Enhancing Maternal and Newborn Health in Low- and Middle-Income Countries: Assessment of Antenatal Care Quality and Utilization of Antenatal Corticosteroids

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Dedication

I would love to dedicate this dissertation to my beloved parents, brother, and sister for their unconditional love throughout my life; their love has nurtured me into who I am today. Even though they are thousands of miles away, I always carry their love with me — to fail, cry, stand up, and grow stronger again and again. To my husband, Scott, for his unyielding and boundless support. This dissertation would not have been possible without his unwavering belief in me. Lastly, to our daughter, Aria, the most precious soul who came from the universe and chose us to be her parents. She fills our lives with love and joy, reminding me each day how beautiful this world is and why it deserves our lifelong efforts to make it a better place.

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I have received countless rejections for numerous opportunities since I came to the US to pursue my dream. These rejections often led to deep self-doubt. I could not help but question my abilities, my qualifications, and my decision to come here. At times, when I felt as if I was almost being consumed by the deepest darkness, there was always a hand reaching out to me – whether it was a stranger on LinkedIn who generously shared her experience, a friend who reviewed my PhD application documents countless times, a professor who opened his or her door and kindly gave me advice, or many, many more. I am so fortunate and feel the utmost gratitude for their genuine kindness, and I have promised myself to give back as much as I can. Those rejections are meaningful, and the help from those kind hearts is also meaningful. As I look back, I see how those dots are connected. I would love to take this opportunity to thank all the kind souls who have helped me in various ways on this journey.

Abstract of Dissertation

Enhancing Maternal and Newborn Health in Low- and Middle-Income Countries: Assessment of Antenatal Care Quality and Utilization of Antenatal Corticosteroids

The world has seen a significant reduction in child mortality, made possible by tremendous global efforts. Despite this process, the burden of maternal and neonatal death globally remains high, with the majority of mortality happening in low-resource countries. More and more pregnant women in low- and middle-income countries (LMICs) have attended antenatal care visits; however, the quality of antenatal care (ANC) remains insufficient, meaning pregnant women do not always receive the essential care they need during those visits. To enhance maternal and newborn health in LMICs, high-quality care in pregnancy is crucial, which should include essential care components to monitor maternal and fetal health and evidence-based intervention to prevent illness and improve outcomes. To assess whether healthcare of good quality is provided to people who need it in settings that can optimize the benefits of care, this dissertation aimed to 1) examine the landscape of antenatal corticosteroid (ACS) utilization, one of the most effective interventions to improve preterm outcome, aiming to identify priority policy directions for ACS scale-up, and 2) investigate the quality of antenatal care, focusing on key care components essential to reduce adverse perinatal outcomes in low-resource countries.

Three papers in this dissertation focused on antenatal corticosteroids in LMICs. The first two studies using health facility survey data from nine countries found low ACS utilization, limited corticosteroid availability, and inadequate facility readiness, with huge gaps between drug availability and actual utilization. To encourage ACS uptake and

ensure its safe and effective provision, our findings suggested that policymakers should equip facilities for proper ACS use and target well-equipped facilities for ACS scale-up. The third study on ACS identified barriers to effective ACS utilization in Ethiopia. The country's health service delivery structure strongly affects the effectiveness of ACS. Simply increasing ACS uptake without taking into account how high-risk pregnancies are managed and referred within a particular health system is unlikely to improve neonatal survival significantly. In addition, knowledge gaps in ACS use and identifying eligible women hinder providers from implementing this intervention appropriately. These three papers on ACS concluded that the benefits of ACS can only be realized in reasonably equipped facilities with competent providers who adhere to guidelines under a country's service delivery structure that can effectively manage labor of varied risks in appropriate settings. Lastly, the fourth paper on the assessment of antenatal care quality found that pregnant women received antenatal care of suboptimal quality in Ethiopia, Kenya, and South Africa; suboptimal ANC quality was significantly associated with an increased risk of late miscarriage and stillbirth. Our findings also suggested the importance of ultrasound examination in antenatal care.

As more and more pregnant women in LMICs have access to antenatal care, improving the quality of antenatal care becomes enormously crucial. The ongoing global efforts should focus on ensuring the provision of essential care components to every pregnant woman and evidence-based interventions to eligible women in settings that can optimize the benefits of healthcare services.

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Chapter 1: Introduction

1.1 Background

Our world has made substantial progress in reducing child mortality. Over the past three decades, the global under-five mortality rate declined significantly, from 93 deaths per 1,000 live births in 1990 to 37 in 2022.(1) However, despite this remarkable improvement in child survival, we did not see similar progress in neonatal survival, and the burden of neonatal death remains high.(1) Neonatal deaths account for nearly half of the under-five mortality globally, primarily attributable to preterm birth-related complications, infections, and intrapartum-related events.(2, 3) Among the estimated 5.3 million under-five mortality in 2019, 46% were neonatal deaths; among neonatal deaths, about one-third were preterm-birth related, which was equivalent to 0.9 million deaths.(2) Preterm births remain a serious global public health issue. A recent series in *The Lancet* proposed a newly developed umbrella term: “small vulnerable newborns,” bringing together preterm births, small for gestational age, and low birth weight newborns.(4) The series presented a conceptual framework for the underlying contextual causes, maternal exposures, and consequences of being small newborns, aiming to facilitate comprehensive and coordinated global efforts to prevent and manage small vulnerable newborns.(4) The global community has invested tremendously in this large population, as saving their lives could help achieve the Sustainable Developmental Goals (SDGs) target of ending preventable child and newborn deaths. Additionally, there were 287,000 maternal deaths in the world in 2020, with 95% happening in low- and middle-income countries (LMICs).(5)

To address the global maternal and newborn health challenges, antenatal care (ANC) is crucial for the health of pregnant women and their newborn babies. The World Health Organization (WHO) guidelines on antenatal care (ANC) outlined the important functions of ANC, including health promotion, disease screening and diagnosis, and prevention of illnesses through good clinical practices and evidence-based interventions.(6) Studies have found that ANC coverage improved in LMICs; however, the quality of ANC is sufficient.(7-9) This phenomenon is particularly concerning as providing ANC with poor quality is ineffective and wasteful, missing the opportunity to promote health, identify risk factors, and prevent illness for pregnant women and their newborn babies.

1.2 Research Overview

This dissertation aimed to investigate a fundamental overarching question: *whether the right care is provided to pregnant women in need at the right time in the right places*. First, this dissertation used antenatal corticosteroid (ACS) utilization among pregnant women at risk of imminent preterm labor as an example to examine if an evidence-based antenatal intervention is provided to eligible women. ACS is a specific antenatal intervention targeting pregnant women who are likely to deliver a newborn prematurely. This intervention improves preterm newborn survival by accelerating fetal lung maturity.(10) However, its utilization remains limited in countries with the highest burden of preterm births.

Second, this dissertation assessed the quality of antenatal care. ANC serves as a platform that provides a wide range of services to ensure the health of pregnant women

and their babies.(6) Massive global efforts have been made to increase ANC utilization, but the quality of ANC is disproportionately insufficient. For example, a rich body of literature has examined the associations between ANC utilization and health outcomes such as neonatal death.(11, 12) However, evidence gaps remained in the content of ANC that constitutes good quality and how quality affects health outcomes. The last part of this dissertation focused on assessing ANC quality, identifying key care components, and investigating how ANC quality relates to perinatal outcomes.

Antenatal corticosteroids: utilization, facility readiness, and factors affecting use

Preterm births are a serious global health issue. Newborns born prematurely are at an increased risk of developing respiratory distress syndrome (RDS), a common respiratory complication and a leading cause of neonatal death. RDS is caused by an insufficiency of surfactant, a substance produced in fetal lung cells that reduces the surface tension of alveoli and helps expand lung cells for gas exchange. Administering ACS to pregnant women who are likely to deliver their babies prematurely accelerates fetal lung maturity by stimulating the synthesis and release of surfactant, greatly reducing the occurrence of RDS and improving the survival of preterm babies.(10) In 1972, Liggins and Howie conducted the first trial of ACS, demonstrating its benefits in reducing RDS among preterm newborns.(13) Since then, many studies have further confirmed the beneficial effects. In 1994, the National Institute of Health Consensus Development Conference Statement recommended ACS use for pregnant women at risk of preterm birth in the United States.(14) More recently, a 2020 Cochrane review summarizing data from 27 trials involving more than 10,000 infants showed that ACS

reduced the risk of RDS by 29% and neonatal death by 22%.(10) Given the potential profound impact of ACS at the population level, the WHO and other professional organizations recommend giving ACS to pregnant women at risk of imminent preterm labor between 24 and 34 weeks of gestation.(15-18) The WHO recommendations also specify that ACS should be given in conditions where the following five criteria are met: 1) Gestational age can be accurately assessed, 2) There is a high likelihood of preterm birth within 7 days of starting ACS therapy, 3) There is no evidence of maternal infection, 4) Adequate childbirth care is available, 5) The preterm newborn can receive adequate care.(17)

While ACS is widely administered in industrialized countries, its adoption in LMICs remains disproportionately low despite the fact that the majority of the world's preterm newborns are born in these areas.(3) There are three primary evidence gaps in ACS utilization in LMICs. First, the current status of ACS use in LMICs is mainly unknown despite some outdated studies reporting ACS coverage rates at the individual level **(Table 1)**. However, no recent data on ACS utilization at the facility level is available. Second, the structural readiness of facilities in LMICs to provide ACS in accordance with international guidelines is unclear. Readiness is defined as the availability of required components to provide health services, such as medicines, equipment, diagnostics, commodities, and staff.(19) While the WHO recommends administering ACS in settings that meet those five criteria, there have been ongoing discussions on the feasibility of some of these criteria, particularly when applied to healthcare settings with varying capacities.(20-25) Measuring facility readiness and identifying appropriate levels of readiness for safe and effective ACS use warrants future

studies. Third, there is an urgent need for a comprehensive understanding of factors influencing ACS utilization. Prior studies have examined factors associated with low ACS in low-resource countries.(26-31) These factors can be broadly grouped into national, facility, and individual levels (including maternal and provider levels). Understanding the complexity of these factors across various levels helps identify priority actions to promote ACS uptake.

To address the above evidence gaps, I conducted two studies that assessed the utilization of antenatal corticosteroids and facility readiness to give this intervention appropriately; I also investigated factors associated with ACS utilization. I used data from the Demographic and Health Survey Program (DHS) Service Provision Assessments (SPA), which are health facility surveys that collect data on service availability and quality of care in LMICs. For the third paper on ACS, I identified barriers to effective ACS utilization, focusing on Ethiopia, which is among the countries with the highest burden of preterm births.(32) Using data from multiple sources, I aimed to understand the landscape of ACS use and identify barriers to its appropriate utilization in Ethiopia. In addition to the 2021-2022 Ethiopian SPA data, I also used data from the 2016 Ethiopian Emergency Obstetric and Newborn Care assessment, reviewed Ethiopian national obstetric and antenatal care guidelines, summarized studies on ACS use in Ethiopia, and conducted informal standardized discussions with Ethiopian policymaker and physicians specialized in obstetrics and neonatology.

Table 1. ACS coverage data in LMICs from the literature

Study (author, year)	Definition of ACS coverage (or term used)	Available data		
		Asia	Latin America	Africa
Silva 1999: Assessment of ACS use (33)	ACS use among women who gave birth at GA 28 to 33 weeks	-	Brazil 4%	-
Tita 2005: Evidence-based reproductive health interventions (34)	ACS use in prematurity	-	-	Cameroon 10%
Pattanittum 2008: ACS use in 4 South East Asian Countries (35)	ACS use for women who gave birth before GA 34 weeks	Indonesia 9%, Malaysia 55%, Philippines 15%, Thailand 73%	-	-
Riganti 2010: ACS use in 3 Latin American countries (36)	ACS use among women who gave birth between GA 24 to 34 weeks	-	Ecuador 35%, El Salvador 55%, Uruguay 71%	-
Bhutta 2014: Evidence on the interventions to prevent maternal and neonatal deaths (37)	Antenatal steroids coverage	41% (weighted average from 75 Countdown countries, including 34 low-income countries and middle-income countries)		
Vogel 2014: The 2011 WHO multicountry survey for 29 countries (38)	ACS use in women who gave birth between GA 26 to 34 weeks	Afghanistan 16%, China 68%, Pakistan 63%, Vietnam 52%, Sri Lanka 65%, Thailand 44%, India 69%, Japan 58%, Mongolia 69%, Nepal 20%, Philippines 47%, Jordan 91%, Lebanon 57%, Occupied Palestinian territory 88%, Qatar 31%	Brazil 30%, Cambodia 58%, Argentina 74%, Mexico 54%, Nicaragua 71%, Peru 75%, Ecuador 35%, Paraguay 69%	Democratic Republic of the Congo 16%, Kenya 32%, Uganda 27%, Angola 26%, Niger 20%, Nigeria 30%
Berrueta 2016: ACT trial, a cluster RCT to scale up ACS use (data from the control clusters) (39)	ACS use among infants with birthweight <5th percentile (a proxy of preterm), restricted to hospital births	India (Belgaum site) 12.4%, India (Nagpur site) 5.6%, Pakistan 6.1%,	Argentina 44.5%, Guatemala 22.3%	Zambia 11.1%, Kenya 3.8%

**Japan and Qatar are high-income countries*

Quality of antenatal care and its association with fetal and neonatal outcomes

Based on the 2016 WHO recommendations on antenatal care for a positive pregnancy experience, high-quality antenatal care is crucial in ensuring the health of pregnant women and their babies.(6) Tremendous global efforts have been made to increase ANC utilization. While studies have shown increased ANC coverage, with more women in LMICs having attended at least one ANC visit or the recommended number of visits, the quality of ANC that women receive is insufficient.(7-9, 40, 41) Globally, healthcare of poor quality has become a bigger challenge to reduce mortality and morbidity globally than limited access to care.(42) In addition, previous research has linked antenatal care to adverse fetal and neonatal outcomes.(11, 12, 43-47) However, most of it focused on the utilization of ANC, meaning the number of ANC contacts. There are still critical evidence gaps in the associations between the quality of ANC and adverse perinatal outcomes.

For the fourth paper in this dissertation, I used the data from the eCohort study, a longitudinal study that collected data on the utilization and quality of antenatal care in four countries (Ethiopia, Kenya, South Africa, and India). This paper used data from three African countries to examine ANC quality and its association with perinatal outcomes, including fetal loss (including late miscarriage, defined as fetal loss between 13 to 28 weeks of gestation, and stillbirth, defined as fetal loss after 28 weeks of gestation), and low birth weight newborns (birth body weight less than 2.5kg).

1.3 Research Aims

To answer the overarching question and address the knowledge gaps, this dissertation has four aims:

Aim 1: Examine the current status of antenatal corticosteroid utilization in low- and middle-income countries and facility readiness to administer antenatal corticosteroids in line with the WHO recommendations

Aim 2: Investigate facility-level factors associated with antenatal corticosteroid utilization in low- and middle-income countries, with a focus on facility characteristics, facility readiness, and past performance of Comprehensive Emergency Obstetric and Newborn Care (CEmONC) signal functions

Aim 3: Assess the landscape of antenatal corticosteroid utilization in Ethiopia and identify barriers to its appropriate provision in the country

Aim 4: Assess the quality of antenatal care and its association with fetal and neonatal outcomes (including late miscarriage and stillbirth, and low birth weight newborns)

Chapter 2: Antenatal Corticosteroids for pregnant women at risk of preterm labor in low- and middle-income countries: utilization and facility readiness

Abstract

Background

Administering antenatal corticosteroids (ACS) to pregnant women at risk of imminent preterm labor improves newborn survival. However, ACS remains substantially underused in low- and middle-income countries (LMICs) despite these countries accounting for the majority of preterm births globally. Providing ACS in inadequately equipped settings can be harmful to both mothers and newborns. Therefore, health facilities must demonstrate readiness to administer ACS appropriately to ensure its safety and effects. This study aimed to assess ACS utilization and facility readiness to administer ACS based on WHO recommendations across nine LMICs.

Methods

The study used data from *S*ervice Provision Assessments in nine LMICs. The primary outcome was ACS utilization, defined as having ever provided ACS in a health facility. We also assessed the availability of injectable corticosteroids (dexamethasone or betamethasone) and facility readiness to administer ACS appropriately. To measure facility readiness, we developed an overall readiness index based on 35 indicators, grouped into four readiness categories based on the WHO recommendations. The results were stratified by the level of facility.

Results

Across eight countries with comparable sampling strategies, only 10.7% (median, range 6.7% - 35.2%) of facilities had provided ACS; one-fourth (median 25.3%, range 4.6% -

61.5%) of facilities had injectable corticosteroids available at the time of the survey. Significant gaps were observed between corticosteroid availability and ACS utilization. We also found low overall readiness indices, ranging from 8.1% for Bangladesh to 32.9% for Senegal. Across four readiness categories, the readiness index was the lowest for criterion 1 (ability to assess gestational age accurately) (7.3%), followed by criterion 2 (ability to identify maternal infections) (24.8%), criterion 4 (ability to provide adequate preterm newborn care) (31.3%), and criterion 3 (ability to provide adequate childbirth care) (32.9%).

Conclusions

We proposed a strategy for measuring facility readiness to implement one of the most effective interventions to improve neonatal survival. Countries should operationalize readiness measurement, improve facilities readiness to deliver this life-saving intervention, and encourage ACS uptake in well-equipped facilities.

2.1 Introduction

Antenatal corticosteroids (ACS) use among pregnant women at risk of imminent preterm labor is one of the most effective interventions for improving neonatal survival. By accelerating fetal lung maturity, ACS can reduce the risks of respiratory distress syndrome by 30% and neonatal death by 20%.(10) The World Health Organization (WHO) and other professional medical organizations recommend administering ACS to pregnant women with a high likelihood of preterm labor at gestational age (GA) of 24 to 34 weeks.(15-18)

However, ACS adoption remains extremely limited in low- and middle-income countries (LMICs) despite these countries accounting for 80% of preterm births globally.(3) An estimated 13.4 million newborns were born prematurely in 2020, with preterm birth being the leading cause of neonatal death and accounting for nearly half (46%) of under-five mortality.(2, 48) In addition, 75% of neonatal deaths occur within the first week of life, with one million neonatal deaths happening within the first 24 hours after birth.(49, 50) These statistics highlight the urgency of prioritizing interventions that target the huge population of preterm babies.(37, 51) ACS has been considered "*the lowest-hanging and sweetest fruit"* as an intervention for improving preterm outcomes in LMICs.(20) While ACS use has been widely advocated in LMICs, its uptake in these countries remains a subject of ongoing discussions, and evidence on the current landscape of ACS use in resource-constrained countries is still scarce.(20-25)

Two significant evidence gaps remain. First, the status of ACS use in LMICs is mainly unknown despite outdated coverage data. Second, the structural readiness of health facilities in LMICs to provide ACS in accordance with international guidelines is

unclear. In 2022, the WHO released its updated recommendations, emphasizing five conditions for safe and effective administration of ACS: 1) GA can be accurately assessed, 2) there is a high likelihood of preterm birth within 7 days of starting ACS therapy, 3) there is no evidence of maternal infections, 4) adequate childbirth care is available, and 5) the preterm newborn can receive appropriate care.(17)

The WHO recommendations caution that these five conditions may not be met consistently across settings due to variations in facility capabilities, highlighting the potential harms of ACS in healthcare settings that cannot meet the criteria.(17) As a potent anti-inflammatory drug, ACS suppresses immune functions. Maternal infections remain a major concern if ACS is given to vulnerable pregnant women who are ineligible for this intervention. Also, observational studies have reported increased neurocognitive disorders among late preterm infants (born at GA 34 to 36 weeks) who were exposed to ACS.(52-54) The balance between the benefits and risks emphasized the importance of locations where ACS should be provided. However, knowledge about facility readiness in resource-constrained countries remains limited. In 2021, Kankaria et al. found that primary and secondary facilities in northern India were not ready to administer ACS safely, which is, to date, the only study assessing facility readiness to give ACS.(55) As facility readiness is crucial for delivering healthcare of good quality(56), there is an urgent need to comprehensively understand the readiness of health facilities in LMICs to implement this life-saving intervention appropriately.

To address these critical evidence gaps, this study aimed to assess ACS utilization, corticosteroid availability, and facility readiness to administer ACS according to the WHO recommendations.

2.2 Methods

Study sample

This study used data from Service Provision Assessment *(*SPA), a health facility survey on service availability and quality of care in LMICs.(57) We restricted our analyses to SPA surveys conducted in the past ten years and used the latest survey available for countries with SPA data. This study included ten surveys from nine countries: Afghanistan 2018-2019, Bangladesh 2017-2018, Nepal 2021, Haiti 2017-2018, the Democratic Republic of the Congo (DRC) 2017-2018, Ethiopia 2021-2022, Malawi 2013-2014, Senegal 2018 and 2019, and Tanzania 2014-2015. All surveys were completed before the release of the 2022 WHO recommendations; most, except Malawi 2013-2014 and Tanzania 2014-2015 surveys, were conducted after the WHO recommendations on interventions to improve preterm birth outcomes in 2015, which included guidelines on ACS use.(58) The sampling strategies varied based on country needs **(Appendix A. Supplemental Table 1)**.(59-68) The majority of surveys adopted stratified random sampling strategies to obtain a nationally representative sample in the country.(59-61, 64, 65) Malawi 2013-2014 and Haiti 2017-2018 SPA surveys were national census.(66, 68) Unlike other surveys, Afghanistan 2018-2019 mainly sampled urban hospitals.(67) Senegal implemented continuous SPA over five consecutive years to survey all health facilities.(62, 63, 69) In order to have similar sample sizes across countries, we merged data for Senegal over two years (2018 and 2019). Our study used data from two core instruments (out of five) of the SPA survey questionnaire: facility inventory and health worker interviews. In each country, only facilities that provided antenatal care (ANC) or delivery services (normal deliveries or Cesarean deliveries) were included.

