
Tigray	5.3	788	2.7	698	4.1	753	2.7	716	-2.6
Afar	2.9	126	2.9	107	1.9	121	2.6	114	-0.3
Amhara	4.8	3202	5.2	2621	4.5	2656	3.2	2072	-1.6
Oromia	5.3	4999	3.8	4411	3.4	5014	2.8	4851	-2.5
Somali	3.8	142	3.0	477	2.9	364	4.1	508	+0.3
Benishangul-Gumuz	6.3	124	3.8	105	4.8	140	2.9	122	-3.4
SNNP	4.0	2602	3.4	2500	3.5	2494	2.5	2296	-1.5
Gambela	5.3	29	2.4	31	3.6	40	2.8	27	-2.5
Harari	3.7	25	2.2	22	4.1	29	3.1	26	-0.6
Addis Ababa	2.8	182	2.9	153	2.2	222	2.1	244	-0.7
Dire Dawa	3.7	40	2.7	37	1.6	39	3.0	47	-0.7
Total	4.8	12260	3.9	11163	3.7	11872	2.9	11023	-2.0



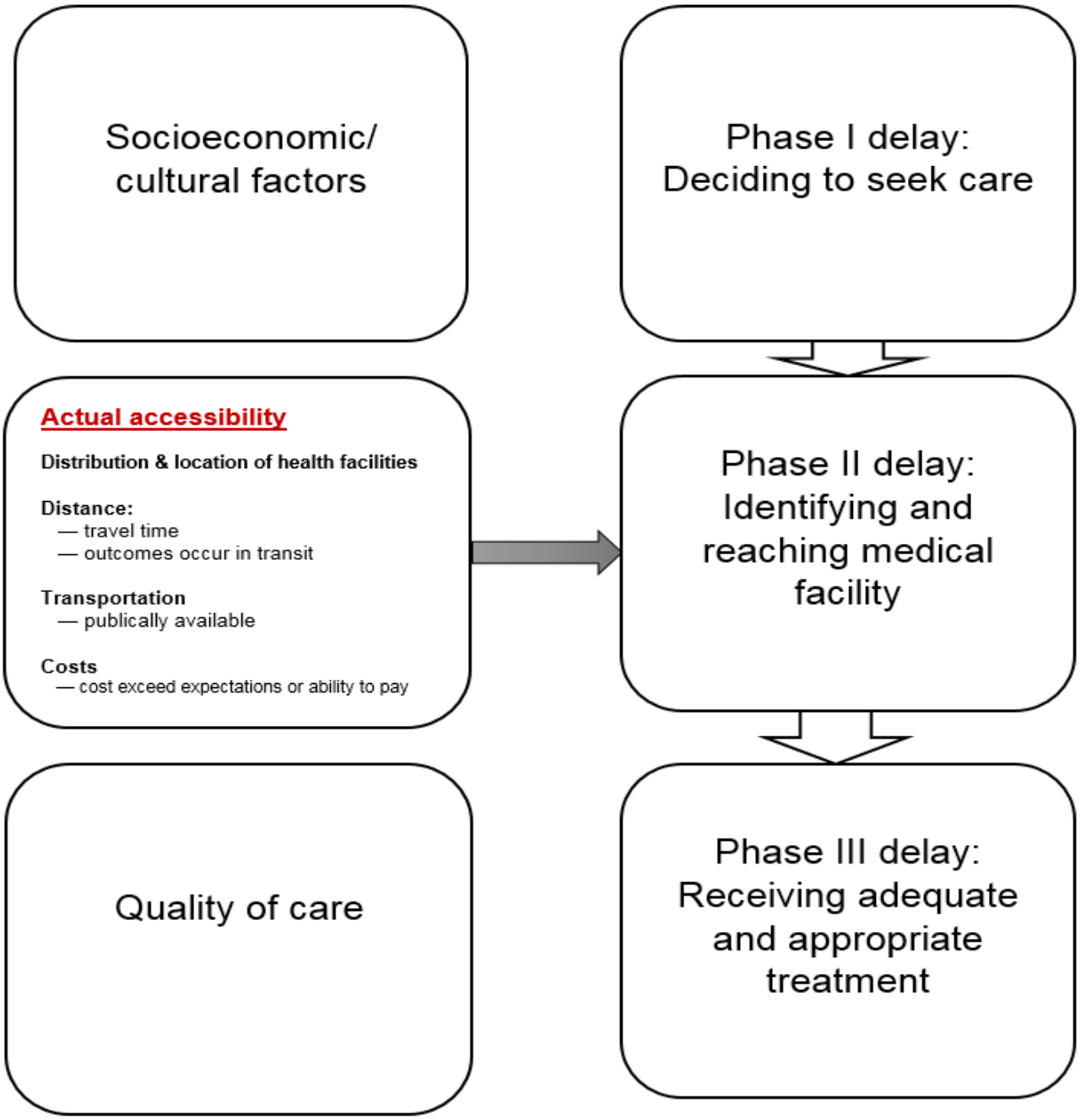
Source: *Soc Sci Med*, 1994; **38**(8): 1091-110.[1]