Measures

Our primary outcome was ACS utilization, defined as facilities having ever provided ACS to pregnant women. We focused on two secondary outcomes: corticosteroid availability (injectable dexamethasone or betamethasone) and facility structural readiness. In SPA surveys, most countries did not assess corticosteroid availability within the maternal and newborn care section, except for the Afghanistan 2018-2019 survey. Alternatively, we used the availability of injectable corticosteroids in the section for medicines for non-communicable diseases as a proxy.

We assessed facility readiness to provide ACS in accordance with the 2022 WHO recommendations on ACS use. We identified 35 indicators from the SPA questionnaire, which were grouped into four readiness categories based on four of the five WHO criteria **(Appendix A. Supplemental Table 2)**. No indicators were identified for the second criterion (a high likelihood of preterm labor), as the diagnosis of imminent preterm labor typically relies on clinical symptoms and signs first. The first readiness category focused on the facility's ability to assess GA accurately, and we included only one indicator for this category (the presence of a functional ultrasound). The second readiness category included 4 indicators and covered the facility's ability to identify maternal infections. The third and fourth categories included 13 and 17 indicators and assessed the facility's readiness to provide adequate childbirth care and preterm newborn care, respectively. For each category, readiness indices were calculated by dividing the number of indicators available by the total number of indicators assessed, with higher percentages indicating higher readiness. An overall readiness index was calculated by averaging the readiness indices from four categories. This approach was chosen based on previous studies on facility readiness to implement health improvement interventions.(70, 71)

Statistical analysis

First, we presented descriptive statistics of ACS utilization, corticosteroid availability, and facility readiness indices, taking facility sampling weights into account. Results were stratified by three facility levels. Level 1 facilities only provided ANC and did not conduct deliveries; ANC was defined as the care that pregnant women receive before birth, including risk identification, prevention, and management of pregnancy-related health conditions, education, and health promotion.(72) Level 2 facilities performed normal deliveries but not Cesarean deliveries, while level 3 facilities performed Cesarean deliveries. Because Afghanistan mainly sampled hospitals, which differed substantially from other countries, it was reported separately. We excluded Afghanistan from the distribution of outcomes across countries and included it only in analyses within each facility level.

Second, we assessed the relationships between ACS use and, respectively, ACS availability and overall readiness indices at sub-national levels (e.g., regions in Ethiopia and provinces in DRC). This approach was driven by the hypothesis that facilities without corticosteroids or with low readiness might refer patients in need of ACS to nearby facilities. We averaged each of the three measures (ACS use, corticosteroid availability, and overall readiness index) for all facilities in each sub-national region. Lastly, we examined the differences in the overall readiness index between facilities that have ever and never used ACS by country. All analyses were performed using R.

2.3 Results

This study included 8669 facilities from ten surveys in nine countries. All surveys had a high response rate (median 94.9%), ranging from 88.8% in Afghanistan to 99.0% in Tanzania **(Appendix A. Supplemental Table 3)**.

The majority of facilities (88.9%, median; range 66.1% - 98.8%) provided maternal health care services and were included in our analyses **(Appendix A. Supplemental Table 3)**. The median sample size was 929 facilities (median; range 108 - 1500) **(Table 2)**. Among eight countries (excluding Afghanistan), 22.6% (median; range 7.1% - 88.7%) of facilities were urban. The proportion of facilities at different levels varied across countries. Across eight countries, one-third (median 32.0%) of the facilities were level 1 facilities that provided antenatal care, with Bangladesh having the largest proportion (76.2%) of level 1 facilities and the DRC having the smallest proportion (1.9%). The proportion of level 2 facilities was 59.4% (median), with Tanzania having the largest proportion (83.3%) and Bangladesh having the smallest proportion (19.5%). Only 6.2% (median) of facilities were level 3 facilities, ranging from 2.7% in Ethiopia to 26.5% of facilities in the DRC **(Table 2)**.

ACS utilization. ACS was underused across all countries. Excluding Afghanistan, the median ACS use was 10.7%, ranging from 6.7% of facilities in Bangladesh to 35.2% of facilities in the DRC that had ever administered ACS **(Figure 1a)**. In Afghanistan, 68.7% of facilities had administered ACS at the time of the survey. We did not find higher ACS use in surveys that were done more recently. While none of the level 1 facilities had provided ACS, ACS use increased by facility level **(Figure 1b)**. Within each level of facilities across nine countries, 21.6% (median, range 5.0% - 26.9%) of

level 2 facilities and 76.3% (median, range 52.7% - 90.3%) of level 3 facilities had administered ACS.

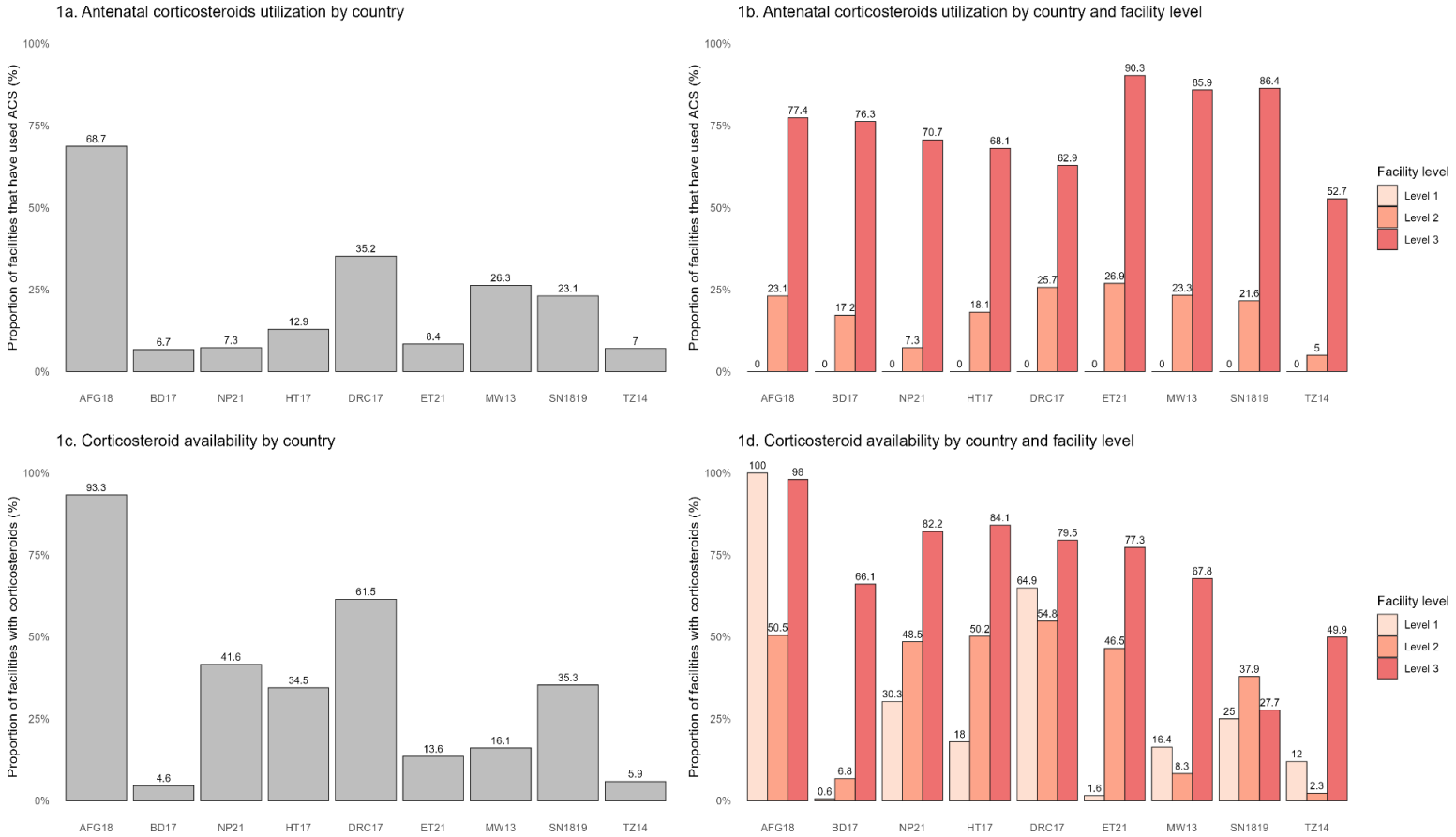
ACS availability. Corticosteroid availability was limited. Across eight countries, one-fourth of the facilities (median 25.3%, range 4.6% - 61.5%) had at least one valid corticosteroid (injectable dexamethasone or betamethasone) available at the time of the survey, while 93.3% of facilities in Afghanistan had it available **(Figure 1c)**. Corticosteroid availability generally increased by facility level within each country **(Figure 1d)**. Notably, significant gaps existed between corticosteroid availability and ACS utilization, particularly in level 2 facilities. Among level 2 facilities across nine countries, 46.5% (median) had injectable corticosteroids available, but 21.6% (median) had administered ACS **(Appendix A. Supplemental Figure 1)**.

Table 2. Characteristics of surveys and facilities included in the study

Country	Survey year	Number of facilities surveyed[1]	Number of facilities included in the analysis[2]	Urban location	Facility type		
					Level 1: Facilities that provide antenatal care	Level 2: Facilities that perform normal delivery	Level 3: Facilities that perform Cesarean section
		N = 9793 Median 1158 (range 142 - 1576)	**N = 8669** Median 929 (range 108 - 1500)	Median 22.6%[3] (range 7.1% - 88.7%)[3]	Median 32.0%[3] (range 1.9% - 76.2%)[3]	Median 59.4%[3] (range 19.5% - 83.3%)[3]	Median 6.2%[3] (range 2.7% - 26.5%)[3]
South Asia							
Afghanistan	2018-2019	142	108	107 (99.4%)	7 (4.1%)	10 (10.1%)	91 (85.9%)
Bangladesh	2017-2018	1524	1498	379 (7.1%)	676 (76.2%)	551 (19.5%)	271 (4.4%)
Nepal	2021	1576	1500	961 (53.2%)	693 (47.5%)	565 (47.1%)	242 (5.3%)
Caribbean							
Haiti	2017-2018	1007	929	340 (36.5%)	567 (61.0%)	255 (27.5%)	107 (11.5%)
Sub-Saharan Africa							
DRC	2017-2018	1380	1364	297 (22.0%)	10 (1.9%)	511 (71.6%)	843 (26.5%)
Ethiopia	2021-2022	1158	911	455 (18.2%)	261 (75.0%)	309 (22.3%)	341 (2.7%)
Malawi	2013-2014	977	645	119 (18.6%)	103 (16.5%)	471 (72.6%)	71 (10.9%)
Senegal	2018 and 2019	841	658	594 (88.7%)	65 (14.3%)	531 (78.6%)	62 (7.1%)
Tanzania	2014-2015	1188	1056	325 (19.1%)	104 (11.5%)	681 (83.3%)	271 (5.2%)

[1] A total of 625 facilities that were sampled had a sampling weight of zero, indicating non-response, refusal, or closure. Those facilities were not surveyed and were excluded.
[2] Only facilities that provided either antenatal care or delivery services (normal delivery or Cesarean section) were included in the analysis.
[3] The median and range were obtained across eight countries, excluding Afghanistan, because its survey used a remarkably different sampling strategy.

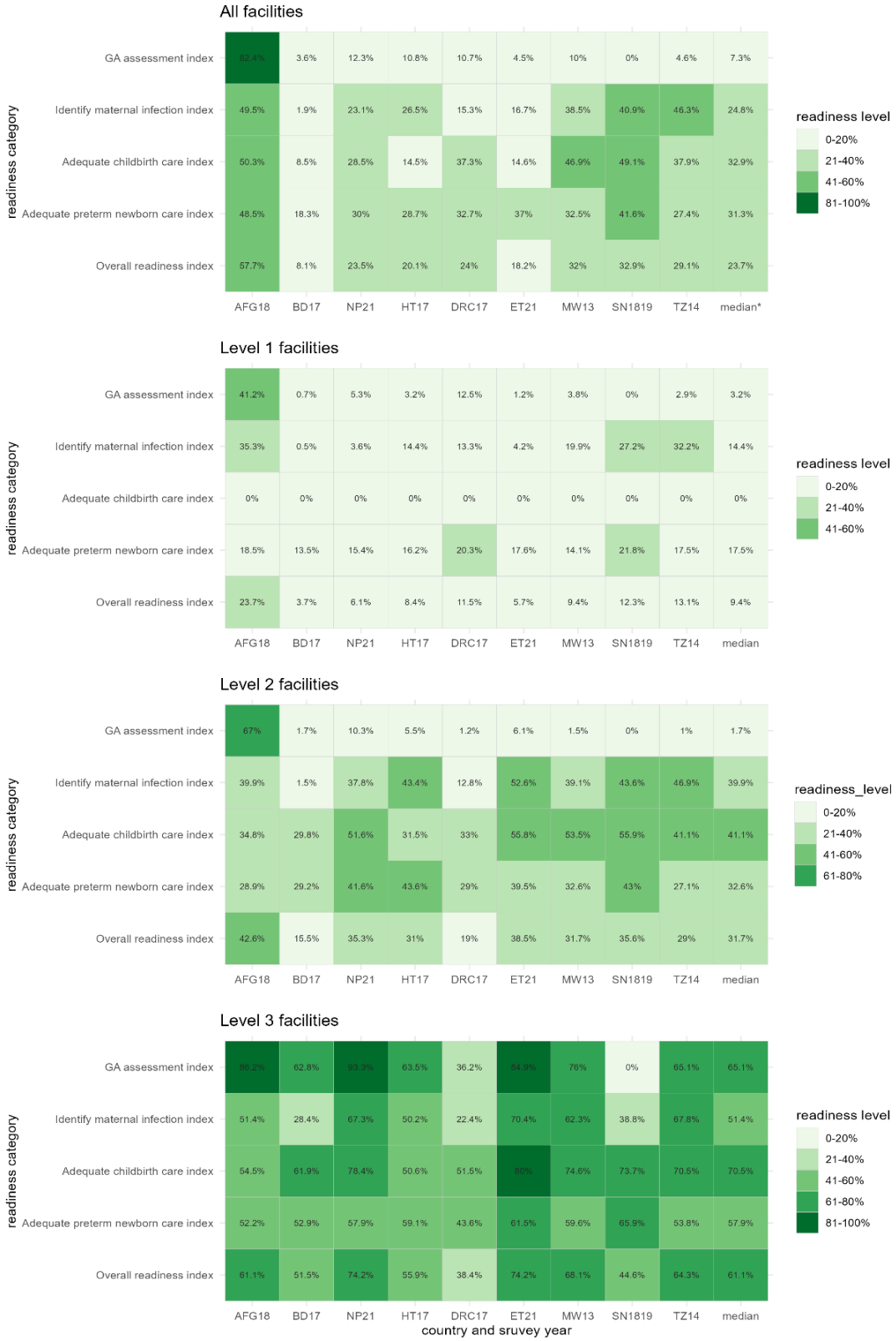
Figure 1a. Antenatal corticosteroids utilization by country, **Figure 1b.** Antenatal corticosteroids utilization by country and facility level, **Figure 1c**. Availability of at least one corticosteroid by country, **Figure 1d.** Availability of at least one corticosteroid by country and facility level



AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017-2018; DRC17: the Democratic Republic of the Congo 2017-2018; ET21: Ethiopia 2021-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015

Facility readiness. Readiness indices were low **(Figure 2)**. Only 22% of the facilities in the sample had an overall readiness index above 50%. Other than Afghanistan, overall readiness indices were low among the eight countries, ranging from 8.1% in Bangladesh to 32.9% in Senegal. Afghanistan had an overall readiness index of 57.7%. We did not see higher overall readiness indices in surveys conducted in more recent years. Also, overall readiness indices increased by facility level. Across four readiness categories among eight countries, facilities performed the worst in the ability to assess GA accurately, with a readiness index of 7.3% (median), followed by the ability to identify maternal infection (median, 24.8%), provide adequate preterm care (median 31.3%), and provide adequate childbirth care (median 32.9%). When delving into the details of specific indicators among the 35 indicators we identified, we found very limited availability for respiratory support-related equipment across countries in the readiness category of adequate preterm newborn care **(Appendix A. Supplemental Table 4, Supplemental Figures 2-5)**.

Figure 2. Facility readiness by country, readiness category, and facility level

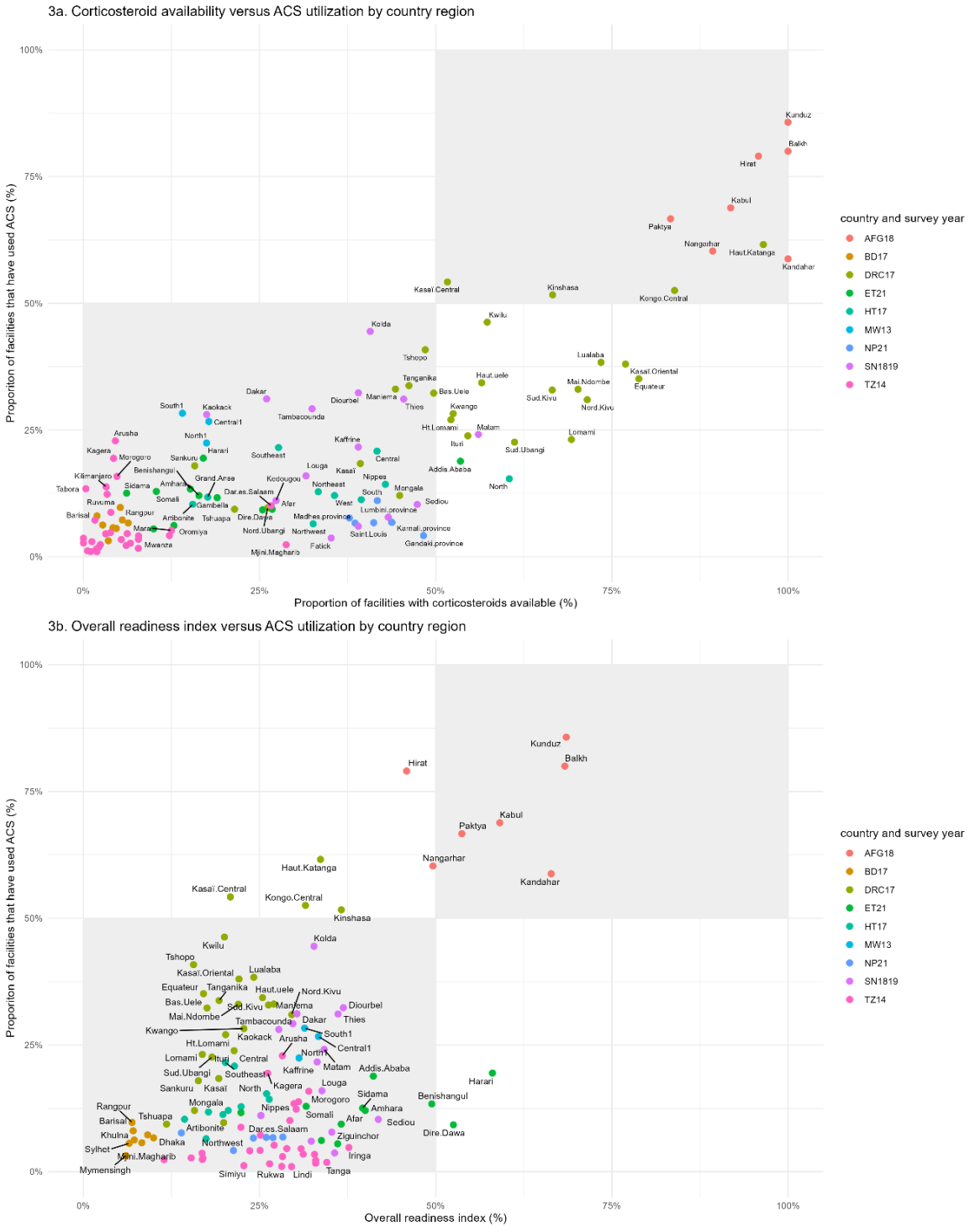


AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017-2018; DRC17: the Democratic Republic of the Congo 2017-2018; ET21: Ethiopia 20121-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015; median*: median across eight countries, excluding AFG18

ACS use, availability, and readiness at sub-national levels. At the sub-national level, positive associations were observed between corticosteroid availability and ACS use, as well as between overall readiness indices and ACS use **(Figures 3a and 3b)**. A few Ethiopian regions (Dire Dawa and Harari) had an average overall readiness index above 50% but low ACS use (<25%). In contrast, some regions of the DRC (Kasaï Central, Kongo Central, Kinshasa, and Haut-Katanga) had low overall readiness indices (<50%), but ACS use greater than 50% **(Figure 3b)**.

At the facility level, overall readiness indices differed between facilities that had ever and never provided ACS within each country **(Appendix A. Supplemental Figures 6-8)**. In most countries (Afghanistan, Bangladesh, DRC, Malawi, Senegal, and Tanzania), the median overall readiness index for facilities (level 2 and level 3) that had utilized ACS was higher than that for facilities that had never used it. In contrast, the results were reversed for Nepal, Haiti, and Ethiopia **(Appendix A. Supplemental Figure 6**).

Figure 3a. Corticosteroid availability versus ACS utilization by region, **Figure 3b.** Overall readiness indices versus ACS utilization by region



AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017; DRC17: the Democratic Republic of the Congo 2017-2018; ET21: Ethiopia 20121-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015

2.4 Discussion

This study assessed ACS use, corticosteroid availability, and structural readiness to implement the intervention appropriately based on international recommendations among 8,669 health facilities from nine LMICs. We had three major findings: 1) ACS was substantially underused, 2) corticosteroid availability was limited, and 3) facilities in these countries had low levels of readiness.

We found limited ACS use, with only one out of ten health facilities having administered ACS. However, it is challenging to compare our results with existing literature since previous research mostly measured ACS coverage among pregnant women who had preterm birth or antenatal exposure to ACS among preterm babies.(33-36, 38, 39) A WHO maternal and newborn health survey for 29 countries in 2011 found that 54% of women who gave birth at GA 26 to 34 weeks were given ACS, with the lowest use in Afghanistan (16%), Nepal (20%), and the DRC (16%).(38) Another analysis using the data from the 2015 Antenatal Corticosteroids Trial (ACT trial) showed an overall low ACS use in control clusters; in Kenya, only 3.8 % of pregnant women of infants born with birthweight less than the 5^{th} percentile, a proxy for preterm births, received ACS.(39) Our findings add crucial value to understanding the status of ACS utilization at the facility level. In addition, we found that only one-fourth of the facilities in the sample had injectable dexamethasone or betamethasone. While dexamethasone is on the WHO List of Essential Medicines, its suboptimal availability remains a barrier to ACS uptake in countries that might benefit from this intervention the most, suggesting the need to maintain supply chain stability and medicine stock.(73) Notably, we observed significant gaps between corticosteroid availability and ACS utilization, highlighting

great potential to prioritize readiness improvement initiatives among facilities where injectable corticosteroids are available.

The locations for administering ACS are crucial. Two landmark studies on the effects of ACS in LMICs presented conflicting results, indicating the importance of healthcare settings in implementing this intervention (74, 75). The 2015 ACT trial, a cluster randomized trial of a multifaceted intervention to promote ACS use in six countries, unexpectedly found increased neonatal deaths and suspected maternal infections among intervention clusters.(74) On the contrary, the WHO Antenatal Corticosteroids for Improving Outcomes in Preterm Newborns Trial (ACTION-I trial) in 2020, an RCT in five countries, showed ACS reduced neonatal deaths without increasing maternal infections.(75) These contradictory findings could partially be explained by the different settings of these two trials: the ACT trial was done in all levels of care, including clinics and primary care centers, whereas the ACTION-I trial included secondary or tertiary hospitals.(75) The drastically different findings emphasized the importance of healthcare settings—more precisely, the readiness level of facilities required for safe and effective use of ACS. Our study offered a strategy for measuring facility readiness to implement this life-saving intervention. However, recommendations on what levels of facilities should administer ACS need to be made carefully. Countries also have different guidelines regarding the levels of care at which ACS should be given. One policy analysis on ACS use in Africa found that ACS was recommended at lower levels of care before referral in Ethiopia and Tanzania, but the DRC and Malawi only allowed ACS use in hospitals.(30) Assuming essential equipment, medicines, and trained staff are available, some level 2 and level 3 facilities with high levels of readiness that

have never provided ACS should be targeted for encouraging ACS use. Also, our sub-national level analyses found that some provinces in the DRC with low overall readiness (<50%) frequently administered ACS. Policymakers should ensure that ACS is delivered in well-equipped settings.

Another critical issue centers around the different aspects of facility readiness. Our readiness index was developed based on the WHO criteria. However, it is debatable, first, whether some criteria could be met across facility levels, and second, whether facilities must meet *all* criteria to safely and effectively administer ACS. For example, ultrasound examination in early pregnancy is the gold standard for GA assessment. However, we found that only 7.3% (median across eight countries, range 0.2% to 12.3%; 82.4% for Afghanistan) of maternal care facilities had a functional ultrasound. Access to obstetric ultrasound for GA dating is limited in LMICs despite its increasing use.(24, 29). In this case, GA dating should occur early in pregnancy, while ACS use occurs later in pregnancy. Thus, the decision to administer ACS should not be based on the ultrasound availability in place but on the availability of accurate GA assessment (which may come from care obtained at another facility). Another crucial element for adequate preterm newborn care from the WHO recommendations is non-invasive respiratory support. However, this recommendation might exclude most preterm newborns that will likely benefit from ACS exposure because they usually lack access to such respiratory support at the primary level of care in LMICs.(76) A similar concern applies to the criteria for adequate childbirth care, referring to nine Comprehensive Emergency Obstetric and Newborn Care signal functions, including blood transfusions and Cesarean sections.

Again, it is debatable whether a facility can give ACS only when it can do blood transfusions.

Our study had several strengths. This is the first study to comprehensively assess ACS utilization, corticosteroid availability, and structural readiness to provide ACS at the facility level. We included data from multiple countries to understand the landscape of ACS use and identified policy directions for areas with a high burden of preterm births. Nonetheless, our study has a few limitations. First, sampling strategies and survey years varied across countries spanning nine years. National guidelines on ACS use also differed by country. We caution careful interpretations for any attempts to make cross-country comparisons. Second, some readiness indicators served as proxies because SPA surveys do not assess the availability of injectable corticosteroids and ultrasound in the maternal and newborn care section. We also used the availability of rapid diagnostic tests for HIV and syphilis to estimate facilities' ability to detect maternal infections. This approach might overestimate or underestimate the true availability or readiness.

Antenatal corticosteroid utilization in LMICs has gained tremendous international attention as its health benefits at the population level could be profound.(37, 77-80) ACS is promising to improve neonatal survival, but it should never be used as a "just-in-case" intervention.(18) It must be given to the right people (pregnant women at risk of imminent preterm labor and without maternal infections), at the right time (the specified GA window), and in the right place (settings that are adequately equipped and ready to provide quality maternal and newborn care). Future research and programs should operationalize readiness measurement, enhance facility readiness to administer ACS and encourage ACS uptake among well-equipped facilities.

Chapter 3: Factors affecting antenatal corticosteroid use in low- and middle-income countries: facility characteristics, structural readiness, and past performance of CEmONC signal functions

Abstract

Background

Antenatal corticosteroids (ACS) utilization is disproportionately limited in low- and middle-income countries where most global preterm newborns who could benefit from this intervention are born. Understanding the factors affecting ACS use is crucial for improving its uptake. This study aimed to investigate facility-level factors associated with ACS use in low-resource countries.

Methods

We used data from ten Service Provision Assessment surveys across nine countries. We restricted the sample to facilities that provided delivery services. Our primary outcome was recent ACS use, defined as having administered ACS within the past three months before the survey. We conducted mixed-effect log binomial regressions, with country as a fixed effect and sub-national divisions as random intercepts, to explore the association between recent ACS use and facility characteristics, injectable corticosteroids and ultrasound availability, facility structural readiness, and past performance of nine Comprehensive Emergency Obstetric and Newborn Care (CEmONC) signal functions.

Results

This study included 6183 facilities from nine countries. Across eight countries with nationally representative data, only 22.7% (median, range 4.0% to 27.4%) of facilities had used ACS recently. Urban facilities had a 21% higher likelihood of recent ACS use

(95% CI 6% to 38%) than rural facilities. Corticosteroid availability in the facility was associated with a 14% higher likelihood of recent ACS use (95% CI 1%–29%). Facilities in the highest readiness tertile were more likely to have recent ACS use than those in the lowest (RR 1.91, 95% CI 1.58–2.30). Each CEmONC signal function, except for vaginal deliveries, was significantly associated with recent ACS use, with neonatal resuscitation having the largest effect (RR 2.62, 95% CI 1.93–3.55).

Conclusion

Facilities that had performed CEmONC services were more likely to administer ACS, highlighting the importance of provider knowledge, skills, and competence in managing obstetric and newborn emergencies for effective ACS provision.

3.1 Introduction

Administering antenatal corticosteroids (ACS) to pregnant women with a high likelihood of preterm labor at gestational age (GA) 24 to 34 weeks is recommended by the World Health Organization (WHO) and major medical associations.(15-18) By accelerating fetal lung maturity, this intervention effectively reduces neonatal mortality and morbidity, particularly respiratory complications.(10) ACS use has been encouraged in low- and middle-income countries (LMICs), where 80% of preterm births occur globally.(3) However, its uptake remains limited in these countries. The WHO Born Too Soon report suggested prioritizing existing highly effective interventions, including ACS.(81) The International Federation of Gynecology and Obstetrics also listed ACS use among its PremPrep-5 initiative of effective and low-cost interventions to improve preterm outcomes.(76) Therefore, a thorough understanding of factors associated with low ACS use in LMICs is urgently needed.

Factors affecting ACS use in low-resource countries are complex.(29) These factors can be primarily grouped into several levels. At the national level, guidelines and policies on ACS use are fundamental. Previous studies have identified limited, unclear, or inconsistent national guidelines as major obstacles.(27, 29-31). The 2023 WHO Model List of Essential Medicines includes dexamethasone, one of the two antenatal corticosteroids, under medicines for reproductive health and perinatal care.(73) However, a study assessing barriers to ACS use found that the absence of ACS from National Essential Medicines Lists was a significant barrier in half of the twelve African and Asian countries examined.(31) Another policy analysis for seven sub-Saharan countries showed that although most countries included ACS use in their national protocols, details on

accurate GA assessment and criteria for identifying eligible women were often unclear.(30) At the facility level, poor healthcare quality—attributed to various factors, such as insufficient medicines and equipment for maternal and newborn care and lack of integration of ACS into regular perinatal care—hinders appropriate ACS use.(29, 31) At the individual level, providers' knowledge gaps in ACS use and identifying preterm labor prevent its proper use.(28, 29, 82). Pregnant women, also at the individual level, may lack access to this intervention due to their underlying socioeconomic constraints; among those who have access, their perceptions of risks and benefits also affect ACS use.(29) Hence, untangling the complexity of factors affecting ACS use is critical for identifying priority actions.

Appropriate settings for safe and effective ACS use are challenging to define. The WHO recommends giving ACS when the following conditions are met: accurate GA assessment, a high likelihood of imminent preterm labor, no clinical maternal infections, and adequate childbirth and preterm newborn care available.(17) However, implementing some of these recommendations in low-resource settings poses practical challenges, raising discussions in the global community.(23, 24, 76) Facilities that can perform Comprehensive Emergency Obstetric and Newborn Care (CEmONC) are considered appropriate settings for administering ACS.(17, 31) Basic Emergency Obstetric and Newborn Care (BEmONC) includes a set of seven signal functions; CEmONC includes all BEmONC services and adds two additional functions: Cesarean section and blood transfusion.(83) This set of health services defines the capability of a facility to manage obstetric and newborn emergencies (84, 85), and health facilities in LMICs are designated as a BEmONC or CEmONC facility based on their capabilities.(83) It is

important to note that many pregnant women who present with obstetric emergencies and require CEmONC services are likely to deliver preterm babies. While managing maternal emergencies, it is also crucial for providers to take a holistic approach and implement interventions that improve preterm outcomes simultaneously, such as administering antenatal corticosteroids. A study comparing indices to measure facility readiness noted that the past performance of CEmONC signal functions reflected a certain or minimally required level of inputs available and provider competence in managing obstetric emergencies.(86) However, no studies have examined the relationships between health facilities' abilities to perform CEmONC signal functions and ACS utilization.

This study aimed to assess the complex relationships among ACS utilization, facility characteristics, corticosteroid and ultrasound availability, structural readiness, and the past performance of CEmONC signal functions.

3.2 Methods

Study sample

We used the same data as the first paper in this dissertation (Chapter 2). Our sample included three countries from Asia (Afghanistan 2018-2019, Bangladesh 2017-2018, Nepal 2021), one from the Caribbean (Haiti 2017-2018), and five from sub-Saharan Africa (the Democratic Republic of Congo (DRC) 2017-2018, Ethiopia 2021-2022, Malawi 2013-2014, Senegal 2018 and 2019, and Tanzania 2014-2015). Most surveys employed a stratified random sampling strategy; some were national censuses. Unlike other surveys, the Afghanistan 2018-2019 survey primarily sampled urban hospitals. Since Senegal implemented continuous SPA over five consecutive years (69),

we merged the 2018 and 2019 Senegal SPA data to achieve a comparable sample size to other surveys and to be consistent with the methods in Chapter 2. The SPA questionnaire has five instruments, of which this study used data from the inventory instrument. We restricted our analyses to facilities that provided delivery services (normal delivery and/or Cesarean sections).

Measures

The primary outcome was recent ACS use at the facility level, defined as having administered ACS within the past 3 months before the survey. Administering ACS within this timeframe was believed to reflect the facility's functionality at the time of the survey.(83) We identified three main groups of facility-level factors to explore their relationships with recent ACS use. First, we included facility characteristics such as location (urban versus rural) and managing authority types. Because surveys used different groupings for managing authority types, we developed a standardized categorization with four groups (public, private for-profit, private not-for-profit/mission or faith-based, and others) **(Appendix B. Supplemental Table 5)**. Second, we identified 28 items essential for safe and effective ACS use based on the WHO recommendations, which could be grouped into four major categories: equipment, diagnostics, medicines and commodities, and guidelines (17); we used these items to develop facility structural readiness **(Appendix B. Supplemental Table 6)**. Based on the number of available items, we developed facility readiness tertiles that were country-specific to account for the vastly different contexts and survey years spanning from 2013 to 2021. A functional ultrasound was included separately because access to ultrasound in early pregnancy is crucial for accurate GA dating. The measure of a functional ultrasound was based on its

availability in a health facility in general. The availability of at least one valid corticosteroid (injectable betamethasone or dexamethasone) was also included separately. However, we used its availability in medicines for non-communicable diseases as a proxy because SPA does not survey corticosteroid availability in the maternal and newborn care section. We adopted the same approach as the first paper (Chapter 2). Additionally, we constructed several binary variables that indicated having at least one medical doctor, midwife, obstetrician/gynecologist, pediatrician, or specialist. Countries surveyed staff types in various ways of grouping. All countries surveyed the availability of medical doctors and midwives. Six countries (Afghanistan, Haiti, DRC, Malawi, Senegal, and Tanzania) assessed the availability of specialists in general but not specifically obstetricians/gynecologists or pediatricians. Conversely, three countries (Bangladesh, Nepal, and Ethiopia) collected data on the availability of obstetricians/gynecologists and pediatricians but not specialists. We used this data to construct a binary variable indicating at least one specialist. The development of staff variables is detailed in **Appendix B. Supplemental Table 7**. Lastly, we included each CEmONC signal function, defined as having ever performed each of them before the survey, in the model.

Statistical analysis

In reporting descriptive statistics, we presented the proportion of facilities that had used ACS within the past three months before the survey by country and facility characteristics. We also reported the proportion of facilities that had performed each CEmONC signal function. In presenting outcome distribution across countries, we presented the median and range from eight countries, excluding Afghanistan, because of its different sampling strategy. To assess factors associated with recent ACS use, we

conducted mixed-effect log binomial regressions to report adjusted relative risks (RR), including country as a fixed effect and sub-national regions within each country as random intercepts. We performed bivariate regressions that also included a fixed effect of country and random intercepts of sub-national divisions. Modified Poisson regressions (with a robust standard error) were conducted to explore country-specific associations for each country.(87) This approach was chosen to obtain effect measures of relative risks and ensure model convergence with smaller sample sizes compared to the pooled regression models. We did not include sub-national divisions as random intercepts in within-country regressions. All analyses were performed using R.

3.3 Results

This study included 6,183 facilities of nine LMICs from ten SPA surveys. Across eight countries (excluding Afghanistan), about one-third of facilities (median 30.5%; range 14.6% to 89.6%) were in urban areas, whereas most (99.4%) facilities in Afghanistan were urban **(Table 3)**. Most facilities were public (median 83.6%; range 43.1% to 91.6%), followed by private for-profit facilities (median 9.8%; range 3.6% to 24.7%) and private not-for-profit/mission or faith-based facilities (median 8.7%; range 0.8% to 27.2%). Staffing of specialized professionals was generally suboptimal. Across eight countries, fewer than one-fifth or one-fifth of facilities had at least one medical doctor (median 17.3%; range 6.1% to 76.5%) or midwife (median 20.2%; range 7.7% to 95.9%). In Afghanistan, 39.6% of the facilities had at least one medical doctor, and most (93.4%) had at least one midwife. For the three countries that assessed the availability of obstetricians/gynecologists and pediatricians, fewer than 10% of the facilities had at least one obstetrician/gynecologist (median 8.9%; range 7.5% to 16.7%) and pediatrician

(median 7.5%; range 5.1% to 12.5%). Similarly, only 9.1% (median; range 3.1% to 70.6%) of the facilities among the six countries that surveyed specialists had at least one specialist.

Table 3. Characteristics of surveys and facilities included in the analysis of 9 LMICs

Facility characteristics	Median (range) [1]	Country and survey year								
		Afghanistan 2018-2019 (n=101)	Bangladesh 2017-2018 (n=822)	Nepal 2021 (n=807)	Haiti 2017-2018 (n=362)	DRC 2017-2018 (n=1354)	Ethiopia 2021-2022 (n=650)	Malawi 2013-2014 (n=542)	Senegal 2018& 2019 (n=593)	Tanzania 2014-2015 (n=952)
Location										
Urban (%)	30.5% (14.6% - 89.6%)	100 (99.4%)	326 (21.9%)	485 (43.3%)	145 (40.0%)	293 (21.8%)	391 (39.0%)	82 (15.1%)	542 (89.6%)	278 (14.6%)
Managing authority type (%)										
Public	83.6% (43.1% - 91.6%)	14 (8.2%)	682 (83.6%)	631 (91.6%)	156 (43.1%)	823 (61.9%)	560 (91.3%)	356 (65.5%)	537 (85.3%)	692 (83.6%)
Private for-profit	9.8% (3.6% - 24.7%)	71 (71.4%)	104 (11.6%)	154 (7.5%)	89 (24.7%)	154 (17.9%)	75 (7.9%)	25 (4.9%)	37 (12.1%)	70 (3.6%)
Private not-for-profit/mission or faith-based	8.7% (0.8% - 27.2%)	16 (20.4%)	36 (4.9%)	22 (0.8%)	52 (14.3%)	377 (20.2%)	15 (0.9%)	148 (27.2%)	19 (2.6%)	180 (12.5%)
Others	0 % (0% - 17.9%)	0 (0%)	0 (0%)	0 (0%)	65 (17.9%)	0 (0%)	0 (0%)	13 (2.5%)	0 (0%)	10 (0.3%)
Staff (%)										
Has at least one medical doctor	17.3% (6.1% - 76.5%)	56 (39.6%)	344 (27.1%)	166 (7.1%)	277 (76.5%)	852 (31.1%)	431 (23.2%)	59 (10.8%)	138 (11.3%)	238 (6.1%)
Has at least one midwife	20.0% (7.7% - 95.9%)	97 (93.4%)	121 (8.6%)	176 (7.7%)	277 (76.5%)	233 (7.9%)	252 (9.3%)	520 (95.9%)	461 (74.3%)	577 (30.6%)
Has at least one obstetrician or gynecologist[2]	8.9% (7.5% - 16.7%)	-	213 (16.7%)	196 (8.9%)	-	-	191 (7.5%)	-	-	-
Has at least one pediatrician[2]	7.5% (5.1% - 12.5%)	-	164 (12.5%)	168 (7.5%)	-	-	144 (5.1%)	-	-	-
Has at least one specialist[2]	9.1% (3.1% - 70.6%)	86 (70.6%)	-	-	165 (45.5%)	107 (3.3%)	-	31 (5.7%)	89 (12.5%)	133 (3.1%)

[1] Median and range were obtained from eight countries excluding Afghanistan.
[2] Only Bangladesh 2017-2018, Nepal 2021, and Ethiopia 2021-2022 surveyed the number of obstetricians or gynecologists, and pediatricians. Other countries surveyed the number of specialists but did not survey specific staff types.

Recent ACS use. The proportions of facilities that had used ACS within the past 3 months varied, ranging from 4.0% in Tanzania to 27.4% in Ethiopia, with a median of 22.7% **(Table 4)**. Afghanistan had 59.4% of the facilities that used ACS recently. Recent ACS use also differed by facility characteristics **(Table 4)**. Urban facilities had more recent ACS use versus rural facilities (44.5% versus 21.1%). Facilities with injectable corticosteroids and a functional ultrasound were more likely to use ACS in the past three months compared to those without. The proportion of facilities that had recently used ACS increased by readiness tertile: 14.6% for the lowest tertile, 21.9% for the middle, and 48% for the highest. Facilities with at least one medical doctor, midwife, or specialist were more likely to administer ACS recently than those without: 56.5% versus 13.2%, 38.8% versus 25.1%, 61.8% versus 23.4%, respectively. In addition, higher proportions of facilities that had provided any of the CEmONC services used ACS recently than those that had never performed the signal function.

CEmONC signal functions past performance. One-fifth of the facilities (19.0%, median of eight countries) had ever performed all nine CEmONC signal functions, compared to two-fifths (40.6%) in Afghanistan. Across eight countries and among nine signal functions, Cesarean sections and the provision of blood transfusions were performed in the smallest proportion of facilities since only CEmONC facilities were designated for these two services. Among seven BEmONC signal functions, the provision of parenteral anticonvulsant was performed in the smallest proportion of facilities (median 37.6%), while oxytocin administration was performed in the largest proportion (median 94.3%) **(Figure 4)**. Ethiopia was the only country among the eight where more than 80% of the facilities had performed each BEmONC signal function.