Figure A1. The 'Three Delays Model'



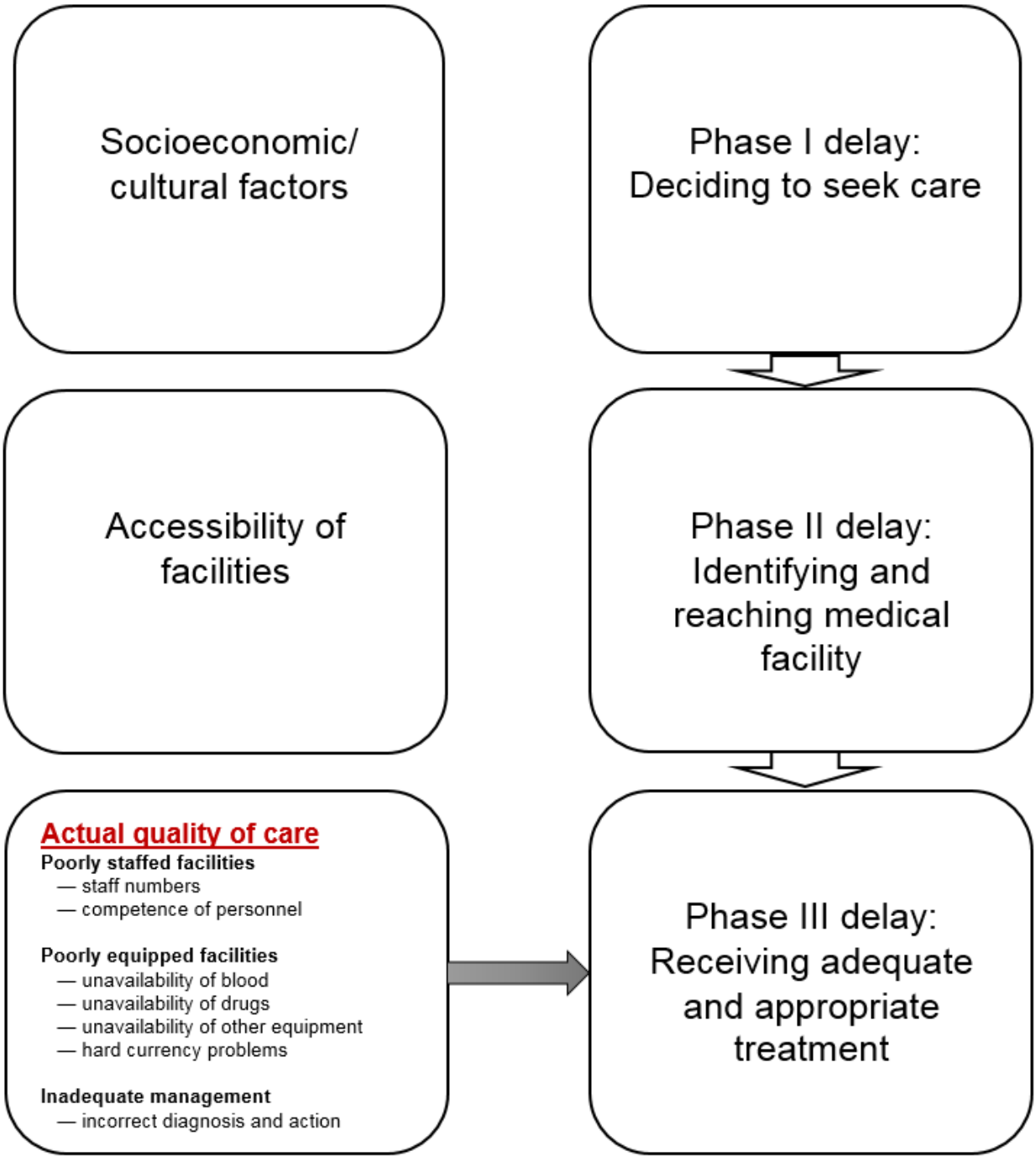
Source: Soc Sci Med, 1994; ***38****(8): 1091-110.*[1]