Factors affecting recent ACS use. **Table 4** details the results of mixed-effect log binomial regressions, showing facility characteristics, structural readiness, and past performance of CEmONC are associated with recent ACS use. Urban facilities had 21% higher recent ACS use than rural ones (RR 1.21, 95% CI 1.06–1.39). Private for-profit facilities and private not-for-profit facilities, compared to public facilities, were associated with lower recent ACS use, although both types showed higher recent ACS use in bivariate regressions. The availability of injectable corticosteroids and ultrasound were associated with increased recent ACS use by 14% (RR 1.14, 95% CI 1.01–1.29) and 26% (RR 1.26, 95% CI 1.10–1.45), respectively. Facilities in the highest readiness tertile had 91% higher recent ACS use than those in the lowest (RR 1.91, 95% CI 1.58–2.30). Staffing types affected recent ACS use: facilities with at least one medical doctor, midwife, or specialist had increased recent ACS use by 43% (RR 1.43, 95% CI 1.22–1.67), 23% (RR 1.23, 95% CI 1.08 to 1.40), and 21% (RR 1.21, 95%CI 1.05–1.39), respectively. Lastly, past experience in performing each CEmONC signal function, except for assisted vaginal delivery, was significantly associated with more recent ACS use, with performing neonatal resuscitation having the largest effect (RR 2.62, 95%CI 1.93–3.56). Country-specific regressions were detailed in **Appendix B. Supplemental Table 8.**

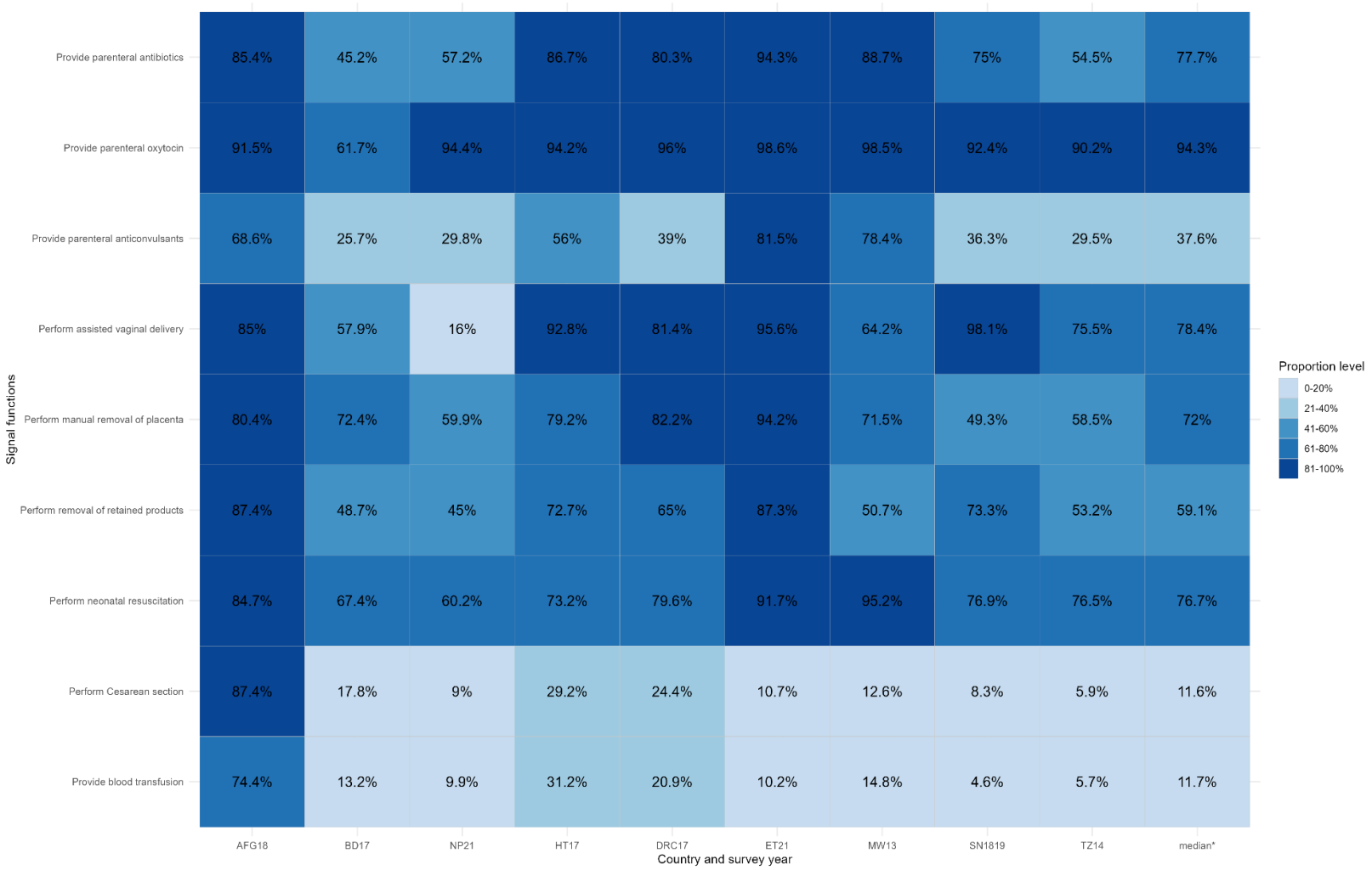
Table 4. Mixed effect log binomial regression models of recent antenatal corticosteroid utilization

	Proportion of facilities with recent ACS use (%)[1]	Bivariate regrssion[2]			Multivariate regression[3]		
		relative risk (RR)	95% CI	p-value	Adjusted relative risk (aRR)	95% CI	p-value
Country							
Afghanistan 2018-2019	59.4%	2.11	1.26 – 3.52	**0.004**	0.89	0.53 – 1.50	0.661
Nepal 2021	8.2%	0.45	0.28 – 0.71	**0.001**	0.34	0.22 – 0.51	**<0.001**
Haiti 2017-2018	23.6%	0.59	0.37 – 0.93	**0.022**	0.32	0.21 – 0.51	**<0.001**
DRC 2017-2018	22.2%	1.05	0.74 – 1.49	0.795	0.76	0.53 – 1.07	0.113
Ethiopia 2021-2022	27.4%	1.53	1.01 – 2.31	**0.043**	0.80	0.54 – 1.18	0.257
Malawi 2013-2014	21.5%	0.44	0.26 – 0.73	**0.002**	0.53	0.32 – 0.87	**0.012**
Senegal 2018 and 2019	23.4%	0.66	0.44 – 0.99	**0.047**	0.95	0.64 – 1.42	0.810
Tanzania 2014-2015	4.0%	0.35	0.24 – 0.51	**<0.001**	0.25	0.17 – 0.36	**<0.001**
Bangladesh 2017-2018	23.2%	*ref*			*ref*		
Facility characteristics							
Location							
Urban *versus* rural[4]	44.5% *versus* 21.1%	3.09	2.77 – 3.45	**<0.001**	1.21	1.06 – 1.38	**0.004**
Managing authority type							
Public	28.0%	*ref*			*ref*		
Private for-profit	43.0%	1.51	1.32 – 1.74	**<0.001**	0.78	0.66 – 0.91	**0.002**
Private not-for-profit/faith or mission-based	37.8%	1.48	1.29 – 1.70	**<0.001**	0.85	0.73 – 0.99	**0.039**
Others	19.5%	1.00	0.59 – 1.68	0.995	0.99	0.58 – 1.69	0.975
Structural readiness							
Corticosteroid availability *versus* unavailability[5]	45.1% *versus* 18.9%	2.72	2.43 – 3.04	**<0.001**	1.14	1.01 – 1.29	**0.032**
Ultrasound availability *versus* unavailability[5]	60.9% *versus* 19.3%	5.00	4.48 – 5.57	**<0.001**	1.26	1.10 – 1.45	**0.001**
Readiness tertile[6]							
High	48.0%	7.52	6.37 – 8.89	**<0.001**	1.91	1.58 – 2.30	**<0.001**
Medium	21.9%	2.27	1.91 – 2.70	**<0.001**	1.23	1.03 – 1.48	**0.021**
Low	14.6%	*ref*			*ref*		
Staffing[7]							
At least one medical doctor *versus* no medical doctor[8]	56.5% *versus* 13.2%	5.99	5.33 – 6.74	**<0.001**	1.43	1.22 – 1.67	**<0.001**
At least one midwife *versus* no midwife[8]	38.8% *versus* 25.1%	3.17	2.84 – 3.55	**<0.001**	1.23	1.08 – 1.40	**0.002**
At least one specialist *versus* no specialist[8]	61.8% *versus* 23.4%	4.37	3.91 – 4.90	**<0.001**	1.21	1.05 – 1.39	**0.009**
CEmONC signal functions[9]							
Ever provide parenteral antibiotics *versus* never	37.8% *versus* 6.1%	7.18	5.70 – 9.05	**<0.001**	1.48	1.15 – 1.90	**0.002**
Ever provide parenteral oxytocin *versus* never	33.1% *versus* 5.5%	8.73	5.80 – 13.14	**<0.001**	1.77	1.15 – 2.73	**0.010**
Ever provide parenteral anticonvulsants *versus* never	46.2% *versus* 11.5%	5.40	4.75 – 6.14	**<0.001**	1.65	1.43 – 1.91	**<0.001**
Ever perform assisted vaginal delivery *versus* never	37.1% *versus* 12.6%	3.44	2.91 – 4.06	**<0.001**	1.12	0.93 – 1.34	0.224
Ever perform manual removal of placenta *versus* never	38.2% *versus* 7.2%	5.62	4.57 – 6.91	**<0.001**	1.98	1.58 – 2.47	**<0.001**
Ever perform removal of retained products *versus* never	39.8% *versus* 11.8%	3.74	3.24 – 4.32	**<0.001**	1.39	1.19 – 1.63	**<0.001**
Ever perform neonatal resuscitation *versus* never	36.7% *versus* 4.4%	9.46	7.06 – 12.66	**<0.001**	2.62	1.93 – 3.55	**<0.001**
Ever perform Cesarean sections *versus* never	63.5% *versus* 13.1%	8.01	7.12 – 9.01	**<0.001**	1.85	1.53 – 2.24	**<0.001**
Ever provide blood transfusion *versus* never	63.8% *versus* 15.1%	6.69	5.99 – 7.47	**<0.001**	1.37	1.16 – 1.63	**<0.001**

[1] Recent ACS use was defined as using ACS within the past 3 months. For each country, the proportions were calculated considering facility sampling weight. [2] Risk ratios (RR) were derived from bivariate regressions that included each independent variable separately, country fixed effects, and sub-national divisions as random intercepts. [3] Adjusted risk ratios (aRR) were derived from mixed

effect log binomial regression model that included all independent variables, country fixed effects, and sub-national regions as random intercepts. [4] Rural is the reference level. [5] Unavailability is the reference level. [6] Readiness tertiles refer to country-specific readiness tertiles, calculated by the available numbers of equipment, diagnostics, medicines and commodities, and guidelines.
[7] These binary variables indicate facilities having at least one medical doctor, midwife, or specialist, which were constructed based on the surveyed staff types for each SPA. [8] No medical doctor, no midwife, or no specialist is the reference level. [9] Facilities that never performed each CEmONC signal function are the reference level.

Figure 4. Proportion of facilities that have performed nine Comprehensive Emergency Obstetric and Newborn Care signal functions



AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017-2018; DRC17: the Democratic Republic of Congo 2017-2018; ET21: Ethiopia 20121-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015; median*: median across eight countries except Afghanistan

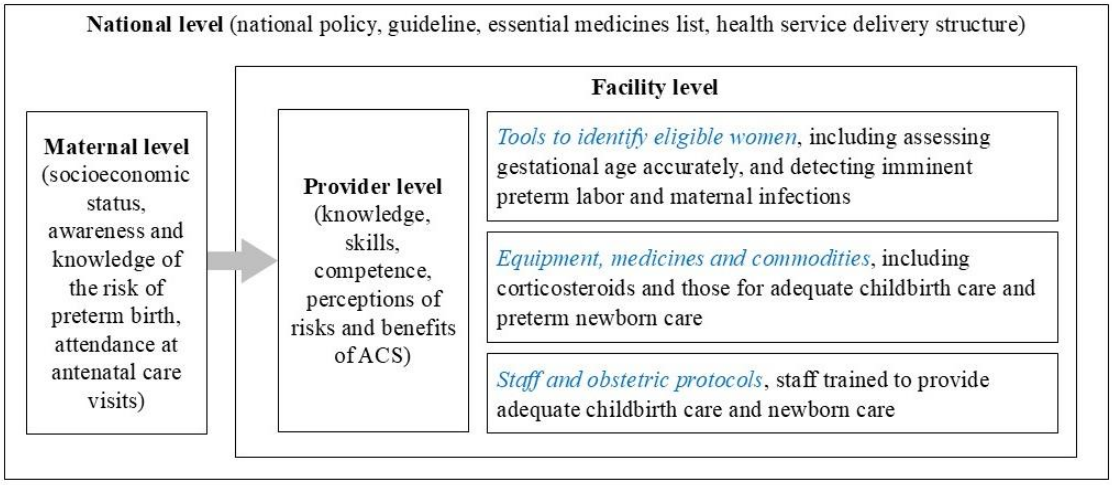
3.4 Discussion

Our study showed the complex relationships between ACS utilization and facility-level factors. We found that recent ACS use was significantly higher in urban facilities, facilities with injectable corticosteroids and ultrasound available, facilities with the highest level of readiness, and facilities that had performed CEmONC services.

A consistent corticosteroid stock is fundamental for promoting ACS use.(88, 89) In our first paper (Chapter 2), we found that only one-fourth of the facilities that provided antenatal care or delivery services in the same eight countries (excluding Afghanistan) had injectable corticosteroids available. Notably, we found a relatively small effect of corticosteroid availability (RR 1.14). As we used the availability of corticosteroids under the medicines for non-communicable diseases as a proxy, this approach might have overestimated their availability in maternal care. Thus, the effect size, while still statistically significant, is not as large as expected. The phenomenon might be explained by the idea that corticosteroid unavailability only partially contributed to the barrier to proper ACS use. In other words, while the availability of corticosteroids is essential, it does not guarantee their use. Our first paper (Chapter 2) also revealed gaps between corticosteroid availability and ACS use. We suspect that the effect of corticosteroid availability might be offset by other factors, such as providers' insufficient knowledge; well-trained providers may help facilitate stable medicine availability. Providers play a critical role in effective ACS utilization, including their awareness and knowledge of ACS, abilities to identify eligible women, and their perceived risks and benefits of ACS.(26, 28, 82, 88, 90) Similarly, the concern about the gap between availability and utilization also applies to facility readiness, meaning that high structural readiness does

not always translate into good clinical practices; for example, the volume of delivery service at a facility is related to its provision of services for managing obstetric emergencies.(91) To triangulate factors affecting ACS use, we proposed a framework for effective and safe ACS use at four levels **(Figure 5)**.

Figure 5. Framework for safe and effective antenatal corticosteroid utilization at four levels



While we found an association between ultrasound availability and recent ACS use, the effect size is relatively small, and the interpretation requires caution. First, ultrasound in early pregnancy, the gold standard for accurate GA dating, is uncommon in low-resource countries. Although its use is increasing in these countries (92), the first study in Chapter 2 showed that only 7.3% of facilities in eight LMICs had a functional ultrasound at the time of the survey. A Bangladesh household survey of 700 women found that only 11% received an ultrasound examination in the first trimester.(93) Another critical point is that many women in LMICs initiate their antenatal care late (94, 95), resulting in missed opportunities. The prevalence of early antenatal care visits, defined as initiating before 14 weeks of gestation, was only 24.0% in LMICs versus

81.9% in high-income countries.(94) The limited ultrasound availability and late presentation to antenatal care might partly explain the small effect size in our findings. Additionally, the ultrasound measurement we used only reflected its availability at the time of the survey, which may not fully represent its availability during women's first antenatal care visits, whether in the same facility or another.

Notably, this study identified strong associations between CEmONC signal functions and recent ACS use. There are a few potential explanations. First, CEmONC signal functions are meant to manage obstetric emergencies, which often involve a high likelihood of preterm birth. In these cases, providers should adopt a comprehensive approach to both save mothers' lives and improve preterm newborn outcomes, including ACS administration to eligible women. For example, studies have demonstrated the benefits of administering ACS to women with severe preeclampsia.(96, 97) Second, this finding highlights the importance of provider knowledge, skills, and competence. The effect sizes for some CEmONC signal functions (RR 2.62 for neonatal resuscitation, RR 1.98 for performing manual removal of placenta, and 1.85 for performing Cesarean sections) are much larger than that for corticosteroid availability (RR 1.14). In other words, by controlling all other factors, facilities with providers who have performed neonatal resuscitations are much more likely to administer ACS. This finding suggests that past performance of CEmONC signal functions reflects two critical aspects: first, providers' knowledge, skills, and competence to perform the services, and second, the availability of a minimal level of medicines and equipment – these two together are crucial for delivering effective care; missing either will not work.(86) Our findings have strong policy implications. Policymakers should prioritize provider training in emergency

obstetric care while improving facility readiness and creating environments that encourage good clinical practice because in-service training alone does not deliver long-lasting effects.(98)

Our study has a few limitations. First, the countries in our sample differed in many aspects.(99) For example, national guidelines about ACS use vary. Some countries, such as Tanzania and Ethiopia, recommend administering ACS at the primary level of care, followed by referrals.(100-102) We recommend careful interpretations in any attempt to compare across countries. Second, there is a temporal discrepancy between corticosteroid availability and recent ACS use, with the former measured at the time of the survey and the latter defined as having provided ACS in the past 3 months before the survey. In addition, ACS utilization in the past 3 months does not represent the appropriateness of ACS use, meaning that the correct doses are given to pregnant women at the eligible GA without infections. Third, we are aware of the collinearity between some independent variables in the regressions. For instance, facilities in the highest readiness tertile are likely to have the equipment, medicines, or staff required for CEmONC signal functions.

This study confirmed the complexity of factors affecting ACS utilization in LMICs. While corticosteroid availability is fundamental, providers' knowledge and skills–reflected by the past performance of CEmONC services in our findings–affect safe and effective ACS administration. Policymakers should examine factors contributing to low ACS use at various levels and identify strategies to promote the implementation of this life-saving intervention.

Chapter 4: Barriers to improving preterm newborn outcomes through effective antenatal corticosteroid use in Ethiopia

Abstract

Ethiopia faces one of the highest burdens of preterm births in the world. The country's national strategy has prioritized high-impact interventions to reduce neonatal death, including antenatal corticosteroid (ACS) utilization. However, effective use of ACS has faced various challenges. In this paper, we used multiple data sources to examine the current landscape of ACS use and to elucidate barriers to effective ACS adoption in Ethiopia, including a review of national obstetric guidelines over the past decade, a review of existing literature, a descriptive analysis of recent health facility data, and informal discussions with local obstetricians and maternal health policymakers.

National obstetric protocols recommend administering ACS in both hospitals and health centers for women at risk of preterm labor. However, ACS remains underused. The 2021 Ethiopian Service Provision Assessment survey revealed that only 22% of facilities providing antenatal care and delivery services had administered ACS in the past 3 months, ranging from only 2.8% in private clinics, 20.8% in health centers, 78.9% in primary hospitals, and 82.5%-86.7% in general and referral hospitals. Only 44.7% of facilities had valid injectable corticosteroids in stock at the time of the survey. Notably, private clinics had both the lowest corticosteroid availability (16.9%) and utilization. At the patient level, the 2016 Ethiopian Emergency Obstetric and Newborn Care Assessment reported that only 5% of preterm infants were born to women who had received ACS.

Through discussions with stakeholders and a review of the literature, we identified several barriers to effective ACS use in Ethiopia, including healthcare service

organization, gaps in healthcare providers' knowledge and skills (particularly at the primary healthcare level), difficulties in accurate gestational age assessment resulted from limited access to early obstetric ultrasound and late antenatal care initiation, gaps in corticosteroid availability. Simply increasing ACS uptake is unlikely to achieve the desired outcomes without improvements in health system re-organization and integration with other life-saving maternal and newborn health interventions. Addressing these barriers requires improvements in infrastructure, drug supply, and human resources capacity building, all of which must build on a well-designed service delivery structure to ensure and optimize the benefits of ACS.

4.1 Introduction

Ethiopia faces a substantial burden of preterm infants.(32) With a prevalence of preterm birth of 10.5% in the country, an estimated 495,900 preterm infants were born in 2020.(32, 103) As a leading cause of neonatal death, preterm birth is a serious public health issue.(104, 105) A study assessing risk factors of neonatal mortality in Ethiopia found that preterm infants had five times the odds of death compared to term infants.(106) In addition, an observational study in the country reported that respiratory distress syndrome (RDS), a common respiratory complication due to fetal lung immaturity, contributed to nearly half (45%) of preterm infant deaths.(107) While Ethiopia has made progress in reducing neonatal mortality rate from 59 per 1,000 live births in 1990 to 26 per 1,000 live births in 2021 (108), the country will fall short of achieving the Sustainable Development Goals to end preventable newborn death by 2030.(105) It is clear that prioritizing interventions for preterm infants is crucial for reducing neonatal mortality in Ethiopia.