Figure A2. Phase I delay, detail



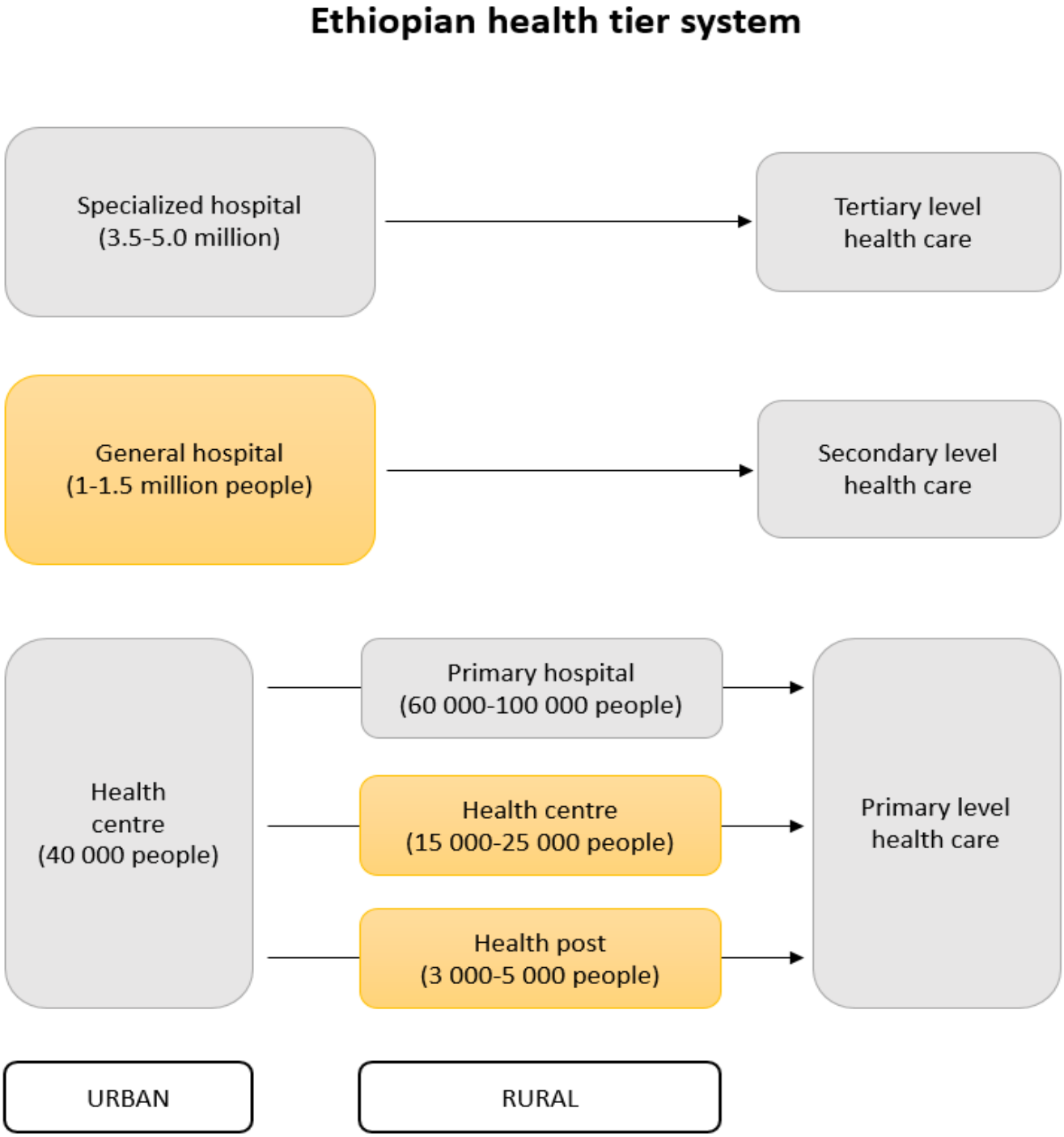
Source: *Soc Sci Med*, 1994; **38**(8): 1091-110.[1]

Figure A3. Phase II delay, detail



Source: *Soc Sci Med*, 1994; **38**(8): 1091-110.[1]

Figure A4. Phase III delay, detail



Source: Ethiopian Health Sector Transformation Plan, 2015,[2] and World Health Organization, 2017. [3]