Antenatal corticosteroids (ACS) use among pregnant women at risk of imminent preterm labor has been proven to significantly improve preterm health outcomes by accelerating fetal lung maturity and reducing respiratory complications. A 2020 Cochrane review, including 27 trials of more than 10,000 infants, found that ACS reduces the risk of RDS and neonatal death by 30% and 22%, respectively.(10) The World Health Organization (WHO) and other medical associations all recommend administering ACS to pregnant women at risk of imminent preterm labor between gestational age (GA) of 24 to 34 weeks.(15, 16, 18, 73) As the majority of preterm births globally occur in low- and middle-income countries (LMICs), ACS use has been strongly advocated in these

countries. A recent *Lancet* series on "small vulnerable newborns" identified a package of antenatal interventions for the health of this vast population, highlighting the benefits of ACS in reducing complications of preterm births.(51) Similarly, Ethiopia's national strategies have prioritized high-impact interventions to improve newborn outcomes, including promoting the use of antenatal corticosteroids.(109-111)

However, there is scarce evidence on the current status of ACS utilization in Ethiopia, despite the country's burden of preterm births and the benefits of ACS at the population level. This study aimed to assess the landscape of ACS utilization in Ethiopia and to identify barriers to its effective implementation.

4.2 Methods

This study drew data from multiple sources, including 1) the 2021-2022 Ethiopia Service Provision Assessment (SPA), 2) the 2016 Ethiopian Emergency Obstetric and Newborn Care (EmONC) assessment, 3) Ethiopian national obstetric and antenatal care guidelines, 4) a literature review on ACS utilization in Ethiopia, and 5) standardized discussions with Ethiopian policymaker and physicians specialized in obstetrics and neonatology.

First, SPA surveys are health facility surveys conducted by the Demographic and Health Survey Program (DHS) to measure service availability and quality of care in LMICs.(57) The 2021-2022 Ethiopia SPA is the most recent assessment for Ethiopia.(60) Using the SPA data, we restricted our analyses to facilities that provided antenatal care (ANC) or provided delivery services (normal spontaneous delivery or Cesarean sections), and we also excluded health posts. We presented the weighted proportions of facilities with injectable corticosteroids (either dexamethasone or betamethasone) available and

those that had administered ACS within the three months before the survey, stratified by subnational regions and facility types (referral hospitals, general hospitals, primary hospitals, private clinics, and health centers). Since SPA did not survey corticosteroid availability in the maternal and child health care section, we used its availability in the section for medicines of non-communicable diseases as a proxy. This approach was adopted to be consistent with the methods for the first two papers (Chapters 2 and 3). Second, the 2016 Ethiopian EmONC assessment is a cross-sectional census of health facilities that provided delivery services in 2015(112). This assessment comprised 14 modules that collected data on facility readiness and quality of care, including physical and human resources, service statistics, provider knowledge, and referrals. One module collected data on newborn complications at the individual level, including newborns with difficulties in breathing, young infants with infections, and preterm and low birth weight babies (birth weight less than 2kg). The information was collected by reviewing medical records of the last two cases admitted in the past month in each facility. We used this data to assess the proportion of infants whose mothers had received ACS before birth.(112) After excluding term and post-term newborns with a birth weight less than 2.0kg, we described the characteristics of facilities according to ACS receipt.

In addition, we identified the country's national guidelines and protocols on maternal and newborn care and reviewed any content in relation to ACS utilization.(101, 102, 113-119) Lastly, we discussed with Ethiopian policymaker (n=1) and physicians in obstetrics (n=3) and neonatology (n=1) to obtain their perspectives on the current status of ACS utilization and barriers to effective use in the country using a standardized

discussion agenda with prespecified questions **(Appendix C. Supplemental Table 8)**; we also invited them to collaboratively contribute to the study.

4.3 Results

National guidelines on antenatal corticosteroid use

Table 5 summarizes the country's national guidelines on ACS use. First, like the WHO Model List of Essential Medicines, injectable dexamethasone is among the listed obstetric medicines in the country's most recent Essential Medicines List (EML). Ethiopian guidelines also recommend the use of betamethasone alternatively, while the WHO list does not include betamethasone.(73, 113) We reviewed two versions of national obstetric guidelines: the 2014 Standard Treatment Guidelines (including separate guidelines for general hospitals, primary hospitals, and health centers) and the 2021 Obstetrics Management Protocols (including separate protocols for hospitals and health centers).(101, 102, 117-119) Both recommend administering ACS in cases of preterm labor at both hospitals and health centers. In fact, ACS use was covered as early as 2013 in the Basic Emergency Obstetric and Newborn Care Manual. (116)

Ethiopian guidelines suggest that ACS should be administered in both hospitals and health centers. In health centers, ACS should be given as a part of pre-referral management, followed by urgent referrals to a higher-level of facility. Regarding eligibility, the Ethiopian guidelines specify the eligible GA as the period between 28 and 34 weeks of gestation; this information is found in the 2014 version but not clearly described in the 2021 protocol. While it is slightly different from the international recommendations of 24 to 34 weeks of gestation, this difference might be attributed to

the viable gestational age in the context. Also, the country's guidelines mention the contraindications of ACS use, recommending not administering ACS in cases with infections like chorioamnionitis. The dose and administration route covered in the country's guidelines generally aligns with international recommendations. Notably, a repeated course of ACS is recommended one week after the first course if the pregnant woman is still under 34 weeks of gestation.

Table 5. Summary of Ethiopian national guidelines on antenatal corticosteroid use

2020 Ethiopian National Essential Medicine List 6th edition (113)
• Dexamethasone is listed in the section for essential obstetrics and gynecological medications. Betamethasone can be used alternatively.
2020 Management Protocol on Selected Obstetrics Topics for Hospitals (115) **2021 Obstetric Management Protocol for Hospitals (101)**
• Administer antenatal corticosteroids (betamethasone 12 mg IM 24 hours apart for two doses or dexamethasone 6 mg IM 12 hours apart for four doses) for lung maturity. • Note that if preterm birth is considered imminent, treatment for short duration still improves fetal lung maturity and chances of neonatal survival. Therefore, the first dose of corticosteroids should be administered even if the ability to give the second dose is thought to be unlikely. • Antenatal corticosteroid therapy should not be administered in women with chorioamnionitis.
2021 Obstetric Management Protocol for Health Centers (102)
• Pre-referral management includes dexamethasone 6 mg IM stat (document the time given on referral paper). Refer urgently after pre-referral care is provided.
2014 Standard Treatment Guidelines for General Hospitals (119) **2014 Standard Treatment Guidelines for Primary Hospitals (118)**
• Steroid therapy for stimulation of surfactant production to be given at 28-34 weeks of gestation. • The first line drug is betamethasone (12mg IV, 24 hours apart for two doses). The second line drug is dexamethasone **(**6mg PO/IM, six hours apart for two doses). • After 48 hours from the first dose, the full effect on maturing the surfactant has been obtained. If the patient does not deliver within one week, the treatment should be repeated if the fetus is less than 34 weeks of gestation. • Use of corticosteroids in the presence of infection is contraindicated.
2014 Standard Treatment Guidelines for Health Centers (117)
• The recommendations are the same as the 2014 Standard Treatment Guidelines for General Hospitals and Primary Hospitals. • Patients with preterm labor should be treated in a center where there is a NICU and should be referred as early as possible.
2013 Basic Emergency Obstetric and Newborn Care Training Manual (116)
• Give corticosteroids to the mother to improve fetal lung maturity (betamethasone 12 mg IM, two doses 12 hours apart; or dexamethasone 6 mg IM, four doses 6 hours apart) • Corticosteroids should not be used in the presence of frank infection. • Consider transferring to the most appropriate service for the care of the newborn, if possible.

* IM: intramuscularly; IV: intravenous; PO: Oral

ACS availability and utilization: evidence from facility assessments and literature

Analyses of the 2021-2022 SPA data showed that among facilities providing ANC or delivery services (n=710), 44.7% had injectable corticosteroids available at the time of the survey, and only 22.1% had administered ACS in the past 3 months prior to the survey **(Table 5)**. ACS availability was highest in primary hospitals (81.3%), followed by general hospitals (77.5%) and referral hospitals (60%), and lowest in health centers (49.4%). ACS utilization increased by the level of care, ranging from 20.8% in health centers to 82.5% and 86.7% in general and referral hospitals, respectively. Notably, private clinics had the lowest availability (16.9%) and utilization (2.8%). Across subnational regions, Somali (53.7%) and Harari (50.0%) had the highest proportion of facilities that had used ACS recently, and Afar had the lowest (10.6%) even though Afar had the highest corticosteroid availability (59.5%). The region of Sidama had the lowest availability (22.4%). There are gaps between availability and utilization across subnational regions, especially in primary hospitals, health centers, and private clinics **(Table 6)**.

Evidence on ACS coverage rates at the individual patient level is limited. The 2016 EmONC assessment reviewed the medical records of the last two preterm babies born across all health facilities providing delivery care in the country. They found that among 1,150 records of preterm and low birth weight babies (<2,000gm) reviewed, 4.5% were born to women who received ACS prior to the delivery.(112) We found variations in facility characteristics between babies who had and had not received ACS **(Table 7)**. Among newborns who received ACS, the majority (71.2%) were born in hospitals, compared to 28.9% born in health centers or specialized MCH centers; in contrast, a

smaller proportion (26.0%) of those who did not receive ACS were found in hospitals.

Few studies have investigated ACS coverage among preterm infants in Ethiopia. All of them found low ACS coverage, even in higher-level facilities.(120-122) Two studies (Girma et al. and Legess et al.) retrospectively reviewed medical records in the highest level of hospitals to assess predictors of neonatal mortality; one study was conducted in two hospitals in Tigray, and the other was done among five hospitals in Oromia.(120, 122) In the study by Girma et al., 14.4% of preterm (< GA 37 weeks) were born to mothers who received ACS. Similarly, another study by Legess et al. revealed a similar coverage rate of 15.0%, but among neonates who were diagnosed with respiratory distress syndrome admitted to neonatal intensive care units (NICU). The former found that ACS exposure was not significantly associated with neonatal survival (120), while the latter showed that ACS administration before birth protected against neonatal death.(122) Another study by Metaferia et al. specifically focused on describing ACS utilization in Ethiopia, prospectively collecting data from five teaching hospitals in different regions of the country.(121) They found that among preterm infants (< GA 35 weeks) admitted to these five hospitals, one-third (37.5%) were delivered by women who received ACS. Regarding delivery locations, almost all those who received ACS were delivered at hospitals, whereas a substantial proportion (19.1%) of those who did not receive ACS were born in health centers.(121) However, this study also found that the risk of early neonatal sepsis was higher among those whose mothers received ACS.

Table 6. Proportion of facilities that had injectable corticosteroids available and had provided antenatal corticosteroids in the past 3 months by sub-national regions and facility types

Subnational regions \ Facility types	Referral hospitals n = 30		General hospitals n = 120		Primary hospitals n = 218		Private clinics (Including MCH specialized clinics) n = 75		Health centers n = 267	
	Availability	**Recent use[2]**	**Availability**	**Recent use[2]**	**Availability**	**Recent use[2]**	**Availability**	**Recent use[2]**	**Availability**	**Recent use[2]**
National (n=710)[1]	44.7%	22.1%	18 (60.0%)	26 (86.7%)	93 (77.5%)	99 (82.5%)	171 (81.3%)	165 (78.9%)	19 (16.9%)	2 (2.8%)	128 (49.4%)	65 (20.8%)
Afar (n = 28)	9/19 (59.5%)	6/28 (10.6%)	1/1 (100%)	1/1 (100%)	2/2 (100%)	2/2 (100%)	3/3 (100%)	2/3 (66.7%)	2/3 (36.7%)	0/3 (0%)	11/19 (57.9%)	1/19 (5.3%)
Amhara (n = 127)	89/127 (47.9%)	74/127 (26.6%)	3/5 (60.0%)	5/5 (100%)	14/16 (87.5%)	12/16 (75.0%)	51/62 (82.3%)	47/62 (75.8%)	3/9 (22.6%)	0/9 (0%)	18/35 (51.4%)	10/35 (28.6%)
Oromiya (n = 176)	118/176 (43.7%)	106/176 (18.2%)	5/7 (71.4%)	7/7 (100%)	34/46 (73.9%)	40/46 (87.0%)	55/67 (82.1%)	51/67 (76.1%)	1/14 (5.5%)	1/14 (5.5%)	23/42 (54.8%)	7/42 (16.7%)
Somali (n = 44)	27/44 (48.7%)	26/44 (53.7%)	1/1 (100%)	1/1 (100%)	4/4 (100%)	4/4 (100%)	7/7 (100%)	6/7 (85.7%)	3/5 (60.0%)	0/5 (0%)	12/27 (44.4%)	15/27 (55.6%)
Benishangul (n = 21)	12/21 (53.0%)	6/21 (24.9%)	NA	NA	1/2 (50.0%)	2/2 (100%)	2/3 (66.7%)	0/3 (0%)	0/1 (0%)	0/1 (0%)	9/15 (60.0%)	4/15 (26.7%)
S.N.N.P (n = 110)	56/110 (42.2%)	58/110 (18.6%)	4/6 (66.7%)	6/6 (100%)	5/10 (50.0%)	9/10 (90%)	32/51 (77.3%)	42/51 (86.9%)	0/5 (0%)	0/5 (0%)	15/38 (39.5%)	3/38 (7.9%)
Gambella (n = 35)	14/35 (35.2%)	11/35 (17.9%)	NA	NA	0/1 (0%)	1/1 (100%)	4/4 (100%)	3/4 (75.0%)	4/12 (31.7%)	0/12 (0%)	6/18 (33.3%)	7/18 (38.9%)
Harari (n = 14)	7/14 (50%)	7/14 (50%)	0/1 (0%)	1/1 (100%)	2/2 (100%)	2/2 (100%)	1/1 (100%)	0/1 (0%)	1/2 (50.0%)	0/2 (0%)	3/8 (37.5%)	4/8 (50.0%)
Addis Ababa (n = 64)	47/64 (53.5%)	29/64 (14.7%)	2/7 (28.6%)	4/7 (57.1%)	22/25 (88.0%)	18/25 (72.0%)	3/3 (100%)	2/3 (66.7%)	2/7 (34.4%)	0/7 (0%)	18/22 (81.8%)	5/20 (22.7%)
Dire Dawa (n = 27)	16/27 (51.7%)	5/27 (15.2%)	1/1 (100%)	0/1 (0%)	5/5 (100%)	3/5 (60.0%)	NA	NA	1/6 (16.9%)	0/6 (0%)	9/15 (60.0%)	2/15 (13.3%)
Sidama (n = 64)	24/64 (22.4%)	29/64 (30.2%)	1/1 (100%)	1/1 (100%)	4/7 (57.1%)	6/7 (85.7%)	13/17 (76.5%)	14/17 (82.4%)	2/11 (18.2%)	1/11 (9.1%)	4/28 (14.3%)	7/28 (25.0%)

[1] Excludes health posts and facilities with zero sample weight. Includes only facilities that provide antenatal care or delivery services (normal spontaneous deliveries or Cesarean sections). Sampling weights were taken into account when reporting proportions.
[2] Provided antenatal corticosteroid within the past three months before the survey
Marked grey where there is a gap between availability and utilization within the past three months
NA: Not applicable due to no sample for the facility type in the region

Table 7. Characteristics of health facilities according to antenatal corticosteroid exposure status of preterm and low birth weight babies (birth weight <2,000gm) from the 2016 Ethiopian Emergency Obstetric and Newborn Care Assessment

Characteristics	Preterm and low birth weight babies (n=1150)		
	With ACS exposure n = 52 (4.5%)	Without ACS exposure n = 1098 (95.5%)	p-value[1]
	Frequency (%)	Frequency (%)	
Urban (ref. rural)	41 (78.8%)	608 (55.4%)	0.001
Managing authority types			
Public	43 (82.7%)	1042 (94.9%)	<0.001
Private for-profit	8 (15.4%)	33 (3.0%)	
Not-for-profit or faith-based/Misson or faith-based	1 (1.9%)	23 (2.1%)	
Facility type			
Referral/Specialized hospitals	7 (13.5%)	36 (3.3%)	<0.001
General hospitals	19 (36.5%)	108 (9.8%)	
Primary hospitals	11 (21.2%)	142 (12.9%)	
Private clinics[2]	3 (5.8%)	19 (1.7%)	
Health centers	12 (23.1%)	793 (72.2%)	
EmONC status			
Designated CEmONC[3] facilities	37 (74.0%)	251 (24.4%)	<0.001
Designated BEmONC[4] facilities	12 (24.0%)	652 (63.5%)	
Not designated EmONC facilities	1 (2.0%)	124 (12.1%)	
Equipment			
Number of beds for obstetric care (mean, SD)	21.6 (22.3)	10.2 (13.0)	<0.001
Have a functioning NICU[5]	29 (55.8%)	213 (19.4%)	<0.001
Have a functioning newborn corner	34 (65.4%)	403 (36.7%)	<0.001
Have a functioning space for the management of maternal complications	27 (51.9%)	263 (24.0%)	<0.001
Have a functioning space for OB/GYN[6] operations	27 (51.9%)	180 (16.4%)	<0.001
Staffing			
Have at least one doctor	40 (76.9%)	296 (27.0%)	<0.001
Have at least one pediatrician/neonatologist	14 (26.9%)	93 (8.5%)	<0.001
Have at least one midwife	51 (98.1%)	1089 (99.2%)	0.942
Have at least one nurse	51 (98.1%)	1095 (99.7%)	0.442

Data source: 2016 Ethiopian Emergency Obstetric and Newborn Care Assessment.(112) In this assessment, individual newborn patient data were collected from a review of medical records for the last two cases of preterm and low birth weight babies (birth weight less than 2,000gm) admitted in the past month in each facility.

[1] p-values are from chi-squared tests for categorical variables and t-tests for discrete variables.

[2] Includes higher clinics, maternal and child health (MCH) specialized clinics, and maternal and child health specialized centers.

[3] CEmONC: comprehensive emergency obstetric and newborn care

[4] BEmONC: basic emergency obstetric and newborn care

[5] NICU: neonatal intensive care unit

[6] obstetrics and gynecology

Barriers to effective ACS use in Ethiopia

Healthcare service organization

According to the latest population-based survey, 50% of women in Ethiopia give birth in health facilities.(123) As 80% of the population in the country lives in rural areas (124), health centers are the primary source of care for pregnant women seeking antenatal and delivery care. It is estimated that nearly three-quarters (72%) of institutional deliveries take place at the primary level of care.(125) It can be reasonably inferred that a significant number of women with signs of preterm labor or obstetric conditions likely to trigger preterm labor will present first in health centers. For these women, both the 2014 and 2021 guidelines recommend ACS use as part of pre-referral management.(102) In-utero transfers to hospitals will then benefit both pregnant women and their incoming preterm babies, as health centers are not equipped to handle preterm labor, related obstetric emergencies, or preterm infants that need immediate intensive care.

However, the success of current practice depends on multiple factors. First, the stage of labor is crucial. If labor is already advanced, immediate attended delivery is warranted. In such cases, even if corticosteroids were given before birth to the pregnant woman, a preterm baby born at a small gestational age that is born in a health center lacking necessary equipment and medications is very unlikely to survive. These babies need immediate care, such as respiratory support, which is usually unavailable in health centers. Referrals of preterm babies are then required, but often challenging because of distance and transportation constraints, as well as limited medical information continuity.

Fundamentally, it is crucial to revisit the country's structure of maternal care

service delivery. One outstanding question is determining the appropriate facility level for labor and delivery services. Since 15% of pregnancies end with complications and the majority of these complications cannot be predicted (126), it is reasonable to question whether health centers are an appropriate setting for childbirth care. Previous studies have examined the effect of service delivery redesign and suggested that shifting deliveries to or close to hospitals could improve maternal and neonatal survival, whereas the primary level of care, such as health centers, should be reserved for antenatal and postpartum care.(127, 128) Pregnant women with signs of preterm labor should be directed to visit hospitals directly, even though the majority of the country's institutional deliveries still occur at the primary level, which includes health centers in urban areas, and health posts, health centers, and primary hospitals in rural areas. Policies regarding patient triage based on risk stratification need to be tailored to the local context, considering feasibility and facility capability. Simply increasing ACS uptake is unlikely to improve preterm newborn survival without consideration of how service delivery structure affects the effectiveness of ACS.

Knowledge gaps and know-do gap

A systemic review of factors affecting the appropriate use of interventions for preterm labor concluded that varied levels of knowledge on ACS use among healthcare providers affected its appropriate use.(29) In Ethiopia, providers' knowledge gaps have been frequently referred to as critical challenges to implementing ACS effectively. These gaps are twofold. First, there is a lack of or insufficient understanding of ACS use and its benefits in promoting fetal lung maturity. Second, there are difficulties in identifying eligible pregnant women at risk of imminent preterm labor. Knowledge gaps are

particularly important in primary-level facilities staffed with midwives and health officers. For example, two qualitative studies in Malawi similarly showed low awareness of ACS and its purpose for accelerating fetal lung maturity among midwives and clinical officers.(28, 82) Not only do these cadres have less training in preterm labor management, but they also see fewer cases each month than those working in larger hospitals. For these reasons, maintaining skills in appropriate ACS administration is challenging at the primary care level. The findings in the 2016 EmONC assessment reflected these two layers of knowledge gaps: among the facilities that had not used ACS in the past 3 months, about one-fourth (23%) reported a lack of training, and nearly two-thirds (63%) reported not having seen any case with indication for ACS use. The latter is worth further investigation, as not seeing cases with the indication could be attributed to low service volume, inability to identify such cases, or both.

Beyond the knowledge gaps in ACS use, the know-do gap among providers is the next challenge. Studies have shown that know-do gaps – the gap between having the knowledge and practice based on the knowledge – are associated with poor quality of care.(129, 130) In the case of ACS use, studies found that the perceived risks and benefits of providers also determine the administration of ACS.(28, 29) The perceived risks, especially the fear of infection, and uncertainties regarding its benefits could partly explain the know-do gap.

Accurate GA assessment

An accurate gestational age assessment is the first and foremost requirement for determining eligibility for ACS use. However, there are practical concerns about GA assessment in the country. First, access to ultrasound in the first trimester – the gold

standard to assess GA – is still limited, while the government planned to scale up obstetric ultrasound services in health centers. (131, 132) The first paper in Chapter 2 that used the 2021-2022 SPA data found that only 4.5% of facilities that provided ANC and/or delivery services had a functional ultrasound, with 1.2% among facilities that provided ANC, 6.1% among those performing normal deliveries, and 84.9% among those doing Cesarean sections. In addition, a large proportion of pregnant women go to their first ANC visit late, resulting in missed opportunities for accurate GA dating.(133) The 2016 Ethiopian Mini DHS showed that only one-third (28%) of women had their first ANC visit in the first trimester.(123) Similarly, a previous study conducted in the Oromia region found that only 44.4% of pregnant women received an ultrasound during their first ANC visit. (134) This study included a large number of private facilities and likely overestimates ultrasound coverage in the region. Second, the date of the last menstrual period (LMP) is often used to determine GA. However, a study in the Amhara region of Ethiopia showed that one-fourth of pregnant women did not know their LMP.(135) Healthcare providers often need to rely on proxies such as fundal height or LMP, making it challenging to diagnose preterm labor and ascertain the GA period eligible for ACS.

Drug availability

The availability of injectable corticosteroids across different facility types is suboptimal, with only 50% of health centers and between 60% to 80% of hospitals at various levels having corticosteroids in stock at the time of the SPA survey **(Table 7)**. There needs to be a stable stock of injectable corticosteroids at all levels of care where ACS is recommended. Injectable corticosteroids are low-cost and should be provided freely in public facilities in Ethiopia. Injectable corticosteroids do not require a specific

temperature for storage. These two features should make it feasible to maintain a consistent stock in Ethiopia.

4.4 Discussion

In this study, we described ACS utilization in Ethiopia and identified a few barriers to its effective use. Our findings confirmed the complexity of these barriers, as exemplified in a framework for safe and effective ACS use proposed in the second paper (Chapter 3). We found that stable corticosteroid availability remains an issue across all levels of care. Even in settings with corticosteroids available, gaps in providers' knowledge of ACS use and difficulties in identifying preterm labor, particularly in primary healthcare facilities, have been cited as critical barriers to effective ACS use. Meanwhile, an accurate GA assessment to identify women who are eligible to receive the drug is challenging in the country. From an overall implementation standpoint, the country's healthcare service delivery structure appears to shape the effectiveness of ACS administration at the primary level. Addressing these barriers requires a strong policy foundation, with investments in facility infrastructure, a stable drug supply chain, workforce capacity, and a redesigned service delivery structure that can maximize the benefits of ACS. Efforts to narrow knowledge gaps should go beyond providing in-service training and workshops because these approaches often generate suboptimal and unsustainable impacts(98), particularly in health centers with low service volumes.

While ACS is a promising intervention for improving preterm newborn survival, it cannot deliver results on its own. ACS must be integrated into a health system where all components function effectively together to ensure positive outcomes. Similar to other

interventions, such as magnesium sulfate for preeclampsia or eclampsia (136), simply increasing ACS uptake without strengthening the health system and thinking about redesigning service delivery is unlikely to improve neonatal health. Efforts to promote ACS uptake should prioritize solutions that address existing barriers and be embedded in a systematic approach to enhance maternal and newborn health.

Chapter 5: Quality of antenatal care and perinatal outcomes: evidence from a cohort study in Ethiopia, Kenya, and South Africa

Abstract

Background

Antenatal care (ANC) is crucial for improving maternal and newborn health. Despite global efforts to improve ANC coverage, quality remains suboptimal. Evidence on how ANC quality affects perinatal outcomes remains limited. This study investigated the association between the quality of antenatal care and fetal loss and low birth weight (LBW) newborns.

Methods

We used data from the eCohort study that collected longitudinal data on ANC utilization and quality and followed women until the end of pregnancy in Ethiopia, Kenya, and South Africa. Primary outcomes included fetal losses (late miscarriages and stillbirths) and LBW. Good quality ANC was defined as receiving six basic care components at the first ANC visit: blood pressure measurement, blood and urine tests, ultrasound, iron and folic acid supplementation, and counseling on pregnancy danger signs. We conducted mixed-effect logistic regressions to assess the associations between good quality ANC and primary outcomes, with a sensitivity analysis where good quality ANC excluded ultrasound.

Results

Among 2,633 pregnant women followed until the end of pregnancy, only 14.0% in Ethiopia, 5.6% in Kenya, and 2.6% in South Africa received all six basic care components. The receipt of ultrasound examinations varied significantly, with 43.4% of

women in Ethiopia and only 7.6% and 8.3% in Kenya and South Africa, respectively. Fetal loss prevalence was 3.6% in Ethiopia, 3.8% in Kenya, and 4.0% in South Africa. Among neonates who were alive at the time of the survey, South Africa had a higher percentage of LBW newborns (12.8%) than Ethiopia and Kenya (8.5%). We found a significant association between good quality ANC and fetal loss (RR 0.44, 95% CI 0.12 – 0.77), but the association was no longer significant when good quality ANC excluded ultrasound (RR 0.80, 95% CI 0.56 – 1.04). No significant associations were observed between good quality ANC and LBW. Multiple pregnancies were rarely detected, with more than half to three-quarters of multiple pregnancies undetected at the first ANC visits.

Conclusion

The quality of ANC received in this study sample is suboptimal. Our regressions highlighted the importance of ultrasound scans. The findings are concerning, as the six basic care components are fundamental for pregnancy health. With increased ANC coverage, future research and programs should prioritize quality improvement, ensuring the delivery of good clinical practice and evidence-based antenatal interventions.

5.1 Introduction

Antenatal care (ANC) is critical in ensuring the health of pregnant women and their babies. It serves several crucial functions, including health promotion, screening and diagnoses of diseases, and prevention of illnesses throughout pregnancy.(6) Thus, quality ANC is tremendously important. The 2016 World Health Organization (WHO) recommendations on ANC emphasize the importance of high-quality ANC in delivering the right care at the right time.(6)

Previous research has linked ANC to reduced adverse neonatal outcomes, yet a large body of evidence has focused specifically on the utilization of ANC, or in other words, the number of ANC visits. Two meta-analyses concluded that at least one ANC visit reduced the risk of neonatal mortality by 34% to 39% in low- and middle-income countries (LMICs) in Asia and sub-Saharan Africa.(11, 12) Additionally, a multicountry study using 193 Demographic and Health Surveys (DHS) from 69 countries showed the effects of at least one and at least four ANC visits in reducing neonatal and infant deaths.(44) In addition to lowering mortality rates, studies also found protective effects of ANC utilization against fetal loss in pregnancy and low birth weight (LBW) newborns.(43-47, 137)

Massive efforts have been made to increase ANC utilization, and nowadays, global attention has gradually shifted to ANC quality. Some LMICs have reached high levels of ANC coverage; however, the quality of ANC continues to be suboptimal.(7) The content of care received by pregnant women remains insufficient even among those who initiated ANC visits timely and met the recommended number of ANC visits.(8, 9) Additionally, the evidence on the association between ANC quality and perinatal

outcomes, although emerging, is still limited compared to the extensive literature on ANC utilization. A study using data from the Ghana Maternal Health Survey, including nearly 5,000 women, found that high-quality ANC decreased the risk of stillbirth.(43) Another study in urban Nairobi, Kenya, demonstrated the beneficial effects of good quality ANC in protecting against stillbirth.(137) On the other hand, there is a wealth of evidence on the effect of a specific antenatal intervention rather than the overall ANC quality on fetal and newborn health.(37) A 2020 Cochrane review reported the positive effects of particular antenatal interventions on stillbirth and perinatal death.(138)

Critical evidence gaps remain in understanding the associations between the quality of ANC and fetal and neonatal health outcomes. First, there is an urgent need to identify the key care components of good quality ANC that contribute to positive health outcomes. Second, research on the effects of ANC quality on LBW newborns is relatively limited compared to other neonatal outcomes, such as neonatal death. Hence, this study aimed to examine ANC quality and its association with fetal loss and LBW newborns.

5.2 Methods

Data source

We used data from the eCohort study, a health system study that collected longitudinal data on the utilization and quality of ANC in four countries (Ethiopia, Kenya, South Africa, and India). Data from three African countries were used for this study. The study was conducted in two sites in each country, with one rural and one urban. Pregnant women were enrolled at their first ANC visits and underwent an in-

person health assessment at baseline, which included blood pressure, weight, height, mid-upper-arm circumference measurement, and a finger prick hemoglobin test for detecting anemia. The follow-up surveys during pregnancy and after delivery were conducted via phone, collecting data on the utilization of antenatal care, the content of care received, participant health, and newborn health if the pregnancy resulted in a live birth. More details of the eCohort methodology are available elsewhere.(139) The present analysis included participants who were followed until the end of pregnancy.

Measures

We specified two primary outcomes: fetal loss and LBW newborns. First, fetal loss included late miscarriages – pregnancy losses between gestational age (GA) 13 to 28 weeks, and stillbirths – pregnancy losses after GA 28 weeks. We excluded participants who experienced early miscarriages (pregnancy losses before 13 weeks of gestation) since miscarriages in the first trimester are mainly caused by chromosomal abnormalities.(140, 141) Second, LBW newborns were defined as newborn babies with a birth body weight of less than 2.5 kg or a birth body size that was smaller than average or very small when birth weight was unknown. Data on newborn birth body size were self-reported by mothers based on a scale of five levels (very large, larger than average, average, smaller than average, and very small). This study collected data on actual birth body weight or self-reported birth body size only for the neonates who were still alive during the follow-up phone survey. GA at baseline, which was used to determine late miscarriage or stillbirth, was estimated based on the date of last menstrual period (LMP), estimated due date (EDD), or self-reported weeks of pregnancy if the previous two dates were unavailable.

We identified a list of independent variables potentially associated with the primary outcomes. First, we assessed the socioeconomic and demographic status of participants, including age, marital or partnered status, whether the current pregnancy was intended, education level (categorized into three groups: no education or some primary education, complete primary education, and complete secondary education or higher), health literacy (defined as answering six health knowledge questions correctly), and wealth status (categorized into country-specific wealth tertiles). Second, maternal health-related variables included self-rated own health as very good or excellent on a Likert scale of five levels (excellent, very good, good, fair, and poor), risk factors at baseline (categorized by the number of risk factors: no risk factor, one risk factor, two risk factors, and three or more risk factors), reporting at least one danger signs at baseline (vaginal bleeding, fever, or fainting or loss of consciousness). Risk factors included any chronic systemic illness(es) known before pregnancy, history of obstetric complications (including Cesarean sections, preterm birth, stillbirth, neonatal death, or postpartum hemorrhage), and multiple pregnancies detected at the first ANC visits. Multiple pregnancies and maternal HIV status were reported separately in descriptive statistics of participant characteristics; both were included in developing the risk factor categorization for regressions.

Antenatal care quality

The primary independent variable was good quality ANC, a binary variable indicating the receipt of six basic care components at the first ANC visits: blood pressure measurement, blood test (either a blood draw or finger prick), urine test, ultrasound examination, iron and folic acid (IFA) given or prescribed, and counseling on pregnancy

danger signs. We also created another good quality ANC variable that excluded ultrasound scans. We restricted the care components to those received at the first visits to avoid immortal time bias since pregnant women who experienced fetal losses would not receive additional ANC components in another follow-up visit.

Statistical analysis

First, we presented the socioeconomic and demographic characteristics of pregnant women. We also presented the proportions of women who received each of the six or all six care components. Second, we reported the descriptive statistics for fetal and neonatal outcomes (late miscarriage, stillbirth, and LBW newborns) at the fetal and neonatal level. Third, we conducted mixed-effect logistic regressions to investigate the associations between good quality ANC and fetal loss and LBW newborns, respectively, including country as a fixed effect, two levels of random intercept (study sites and facilities), and robust standard errors. We used post-estimation commands and marginal probabilities to obtain risk ratios for the association between good quality ANC and each of the perinatal outcomes.

Regressions were performed at the fetal and neonatal level. We conducted eight regressions. In our primary analyses, the fetal loss model was restricted to women whose first ANC visits occurred in the first trimester of pregnancy to avoid selection bias. Including pregnant women who were already in the second or third trimester at baseline will introduce bias because pregnancies that have progressed to the second or third trimester are less likely or impossible to develop late miscarriages, which by definition occur in the second trimester. In other words, participants who have passed the period during which particular outcomes of interest could occur should not be included in the

sample. The LBW regression model included all women (regardless of pregnancy stage at enrollment) but controlled for GA at the first ANC visit (in trimesters) (first trimester: <13 weeks of gestation, second trimester: ≥13 to <28 weeks of gestation, third trimester: ≥28 weeks of gestation). We performed two sensitivity analyses. First, we used subsets of the sample for both primary outcomes. For the outcome of fetal loss, we used a sample subset with a more reliable baseline GA, defined as baseline GA calculated based on LMP or EDD, and excluded women whose baseline GA was self-reported weeks of pregnancy. For the outcome of LBW newborns, the subset was restricted to those newborns with actual birth weight data available and excluded those with only birth body size data. Second, all the regressions were repeated using a good quality ANC variable that excluded ultrasound. All analyses were performed using STATA version 18.0.

5.3 Results

This study included 2633 women followed until the end of pregnancy **(Table 8)**. The mean ages of participants across the three countries ranged from 25.6 to 26.9 years old, with more adolescents in South Africa. Nearly all participants in Ethiopia (97.6%) and the majority in Kenya (78.1%) were married or partnered, compared to a small proportion (11.7%) in South Africa. Pregnancy intention varied widely, with 73.4% in Ethiopia, 60.9% in Kenya, and only 16.9% in South Africa reporting the current pregnancy as intended. South Africa had more women (70.1%) who completed secondary or higher education, compared to 57.8% in Kenya and 22.2% in Ethiopia. However, health literacy across the three countries did not differ as much: 44.4% of women in Kenya, 32.5% in South Africa, and 26.8% in Ethiopia correctly answered six health

literacy questions. In addition, maternal health status differed. More than half (56.0%) in Kenya, 42.4% in South Africa, and 37.9% in Ethiopia rated their health as very good or excellent. Three-quarters of participants in Ethiopia (75.9%) and Kenya (72.0%) reported no risk factors at the baseline, compared to half (49.8%) in South Africa. Additionally, 25.5% of women in South Africa, 13.1% in Ethiopia, and 8.3% in Kenya reported at least one of the three pregnancy danger signs at their first ANC visits. There was a higher proportion of women with HIV in South Africa (28.6%) than in Kenya (1.7%) and Ethiopia (1.5%). Notably, we found low detection of multiple pregnancies at first ANC visits. In Ethiopia, Kenya, and South Africa, respectively, only 43.8% (7/16), 22.2% (4/18), and 26.3% (5/19) of multiple pregnancies identified at delivery were known at the first ANC visits.

Table 8. Characteristics of pregnant women followed until the end of pregnancy in three countries[1]

	Ethiopia N=883 Frequency (%)		Kenya N=896 Frequency (%)		South Africa N=854 Frequency (%)	
Socioeconomic and demographic status						
Age (mean/standard deviation)	25.6 (0.2)		26.9 (0.2)		26.7 (0.2)	
Age range						
15 to <20 years old	73	8.3%	104	11.6%	142	16.6%
≥20 to <35 years old	753	85.3%	667	74.4%	591	69.2%
≥35 years old	57	6.5%	125	14.0%	121	14.2%
Married or partnered	862	97.6%	700	78.1%	100	11.7%
Intended pregnancy	648	73.4%	546	60.9%	144	16.9%
Education level						
No education or some primary	334	37.8%	65	7.3%	6	0.7%
Complete primary	353	40.0%	313	34.9%	248	29.0%
Complete secondary or higher	196	22.2%	518	57.8%	599	70.1%
Health literacy[2]	237	26.8%	398	44.4%	277	32.4%
Wealth status[3]						
Poorest	283	32.0%	299	33.4%	228	26.7%
Middle	286	32.4%	383	42.8%	339	39.7%
Richest	296	33.5%	209	23.3%	286	33.5%
Maternal health						
Self-rated own health as very good or excellent[4]	335	37.9%	502	56.0%	362	42.4%
Risk factor at baseline[5]						
No risk factor	670	75.9%	645	72.0%	425	49.8%
One risk factor	179	20.3%	190	21.2%	280	32.8%
Two risk factors	28	3.2%	34	3.8%	104	12.2%
Three or more risk factors	6	0.7%	27	3.0%	45	5.3%
HIV status[6]	13	1.5%	15	1.7%	244	28.6%
Pregnancy characteristics						
Trimester of the first ANC visit						
The first trimester[7]	259	29.3%	124	13.8%	319	37.8%
The second trimester[7]	559	63.3%	613	68.4%	444	52.0%
The third trimester[7]	48	5.4%	159	17.8%	77	9.0%
Report at least one danger sign at baseline[8]	116	13.1%	74	8.3%	218	25.5%
Multiple pregnancies known at baseline	7	0.8%	4	0.5%	5	0.6%
Multiple pregnancies identified at delivery	16	1.8%	18	2.0%	19	2.2%

[1] Participants who had an early miscarriage (fetal loss before 13 weeks of gestation) or lost to follow-up after the first ANC visits were excluded.
[2] Defined as answering six health knowledge questions correctly. The six questions were adopted from the Indian Health and Human Development Survey.
[3] Wealth tertile is country-specific.
[4] Self-rated own health was based on a Likert scale of five levels (excellent, very good, good, fair, and poor).
[5] Includes any chronic systemic illness(es) known before pregnancy (including diabetes, hypertension, cardiac disease, HIV, mental health disorder, schizophrenia, epilepsy, seizure, renal disorder, asthma, tuberculosis, anemia, hemoglobinopathy, chronic pelvic inflammatory disease, ovarian cyst, fibroids, uterine myoma, genital tract abnormalities, thyroid cancer, thyroid disease, peptic ulcer disease, gestational hypertension in a previous pregnancy, a history of stroke) and any history of obstetric complications (Cesarean section, stillbirth, preterm birth, neonatal death, and postpartum hemorrhage)
[6] HIV was reported separately in descriptive statistics, but it was included in developing the categorization of risk factors.
[7] The first trimester is defined as less than 13 weeks of gestation; the second trimester is defined as between 13 to less than 28 weeks of gestation; the third trimester is defined as above 28 weeks of gestation
[8] Includes vaginal bleeding, fever, and fainting or loss of consciousness.

Only 7.4% of women received all six care components at their first ANC visits, with 14.0% in Ethiopia, 5.6% in Kenya, and 2.6% in South Africa (**Table 9**). Nearly all participants in South Africa received pressure measurement, blood test, and urine test; in Ethiopia and Kenya, the proportions remained close to or exceeded 90% for these three care components, except that only three-quarters (72.5%) in Ethiopia had blood pressure measured. The proportion of women who received an ultrasound scan at their first ANC visits was much lower and varied across the countries, with 43.4% in Ethiopia but only 8.3% in Kenya and 7.6% in South Africa. Counseling on danger signs of pregnancy was highest in Kenya (60.7%), followed by 49.2% in South Africa, and lowest in Ethiopia (30.9%). Iron and folic acid supplements were given or prescribed to more than 92.7% and 92.5% of women in Kenya and South Africa, respectively, and 80.7% in Ethiopia. Excluding ultrasound, the proportion of women who received all five care components was higher in Kenya (52.5%) and South Africa (47.0%) than in Ethiopia (20.3%). **Appendix D. Supplemental Table 9** shows results stratified by research sites in each country.

Table 10 details the descriptive statistics of outcomes at the fetal and neonatal level. The prevalences of fetal loss were similar, with late miscarriage ranging from 2.3% in Ethiopia and Kenya to 2.7% in South Africa and stillbirth ranging from 1.3% in Ethiopia and South Africa to 1.5% in Kenya. Among neonates who were alive at the postpartum follow-up survey, South Africa had a higher percentage of LBW infants (12.8%), compared to 8.5% in both Ethiopia and Kenya. In Ethiopia, the data on EDD and LMP were available for only half (51.1%) of fetuses and neonates, and actual newborn birth body weight data were available for 60% of newborns who were still alive

at the postpartum survey. In contrast, the other two countries had over 90% or close to 100% having this information available.

Table 9. Proportion of pregnant women who received each of the six and all six care components at first ANC visits in three countries

ANC quality care components	Overall N=2633		Ethiopia N=883		Kenya N=896		South Africa N=854	
	Frequency (%)		Frequency (%)		Frequency (%)		Frequency (%)	
Physical examination								
Blood pressure measurement	2404	89.5%	640	72.5%	861	96.1%	852	99.8%
Test and examinations								
Blood test (blood draw or finger prick)	2621	97.5%	838	94.9%	876	97.8%	853	99.9%
Urine test	2456	91.4%	752	85.2%	801	89.4%	850	99.5%
Ultrasound	532	19.8%	383	43.4%	74	8.3%	65	7.6%
Counseling								
Signs of pregnancy complications	1271	47.3%	273	30.9%	544	60.7%	420	49.2%
Preventions								
Iron and folic acid given or prescribed	2376	88.4%	713	80.7%	831	92.7%	790	92.5%
Completeness of all six care components[1]	200	7.4%	124	14.0%	50	5.6%	22	2.6%
Completeness of all five care components[2]	1078	40.1%	179	20.3%	470	52.5%	401	47.0%

[1] Include blood pressure measurement, blood test, urine test, ultrasound examination, iron and folic acid given or prescribed, counseling on signs of pregnancy complications
[2] Include all the care components except for ultrasound examination.