Figure A5. Ethiopian health system structure

References

1. Thaddeus S, Maine D. Too far to walk: maternal mortality in context. *Soc Sci Med* 1994; **38**(8): 1091-110.

2. Ministry of Health. Health Sector Transformation Plan. Addis Ababa: Federal Democratic Republic of Ethiopia; 2015.

3. WHO. Primary health care systems (PRIMASYS): case study from Ethiopia, abridged version. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 1-3	(See Title and Abstract): "The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys"
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2	(see Abstract: Main outcome measures; Results)
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 4-5	(see Introduction)
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5	"We use Ethiopian DHS data from 2000, 2005, 2011, and 2016 to examine the changing temporal association between caesarean birth and neonatal death. We then apply the 'Three Delays Model' developed by Thadeus and Maine to facilitate the interpretation of the association between caesarean birth and neonatal death in Ethiopia using the 2016 data."
Methods				
Study design	4	Present key elements of study design early in the paper	Page 6	(see Methods—Study design and data samples)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 6	(see Methods—Study design and data samples)
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of	Page 6	"The DHS questionnaire asks

		participants		women about pregnancy, antenatal, and delivery care for livebirths they have reported in the past 5 years. For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally."
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 6-9	(see Methods—Exposure, Outcome and Confounding)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 6	**"Exposure** The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for livebirths they have reported in the past 5 years. The data on caesarean section and other variables in the DHS was collected based on mothers' self-report. For example, the self-reported data on caesarean section was collected by asking women a question that reads, "Was (NAME) delivered by caesarean section, that is, did they cut your belly open to take the baby out?" Stanton and colleagues[25] in their study demonstrated that the DHS caesarean section rates, compared with facility-based records of caesarean section rates, are reliable for national and global monitoring

				in developing countries. For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally. **Outcome** Neonatal death includes children who were born alive in the 5 years before the survey, but died within the first 28 days of life. The outcome variable, neonatal death, was measured from two variables (whether the child is alive and age at death (in days)).”
Bias	9	Describe any efforts to address potential sources of bias	Page 7-10	(see Methods—Statistical analysis)
Study size	10	Explain how the study size was arrived at	Page 6	(see Methods—Study design and data samples): “We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela, and Harari), and two city administrations (Addis Ababa and Dire Dawa).”
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 6-7	(see Methods— Confounding)
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Page 7-8	(see Methods—Statistical analysis)

		(*b*) Describe any methods used to examine subgroups and interactions	Page 8-9	(see Methods—Statistical analysis)
		(*c*) Explain how missing data were addressed		Not applicable
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	Page 7	"All analyses (i.e., Ethiopian DHS 2000, 2005, 2011 and 2016) were weighted to be nationally representative. As women may have had more than one births within the five-year survey periods, we also accounted for both clustering of caesarean deliveries within women as well as the complex survey design during the data analyses using the unit of analysis (i.e., children) study number and sample weights."
		(*e*) Describe any sensitivity analyses		Not applicable
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 11	(see Results): "Table 1"
		(b) Give reasons for non-participation at each stage		Not applicable
		(c) Consider use of a flow diagram		Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 11	(see Results)
		(b) Indicate number of participants with missing data for each variable of interest		Not applicable
Outcome data	15*	Report numbers of outcome events or summary measures	Page 11-12	(see Results)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	page 11-12	(see Results)
		(*b*) Report category boundaries when continuous variables were categorized	Page 11-12	(see Results)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a		

		meaningful time period		Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 11-12	(see Results)
Discussion				
Key results	18	Summarise key results with reference to study objectives	Page 13 & page 18	(See Interpretation and Discussion sections)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 20	(See Discussion: "We acknowledge the following limitations of this study. Firstly, as both the proportion of institutional deliveries and caesarean section rate is low in Ethiopia, especially rural area, the number of neonatal deaths following caesarean section may be low. However, since our analyses are weighted, we believe that the weight improves the representativeness of the data in terms of size, distribution and characteristics of the Ethiopian population. The weight may also ensure that our estimates are unbiased though the confidence interval for some subgroup analyses are somewhat wide. Secondly, the interpretation of our study is specific to the context of Ethiopia and may not be generalizable to other developing countries in Africa or elsewhere. Another limitation is the mother's recall of the child's

				size at birth was used as a substitute for the child's birth weight in this study because the data for birth weight was not collected for more than 50% of the neonates in DHS")
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13-20	(See Interpretation and Discussion sections)
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 20	(See Discussion)
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 22	(See Funding—The first author is fully supported by an Australian Government Research Training Programme (RTP) Scholarship. The funder does not have role in the design of the study.)

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.