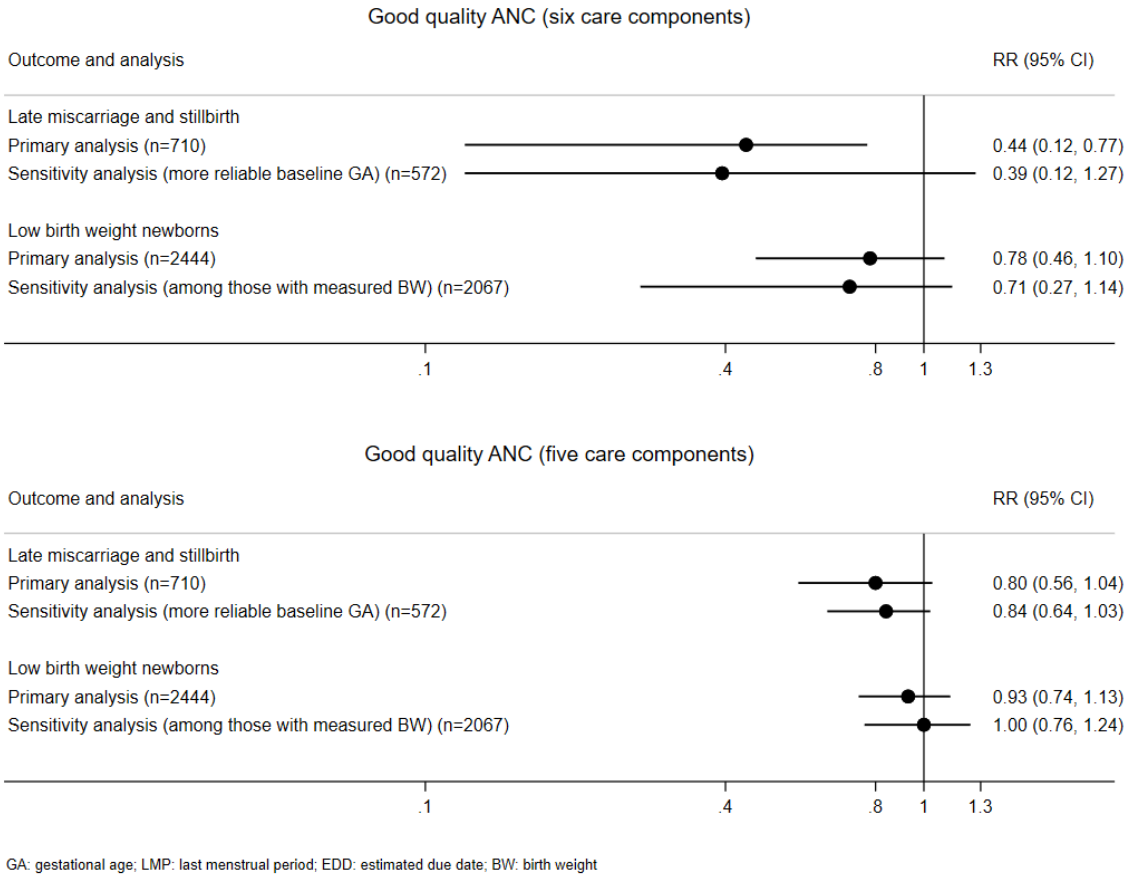
Table 10. Fetal and neonatal outcomes among three countries

	Ethiopia N=900		Kenya N=914		South Africa N=873	
Fetal outcomes	**Frequency (%)**		**Frequency (%)**		**Frequency (%)**	
Late miscarriages[1]	21	2.3%	21	2.3%	24	2.7%
Stillbirths[2]	12	1.3%	14	1.5%	11	1.3%
Livebirths	867	96.3%	879	96.2%	833	96.0%
Neonatal outcomes (among neonates still alive at the time of the survey)	**N=851**		**N=862**		**N=828**	
Low birth weight newborns[3]	72	8.5%	73	8.5%	106	12.8%
Fetal outcomes (among those with more reliable baseline GA)[4]	**N=460** (51.1%)[6]		**N=875** (95.7%)[6]		**N=868** (99.4%)[6]	
Late miscarriages[1]	9	2.0%	20	2.3%	24	2.8%
Stillbirths[2]	6	1.3%	13	1.5%	11	1.3%
Neonatal outcomes (among neonates still alive at the time of the survey and who had data on actual birth weights)	**N=507** (59.6%)[7]		**N=842** (97.7%)[7]		**N=773** (93.4%)[7]	
Low birth weight newborns[5]	37	7.3%	69	8.2%	93	12.0%

[1] Defined as fetal loss between 13 to 28 weeks of gestation
[2] Defined as fetal loss after 28 weeks of gestation
[3] Defined as newborn birth body weight less than 2.5kg, or self-reported newborn size as smaller than average or very small if actual birth weight was unavailable.
[4] More reliable baseline GA was determined by last menstrual period or estimated due date.
[5] Defined as newborn birth body weight less than 2.5kg.
[6] The percentage was calculated by dividing the number with a more reliable baseline GA by the number with a more reliable baseline GA or mothers' self-reported weeks of pregnancy if last menstrual period and estimated due date were unknown.
[7] The percentage was calculated by dividing the number with actual birth weight by the number with actual birth weight and Mothers' self-reported birth size if actual birth body weight was unknown.

Figure 6 summarizes risk ratios (RR) for the associations between good quality ANC and perinatal outcomes from the eight regression models. Our primary analysis found that receiving all six care components was associated with a 56% reduced risk of fetal losses (RR 0.44, 95% CI 0.12–0.77). The predicted probabilities of fetal loss for receiving good qulaity ANC and not receiving good qulaity ANC were 2.9% and 6.6%, respectively. The sensitivity analysis in the sample of women with a more reliable baseline GA found no significant association (RR 0.39, 95% CI 0.12–1.27). Regressions for LBW newborns, both primary and sensitivity analyses, did not show associations between good quality ANC and LBW newborns. On the other hand, in the sensitivity analysis with good quality ANC defined as receiving five care components (excluding ultrasound), no significant associations were found for both outcomes. Modifying the definition of good quality ANC from six to five care components, we observed that effect sizes shifted toward 1 for both outcomes and both primary and sensitivity analyses done in subsets. In addition, pregnant women who presented any of the three danger signs at baseline were associated with increased fetal loss in both regressions using good quality ANC of six care components (OR 1.56, 95% CI 1.11–2.20) and five (OR 1.61, 95% CI 1.14–2.27) **(Table 11)**. In the regressions for LBW newborns, South Africa was associated with increased LBW newborns; women aged 20 to 35 years old, compared to those younger than 20 years old, had significantly lower odds of delivering an LBW newborn **(Appendix D. Supplemental Table 10**).

Figure 6. Risk ratio (RR) of fetal loss (late miscarriage and stillbirth) and LBW newborns between those who received and who did not receive good quality ANC



GA: gestational age; LMP: last menstrual period; EDD: estimated due date; BW: birth weight

Results are from eight mixed-effect logistic regression models that assessed the associations of good quality ANC (defined as receiving six basic care components at first ANC visits or five, excluding ultrasound) and fetal losses and LBW newborns, respectively. For each outcome, a sensitivity analysis was performed among a sample subset: a sample subset with a more reliable baseline GA was used for the model of fetal loss; a sample subset with measured BW data available was used for the LBW model. All regressions included country as a fixed effect, study site and facility as random intercepts, and a list of covariates, including age, education level, health literacy, health status, pregnancy intention, risk factor categories, and presence of any danger signs at first ANC visits. For LBW regression, the time of enrolment at the first ANC visits (in the trimester) was also included as a covariate.

Table 11. Results of mixed-effect logistic regressions for fetal loss (late miscarriage and stillbirth)

	Good quality ANC (received six care components) N = 710			Good quality ANC (received five care components) N= 710		
	Odds Ratio (OR)	**95% Confidence Interval (CI)**	***p*-value**	**Odds Ratio (OR)**	**95% Confidence Interval (CI)**	***p*-value**
Received good quality ANC	**0.42**	**0.19 – 0.90**	**0.027**	0.78	0.56 – 1.09	0.143
Socioeconomic and demographic status						
Country						
Ethiopia	*ref*			*ref*		
Kenya	0.86	0.46 – 1.61	0.632	0.99	0.45 – 2.19	0.981
South Africa	0.52	0.12 – 2.18	0.368	0.60	0.12 – 2.94	0.530
Age range						
15 to <20 years old	*ref*			*ref*		
≥20 to <35 years old	0.92	0.36 – 2.32	0.855	0.91	0.35 – 2.37	0.844
≥35 years old	1.64	0.33 – 8.07	0.541	1.60	0.31 – 8.13	0.572
Intended pregnancy	0.84	0.32 – 2.21	0.723	0.84	0.31 – 2.28	0.736
Education level						
No education or some primary	*ref*			*ref*		
Complete primary	1.11	0.48 – 2.60	0.803	1.06	0.45 – 2.51	0.898
Complete secondary or higher	1.34	0.70 – 2.59	0.375	1.29	0.66 – 2.55	0.456
Health literacy[1]	1.59	0.73 – 3.44	0.242	1.59	0.74 – 3.40	0.236
Wealth						
Poorest	*ref*			*ref*		
Middle	0.66	0.33 – 1.33	0.242	0.67	0.34 – 1.34	0.258
Richest	0.85	0.56 – 1.28	0.430	0.85	0.58 – 1.23	0.385
Maternal health						
Self-rated own health as very good or excellent[2]	0.69	0.38 – 1.28	0.242	0.70	0.39 – 1.26	0.234
Risk factor at baseline[3]						
No risk factor	*ref*			*ref*		
One risk factor	1.16	0.66 – 2.06	0.606	1.19	0.67 – 2.11	0.546
Two risk factors	1.15	0.36 – 3.68	0.818	1.10	0.36 – 3.39	0.868
Three or more risk factors	1.88	0.60 – 5.95	0.281	2.03	0.68 – 6.10	0.205
Reported any pregnancy danger signs at baseline[4]	**1.56**	**1.11 – 2.20**	**0.011**	**1.61**	**1.14 – 2.27**	**0.007**

[1] Defined as answering six health knowledge questions correctly. The six questions were adopted from the Indian Health and Human Development Survey.
[2] Self-rated own health was based on a Likert scale of five levels (excellent, very good, good, fair, and poor)
[3] Risk factors at baseline include any chronic systemic illness(es) known before pregnancy (including diabetes, hypertension, cardiac disease, HIV, mental health disorder, schizophrenia, epilepsy, seizure, renal disorder, asthma, tuberculosis, anemia, hemoglobinopathy, chronic pelvic inflammatory disease, ovarian cyst, fibroids, uterine myoma, genital tract abnormalities, thyroid cancer, thyroid disease, peptic ulcer disease, gestational hypertension in previous pregnancy, a history of stroke), any history of obstetric complications (Cesarean section, stillbirth, preterm birth, neonatal death, and postpartum hemorrhage), and multiple pregnancy known at the first ANC visit
[4] Pregnancy danger signs at baseline include vaginal bleeding, fever, and fainting or loss of consciousness

5.4 Discussion

In this analysis, we used data from the eCohort study in three African countries and investigated associations between ANC quality and perinatal outcomes. We found that less than 10% of pregnant women in the study received all six basic care components at their first ANC visits. While blood pressure measurement and blood and urine tests were performed in nearly all women, the proportion of women receiving ultrasound examinations was much lower. Our regression analyses also found that receiving six care components was associated with a reduction in fetal losses (late miscarriages and stillbirths) but not in LBW.

The significant association between good quality ANC and fetal loss confirmed the importance of ultrasound examinations, as the association became insignificant when excluding ultrasound from defining good quality ANC. We observed a larger effect size, with a 56% reduction in the risk of fetal loss when good quality ANC included ultrasound, compared to a 20% reduction when excluding ultrasound. Notably, another significant finding was the low detection of multiple pregnancies at the first ANC visits. For example, more than three-quarters of multiple pregnancies in South Africa were not detected at the first ANC visits; meanwhile, South Africa had the lowest proportion who had an ultrasound scan at first visits. This phenomenon is particularly concerning, as multiple pregnancy is a well-studied risk factor for numerous adverse outcomes.(142) Early identification of multiple pregnancies helps in risk stratification and benefits high-risk pregnancies from timely referrals. In addition to detecting multiple pregnancies, obstetric ultrasounds can assess GA accurately, monitor fetal growth, identify congenital anomalies, and detect breech babies and obstructed labor – all of which are critical for

ensuring the health of pregnant women and their babies.(143) However, a cluster randomized trial assessing the effects of ultrasound in ANC in five LMICs found anticipated higher detection of multiple pregnancies but no improvement in maternal, fetal, and neonatal death.(144) There remain two critical gaps in obstetric ultrasound use in LMICs. First, access to obstetric ultrasound is still limited despite increasing use.(145) Second, obstetric ultrasounds are mainly diagnostic, and the ability to use ultrasound scan results for improving maternal and newborn health varies depending on the facility capacities.(144) While we found the associations between fetal loss and good quality ANC that included ultrasound and acknowledged its benefits, we cautioned careful scale-ups of obstetric ultrasound use in low-resource settings.

A few studies have alerted the global community to the poor quality of ANC despite increased coverage.(7-9, 40, 41) The question, "What constitutes good quality ANC?" remains. A few studies have used the DHS household survey data to examine the content of ANC received by women. A study using the Demographic and Health Survey (DHS) of 91 LMICs found that one-third of women who used ANC did not receive a package of three essential care components (blood pressure measurement, blood test, and urine test).(7) Similar findings of achieving the recommended number of ANC visits but not receiving essential care contents were also found in other studies.(8, 9) Another study of 10 LMICs reported that the majority of women in need of ANC had at least one visit and two-fifths had at least 4; however, the content of care they received was suboptimal, with blood pressure measurement being the most commonly performed and the counseling on complications the least, which was similar to our findings.(9)A recent study in India also revealed the poor coverage of quality-adjusted ANC, defined as

receiving care including blood pressure and weight measurement, abdomen examination, and blood and urine tests.(40) It is worth noting that most prior studies did not include ultrasound in defining the essential components for good quality ANC, while the WHO recommends ultrasound before 24 weeks of gestation for all pregnancies.(6) Our findings, together with prior research, suggest that global efforts should shift to ensuring the delivery of necessary care at ANC visits over merely increasing the number of contacts.

Stillbirths have significant economic and psychosocial consequences.(146) Nearly two million babies were stillborn globally every year, with 98% occurring in LMICs.(147, 148) The Every Newborn Action Plan aimed to reduce stillbirths to 12 or fewer per 1,000 births by 2030.(149) While 40% of stillbirths occur during labor and some could be avoided primarily by improved delivery care (148), antepartum stillbirths are linked to several modifiable risk factors, including maternal infections (malaria, syphilis, HIV), non-communicable diseases such as hypertension and diabetes, nutrition, and lifestyle factors.(147, 150-153) Hence, high-quality ANC is crucial to prevent antepartum stillbirths by addressing these risk factors. However, a conceptual framework on stillbirth in LMICs proposed by UNICEF in 2022 mentioned notable evidence gaps in measuring the overall effects of ANC quality on stillbirth.(154) A study in Ghana developed an addictive ANC quality index of receiving nine care components during any of their ANC visits; this study found that the receipt of eight or nine care components was associated with a significant reduction in stillbirth (OR 0.50, 95% CI 0.29 – 0.84).(43) Our study adds value to the limited body of evidence on this topic.

LBW babies are also a serious global health problem, with an estimated 14.7% of

liveborn newborns being LBW globally in 2020.(155) Our study found that 8.5% of babies who were still alive at the follow-up survey in Ethiopia and Kenya and 12.8% in South Africa were LBW. The actual prevalence of LBW might be higher because the data on birth weight or size were unavailable for cases of neonatal and infant deaths. Also, there was a higher prevalence of LBW in South Africa, which might be attributable to more adolescent pregnant women and HIV carriers. Evidence-based antenatal interventions have been identified to prevent LBW, including a number of nutritional interventions such as supplementations of IFA, balanced protein/energy, micronutrients, etc.(156, 157) However, evidence regarding the associations between ANC quality and LBW newborns is relatively limited compared to other neonatal outcomes, such as neonatal death. Available evidence suggested that ANC attendance and good quality ANC reduced LBW newborns.(44-46) Recently, a conceptual framework brought together preterm infants, small-for-gestational-age babies, and LBW newborns under the newly developed term "small vulnerable newborns," emphasizing a comprehensive approach that integrates effective interventions and necessary care components into ANC to support this vast population of small babies globally.(4, 51) In our analysis, we did not see the linkages between good quality ANC and LBW newborns. There are a few potential explanations. First, the ANC care components we identified were proxies of good quality ANC, which might not capture all aspects of quality. Second, receiving the core ANC care components does not guarantee adherence to medical advice or appropriate management when risk factors are detected.(158)

Our study had limitations. First, our analyses and inference testing are limited by small sample sizes. Late miscarriages and stillbirths are rare outcomes; only 3.9% of

women in our study experienced late miscarriages or stillbirths, which led to large estimates of standard errors. Similarly, some of the sensitivity analyses were likely underpowered. Second, we caution that our results may have limited generalizability as the study enrolled participants from two particular sites in each country, meaning that the samples were not nationally representative. Third, we only included care components at the first ANC visit to define good quality. These care components, while fundamental, are surrogate indicators for the overall ANC quality throughout pregnancy. The rationale for not including care content at follow-up visits and ANC utilization (the number of ANC visits) is to avoid immortal time bias. This bias often occurs in perinatal epidemiology studies assessing the associations between stillbirths and pregnancy complications, where pregnancy complications are often treated as exposures. If a pregnancy ends in stillbirth before the pregnancy complication develops, the exposure status will be inaccurately assigned, as the woman does not have the opportunity to experience the exposure.(159, 160) Similarly, it is impossible for women who have developed feta losses to attend additional ANC visits and receive additional care at follow-up visits. Fourth, the LBW analysis may be limited by inaccurate birth weights that were self-reported by mothers since 56.6% of women in Ethiopia, 92.4% in Kenya, and 88.8% in South Africa knew their babies' weight at birth. Fifth, newborn birth weight and size data were only collected for babies alive at the time of the survey, excluding neonatal and infant deaths, some of which might be LBW, as LBW newborns were at a higher risk of death compared to normal-weight babies. In addition, we were unable to distinguish between antepartum and intrapartum stillbirths in the fetal loss analysis. Lastly, these three countries differed in their national ANC guidelines. For instance,

Ethiopia and Kenya recommend an ultrasound scan for all women before 24 weeks of gestation, while South Africa's 4th edition national ANC guidelines recommend an ultrasound scan only for women who are unsure about their LMP, resulting in a lower proportion of women receiving an ultrasound at first ANC visits in South Africa.

As more women in LMICs have made ANC contacts, the challenge remains in delivering ANC of good quality in areas with the highest burdens of maternal and newborn morbidity and mortality. Future programs and research should continue to examine the relationship between overall ANC quality and perinatal outcomes, expand the dialogue on ANC quality from care components that detect health conditions to appropriate management of those health conditions, and consider scaling up obstetric ultrasound in identifying high-risk pregnancies.

Chapter 6: Discussion

6.1 Summary of Findings

This dissertation has several significant findings. In the first two papers on corticosteroid utilization and facility readiness, I found that, first, antenatal corticosteroids among pregnant women at risk of imminent preterm labor were substantially underused, with only one out of ten health facilities having administered ACS in the 9 LMICs in the sample. Second, corticosteroid availability was still limited, as one-fourth of the facilities had either injectable dexamethasone or betamethasone available at the time of the survey. Significant gaps existed between drug availability and actual utilization. Third, health facilities in these countries had low levels of readiness to administer ACS appropriately based on the WHO recommendations on ACS use. In addition, one-fifth of the facilities had an overall readiness index above 50%. Lastly, in identifying facility-level factors affecting ACS use, past performance of CEmONC signal functions was significantly associated with recent ACS provisions, with neonatal resuscitation having the largest effect (RR 2.62). As the past performance of CEmONC reflected a minimal level of provider competence in managing obstetric emergencies, this finding highlighted the importance of provider knowledge, skills, and competence in delivering corticosteroids appropriately.

In the third paper on Ethiopia, a few major barriers to the appropriate provision of ACS were identified, including health service delivery structure, knowledge gaps among providers, accurate GA assessment, and drug availability. The country's health service structure largely affects the effectiveness of ACS utilization. Ethiopia's national obstetric protocols suggest administering ACS at health centers, the primary care level where

many women seek antenatal and delivery care. However, health centers lack the necessary equipment and medicines to take care of preterm newborns; these babies are unlikely to survive even if they might have received corticosteroids before birth. Additionally, insufficient provider knowledge hinders the appropriate utilization of ACS. These knowledge gaps are twofold: first, the existence of ACS, its function and benefits, and how to administer it accurately, and second, the identification of women with imminent preterm labor.

Our last paper found suboptimal ANC quality in Ethiopia, Kenya, and South Africa. Only 7.4% of women in the sample received good quality ANC, defined as receiving all six core care components at their first ANC visits. Good quality ANC was significantly associated with a reduction in the risk of late miscarriage and stillbirth. Yet, the association became insignificant when ultrasound scan was removed from defining good quality ANC. This finding highlighted the importance of ultrasound examinations in antenatal care.

6.2 Strengths and Limitations

To our knowledge, this dissertation is the first study to comprehensively examine the landscape of availability and utilization of ACS at the facility level and facility structural readiness in multiple countries using the DHS SPA data. As most previous research on ACS utilization studied coverage rates at the individual level, this dissertation adds significant value in addressing the evidence gaps. Our second paper found significant associations between recent ACS use and the past performance of CEmONC services, which was considered a particular strength, as very few studies have explored

this relationship. Additionally, the third paper, focusing on Ethiopia, conducted a detailed and comprehensive investigation of the current landscape of ACS utilization and identified several barriers to appropriate ACS provision. Based on the findings, we are able to suggest priority areas for policy changes in the country with one of the highest numbers of preterm newborns globally. Lastly, the last paper on the association of good quality ANC and perinatal outcomes added value to the limited body of literature on the associations between ANC quality and positive birth outcomes. Our findings highlighted the importance of ultrasound examinations, which were less commonly studied in previous research on ANC quality.

On the other hand, this dissertation has limitations. For the first two papers, I am aware of the inherent limitations of using the SPA facility survey data. The nine countries in the sample varied in various aspects, so careful interpretation was suggested if attempting to do cross-country comparisons. Some indicators used for constructing the readiness variable are proxies, which might over- or underestimate the true availability. In the third paper on the barriers to effective ACS provision in Ethiopia, I summarized our findings through a standardized discussion with stakeholders without adopting a standard qualitative research approach. Certain nuances might not be captured without a standard coding and theme development process. The last paper on ANC quality using eCohort study data also has limitations. First, my analysis might be underpowered due to small sample sizes and rare outcomes. In defining good quality ANC, I restricted care components to those provided at the first ANC visits in order to avoid immortal time bias, as pregnant women who develop fetal losses are unlikely to have additional ANC visits and more care inherently. To avoid selection bias, I restricted the sample to women

enrolled in their first trimester for regressions for fetal loss. These restrictions resulted in small sample sizes. Second, some limitations came from the data collection process. For example, only newborns who were alive during follow-up surveys had birth weight and birth size data available. Third, the six care components, while fundamental, are surrogate indicators of the overall quality of antenatal care.

6.3 Conclusion

Antenatal corticosteroid utilization is a promising intervention to improve preterm outcomes in low-source countries, but it is not a silver bullet that can independently save thousands of preterm newborns' lives on its own. In order to realize the population benefits of ACS, policymakers should be cautious about their strategies in ACS scale-up, taking into account the country's specific context. Fundamentally, ACS uptake needs support from national guidelines and requires leadership-level commitments to encourage nationwide ACS uptake in adequately equipped facilities. Meanwhile, a country's health service delivery structure affects the effectiveness of ACS, as the levels of care where ACS provisions and preterm deliveries take place matter tremendously. At the facility level, countries should equip specific levels of facilities for safe and effective use based on the countries' strategies. ACS needs to be administered in healthcare settings that are *ready*. The benefits of this intervention — reducing respiratory complications and neonatal death through accelerating fetal lung maturity — can only be realized when the equipment and medicines required for managing preterm deliveries and preterm newborns are available. Additionally, concerted efforts across policymakers, health facilities, and providers are needed to improve providers' knowledge, skills, and

competence. ACS provision should be incorporated into routine training for providers who will attend birth and manage preterm deliveries. On the other hand, the overall quality of antenatal care received by pregnant women is suboptimal, and ultrasound examination is substantially underused. This finding is particularly concerning as providing health services with poor quality is ineffective, wasteful, and ineffective.(42) The global community should continue its efforts to ensure the delivery of essential care components during ANC visits.

No single solution – either a specific antenatal intervention or a particular care component – could independently improve population health dramatically. All the solutions must be incorporated into health systems that can function properly and collaboratively across different levels. We have passed the halfway point towards the deadline of Sustainable Developmental Goals, and some evidence suggests that the global community is unlikely to achieve the target of ending preventable child and newborn deaths. Nevertheless, there is still a silver lining: we have actionable evidence on how to enhance maternal and newborn health. The global community has to ensure that the right care is provided to pregnant women in need at the right times in the right places.

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Appendix A. Chapter 2 Supplemental tables and figures

Supplemental Table 1. Sampling strategies of included SPA surveys

Survey	Sampling strategy[1]
Afghanistan 2018-2019	The survey focused on major public and private hospitals in the country's main seven provinces (including Nangarhar, Paktya, Kunduz, Balkh, Kandahar, and Herat, and Kabul). Among six provinces excluding Kabul, all 12 public hospitals, 37 private hospitals, and 52 private clinics were included. In Kabul, all 26 public and 20 private hospitals were surveyed, but a randomly selected sample of 13 private clinics (out of 84) were included.
Bangladesh 2017-2018	The survey adopted a stratified random sampling strategy for 1,600 facilities to obtain nationally representative data for different facility types, different facility management authorities, and each of the eight divisions (Barisal, Chittagong, Dhaka, Khulna, Mymensingh, Rajshahi, Rangpur, and Sylhet) of the country.
Nepal 2021	The survey adopted a stratified random sampling strategy for 1,633 health facilities through an equal probability systematic sampling. All government hospitals, all non-government hospitals with at least one bed, and all non-government hospitals in the provinces of Karnali and Sudurpashchim were included because of their small numbers. Also, all primary health care centers (PHCCs) and stand-alone HIV testing and counseling centers (stand-alone HTCs) were included.
Haiti 2017-2018	The survey was a national census of all operational health facilities in the country during the survey period of 2017 to 2018.
The Democratic Republic of the Congo 2017-2018	The survey adopted a probability sampling strategy from 12,059 health facilities in the country, excluding health posts. On average, approximately 50 facilities were selected for each of the 26 provinces, reaching a sample of 1,380 facilities.
Ethiopia 2021-2022	The survey adopted a stratified random sampling strategy, reaching a sample of 1,407 health facilities via an unequal probability systematic sampling. Within each region, stratification was achieved by facility type. All public and private hospitals were included because of their small numbers and crucial roles in the country's health system. Health centers were sampled, but all health centers in Dire Dawa and Harari were included. Clinics were sampled with all higher clinics included, and all clinics in Harari included. Health posts were sampled.
Malawi 2013-2014	The survey was a national census of all formal-sector health facilities, including public, private, and other managing authority types, in the country during the survey period between 2013 to 2014.
Senegal 2018 and 2019	Senegal implemented a continuous SPA, which was designed to continuously collect data on health facilities over a period of 5 years from 2012 to 2017, aiming to survey all health facilities in the country.
Tanzania 2014-2015	The survey was a sample of formal-sector health facilities, including public and private, during the survey period between 2014 and 2015. The sample was selected to obtain national representative data by facility type, managing authority type, and region.

[1] Information obtained from SPA reports.

Supplemental Table 2. The indicators used to assess facility readiness based on the 2022 WHO recommendations on ACS use

Antenatal corticosteroid therapy is recommended for women with a high likelihood of preterm birth from 24 to 34 weeks of gestation when the following conditions are met:				
WHO conditions/criteria	**Readiness categories**	**Indicators indentified from the SPA survey**		**SPA dataset**
1. Gestational age assessment can be accurately undertaken.	Readiness to accurately assess GA	Equipment	ultrasound	Inventory dataset
2. There is no clinical evidence of maternal infection.	Readiness to identify maternal infections	Equipment	thermometer	
		Diagnostics	hematology analyzer	
			HIV rapid diagnostic test	
			syphilis rapid diagnostic test	
3. Adequate childbirth care is available (including the capacity to recognize and safely manage preterm labor and birth).	Readiness to provide adequate childbirth care	Equipment	delivery pack	
			cord clamp	
			manual vacuum extractor	
			vacuum aspiration kit or D&C kit	
			forceps (large)	
			forceps (medium)	
		Medicines and commodities	parenteral antibiotics	
			parenteral anticonvulsants (diazepam)	
			parenteral oxytocin	
		Staff and guidelines	a health worker who can perform C/S	
			an anesthetist	
			national guidelines for BEmONC	
			national guidelines for CEmONC	
4. The preterm newborn can receive adequate care (including resuscitation, kangaroo mother care, thermal care, feeding support, infection treatment, and respiratory support, including continuous positive airway pressure as needed).	Readiness to provide preterm newborn care	Equipment	suction bulb or penguin sucker	
			stethoscope	
			newborn masks (0, 1), neonatal size self-inflating bag	
			incubator	
			other external heat source	
			pulse oximeter	
			oxygen concentrator	
			filled oxygen cylinder	
			oxygen distribution system	
		Medicines and commodities	glucometer	
			glucometer strips	
			hand-washing soap	
			disposable latex gloves	
		Staff and guidelines	staff trained on Integrated Management of Pregnancy and Childbirth (IMPAC)	Health worker interview dataset[1]
			staff trained in Comprehensive Emergency Obstetric and Newborn Care	
			staff trained on routine care for labor and normal vaginal delivery	
			guidelines on the management of preterm labor	Inventory dataset

*GA: gestational age; C/S: Cesarean section; BEmONC: Basic Emergency Obstetrics and Newborn Care; CEmONC: Comprehensive Emergency Obstetrics and Newborn Care

[1]To report readiness at the facility level using data from health worker interviews, we converted data from the health-worker level to the facility level by measuring the facility with at least one health worker who had received relevant training.

Supplemental Table 3. Survey response rates and number of facilities sampled, surveyed, and included in the analysis

Country	Survey year	Response rate[1]	Number of facilities sampled	Number of facilities surveyed[4]	Number (%) of facilities included in the analysis[5]
		median 94.9% (range 88.8%, 99.0%)	**N =10418** median 1130 (range 160, 1626)	**N = 9793** median 1158 (range 142, 1576)	**N = 8669** median 929 (range 108, 1500)
South Asia					
Afghanistan	2018-19	88.8%[2]	160	142	108 (76.1%)
Bangladesh	2017-18	95.3%	1600	1524	1498 (98.3%)
Nepal	2021	97.0%	1626	1576	1500 (95.2%)
Caribbean					
Haiti	2017-18	97.5%	1033	1007	929 (92.3%)
Sub-Saharan Africa					
DRC	2017-18	97.7%	1412	1380	1364 (98.8%)
Ethiopia	2021-22	82.3%	1407	1158	911 (78.7%)
Malawi	2013-14	92.2%	1060	977	645 (66.1%)
Senegal	2018	89.3%	466	841 (2018: 416; 2019: 425)	601 (71.5%)
Senegal	2019	94.5%[3]	454		
Tanzania	2014-15	99.0%	1200	1188	1056 (88.9%)

[1] Response rates were obtained from SPA final reports.
[2] Afghanistan 2018-2019 survey does not have a publicly available SPA final report. Its response rate was manually calculated.
[3] The response rate for Senegal 2019 is 94.5%, calculated by excluding health huts. The rate is 93.6% (425/454) if including health huts.
[4] The number of facilities surveyed is smaller than the number of facilities sampled because of non-response, refusal, or closure.
[5] Facilities included in the analysis are facilities that either provided antenatal care, performed normal deliveries, or performed Cesarean sections. The proportion was calculated by dividing the number of facilities included in the analysis by the number of facilities surveyed.

Supplemental Table 4. Facility structural readiness for 35 indicators by country and facility level

Four readiness categories based on WHO criteria		The proportion of facilities with the indicators available			South Asia							
					Afghanistan 2018-19				Bangladesh 2017-18			
				Median (range)[1]	Overall	Level 1	Level 2	Level 3	Overall	Level 1	Level 2	Level 3
1. Assess GA	**Equipment**	The proportion of facilities with a functional ultrasound machine in use		7.3% (0.2%, 12.3%)	92(82.4%)	3(41.2%)	5(67%)	84(86.2%)	178(3.6%)	13(0.7%)	19(1.7%)	92(82.4%)
2. Identify maternal infections	**Equipment**	The proportion with equipment	thermometer	52.3% (20.7%, 76.2%)	65(58.6%)	0(0%)	6(75%)	59(59.4%)	734(20.7%)	0(0%)	481(85.2%)	65(58.6%)
	Diagnostics	The proportion of facilities with the following diagnostics	(1) hematology analyzer	7.6% (2.7%, 30.5%)	94(92%)	6(86.3%)	5(70.1%)	83(94.8%)	131(2.7%)	11(0.5%)	16(1.7%)	94(92%)
			(2) HIV rapid diagnostic test	52.4% (21.2%, 82.1%)	37(25.8%)	2(27.5%)	1(7.2%)	34(27.9%)				
			(3) syphilis rapid diagnostic test	13.8% (3.0%, 68.8%)	30(21.9%)	2(27.5%)	1(7.2%)	27(23.3%)	128(3%)	18(1.1%)	22(2.7%)	30(21.9%)
3. Provide adequate childbirth care	**Equipment**	The proportion of facilities with the following equipment to perform CEmONC (obstetric-related)	(1) delivery pack	62.5% (19.0%, 87.5%)	80(74.5%)	0(0%)	5(28.6%)	75(83.4%)	692(19%)	0(0%)	449(77.5%)	80(74.5%)
			(2) cord clamp	55.8% (15.8%, 82.1%)	78(70.3%)	0(0%)	6(37.3%)	72(77.5%)	566(15.8%)	0(0%)	358(63.6%)	78(70.3%)
			(3) manual vacuum extractor	9.1% (4.7%, 33.9%)	76(69.1%)	0(0%)	3(17.4%)	73(78.4%)	214(4.8%)	0(0%)	90(14.7%)	76(69.1%)
			(4) vacuum aspiration kit or D&C kit	10.9% (5.8%, 49.4%)	74(60.5%)	0(0%)	6(37%)	68(66.1%)	303(5.8%)	0(0%)	125(14.5%)	74(60.5%)
			(5) forceps (large)	32.2% (5.4%, 73.5%)	85(74.9%)	0(0%)	10(100%)	75(75.6%)	718(19.7%)	0(0%)	473(80.4%)	85(74.9%)
			(6) forceps (medium)	34.8% (5.2%, 82.2%)	84(74.3%)	0(0%)	10(100%)	74(74.8%)	697(19.4%)	0(0%)	451(79.4%)	84(74.3%)
	Medicines and commodities	The proportion of facilities with the following medicines	(1) parenteral antibiotics	31.4% (4.6%, 51.3%)	45(42%)	0(0%)	2(50%)	43(43%)	281(4.6%)	0(0%)	82(7.6%)	45(42%)
			(2) parenteral anticonvulsants (diazepam)	31.8% (4.7%, 66.6%)	49(45.1%)	0(0%)	2(50%)	47(46.7%)	264(4.7%)	0(0%)	73(8.6%)	49(45.1%)
			(3) parenteral oxytocin	56.4% (7.5%, 79.2%)	78(74.4%)	0(0%)	5(32.2%)	73(82.8%)	401(7.5%)	0(0%)	178(21.6%)	78(74.4%)
	Staff and guidelines	The proportion of facilities that have the following staff	(1) a health worker who can perform C/S	4.0% (2.2%, 20.5%)	46(32.5%)	0(0%)	0(0%)	46(37.8%)	158(2.5%)	0(0%)	0(0%)	46(32.5%)
			(2) an anesthetist	3.8% (1.9%, 12.3%)	36(26.6%)	0(0%)	0(0%)	36(31%)	118(1.9%)	0(0%)	0(0%)	36(26.6%)
		The proportion of facilities with the following guidelines	(1) national guidelines for BEmONC	18.2% (2.8%, 40.9%)	9(5.1%)	0(0%)	0(0%)	9(5.9%)	132(2.8%)	0(0%)	80(10.9%)	9(5.1%)
			(2) national guidelines for CEmONC	13.4% (2.2%, 41.9%)	9(5.1%)	0(0%)	0(0%)	9(5.9%)	114(2.2%)	0(0%)	65(8.7%)	9(5.1%)
4. Provide adequate preterm newborn care	**Equipment**	The proportion of facilities with the following equipment for neonatal resuscitation	(1) suction bulb or penguin sucker	46.2% (15.8%, 80.4%)	78(81.6%)	0(0%)	7(79.4%)	71(85.7%)	652(15.8%)	0(0%)	414(62.6%)	78(81.6%)
			(2) stethoscope (in general)	51.1% (23.1%, 81.3%)	87(87.4%)	0(0%)	5(69.7%)	82(93.7%)	804(23.2%)	0(0%)	540(97.6%)	87(87.4%)
			(3) newborn masks, self-inflating bag	37.3% (13.1%, 74.4%)	83(77.3%)	0(0%)	6(37%)	77(85.7%)	601(13.1%)	0(0%)	358(48%)	83(77.3%)
		The proportion of facilities with thermal care equipment	(1) incubator	4.5% (2.2%, 6.6%)	54(55.4%)	0(0%)	2(11.1%)	52(63.3%)	127(2.2%)	0(0%)	29(2.7%)	54(55.4%)
			(2) other external heat source	14.6% (4.2%, 58.4%)	68(64.1%)	0(0%)	3(16.7%)	65(72.7%)	176(4.2%)	0(0%)	61(10.7%)	68(64.1%)
		The proportion of facilities with equipment for respiratory care, including safe oxygen use	(1) pulse oximeter	8.8% (2.8%, 42.0%)	49(53.7%)	1(13.7%)	1(5.6%)	47(61.2%)	142(3%)	7(0.4%)	18(1.1%)	49(53.7%)
			(2) oxygen concentrator	9.2% (2.4%, 15.2%)	40(48.2%)	0(0%)	0(0%)	40(56.1%)	192(3.2%)	6(0.3%)	69(5.8%)	40(48.2%)
			(3) filled oxygen cylinder	9.8% (1.8%, 22.5%)	82(84.9%)	3(45.1%)	7(82.4%)	72(87.1%)	334(6.6%)	23(1%)	122(13.2%)	82(84.9%)
			(4) oxygen distribution system	3.5% (1.6%, 8.5%)	16(13.3%)	2(27.5%)	1(5.6%)	13(13.5%)	84(1.6%)	2(0.1%)	26(2%)	16(13.3%)
	Medicines and commodities	The proportion with commodities for monitoring blood glucose	(1) glucometer	22.2% (19.3%, 79.7%)	42(37%)	0(0%)	3(55.5%)	39(36.6%)	310(21.1%)	124(21.7%)	64(10.6%)	42(37%)
			(2) glucometer strips	20.6% (17.4%, 82.0%)	37(34%)	0(0%)	3(55.5%)	34(33.1%)	303(21.3%)	126(22.2%)	57(9.9%)	37(34%)
		The proportion with commodities for infection management	(1) hand-washing soap	50.8% (45.3%, 88.5%)	71(62.6%)	7(100%)	4(22.7%)	60(65.5%)	1075(72.8%)	473(72.1%)	406(77.3%)	71(62.6%)
			(2) disposable latex gloves	89.8% (69.4%, 96.4%)	102(88.9%)	7(100%)	8(50.5%)	87(92.9%)	1158(73.7%)	458(70.3%)	472(84.7%)	102(88.9%)
	Staff and guidelines	The proportion of facilities with at least one health worker who has received training about the following in the past 24 months	(1) IMPAC[2]	18.6% (2.4%, 37.8%)	15(12.9%)	1(13.7%)	0(0%)	14(14.3%)	116(15%)	32(16.6%)	45(11.7%)	15(12.9%)
			(2) CEmONC[3]	17.6% (2.0%, 29.6%)	7(4.2%)	0(0%)	0(0%)	7(4.9%)	84(10.6%)	19(12.3%)	32(6.1%)	7(4.2%)
			(3) Routine care for labor, normal delivery	24.0% (2.8%, 43.5%)	16(13.5%)	1(13.7%)	0(0%)	15(15.1%)	153(18.2%)	32(20.5%)	78(14.8%)	16(13.5%)
		The proportion of facilities with the following guidelines	guidelines on the management of preterm labor	10.2% (3.2%, 34.7%)	9(5.1%)	0(0%)	0(0%)	9(5.9%)	140(3.2%)	0(0%)	85(13.6%)	9(5.1%)

[1] Median and range were obtained from data across eight countries (excluding Afghanistan). [2]Integrated Management of Pregnancy and Childbirth. [3]Comprehensive Emergency Obstetric and Newborn Care. : data unavailable

Supplemental Table 4. Facility structural readiness for 35 indicators by country and facility level (continued)

Four readiness categories based on WHO criteria		The proportion of facilities with the indicators available		South Asia				Caribbean			
				Nepal 2021				Haiti 2017-2018			
				Overall	Level 1	Level 2	Level 3	Overall	Level 1	Level 2	Level 3
1. Assess GA accurately	**Equipment**	The proportion of facilities with a functional ultrasound machine in use		422(12.3%)	61(5.3%)	135(10.3%)	226(93.3%)	100(10.8%)	18(3.2%)	14(5.5%)	68(63.5%)
2. Identify maternal infections	**Equipment**	The proportion with the equipment	thermometer	731(48%)	0(0%)	515(91.7%)	216(90.1%)	310(33.4%)	0(0%)	227(89%)	83(77.5%)
	Diagnostics	The proportion of facilities with the following diagnostics	(1) hematology analyzer	309(8.6%)	37(3.8%)	70(5.4%)	202(79.3%)	283(30.5%)	123(21.7%)	88(34.5%)	72(67.3%)
			(2) HIV rapid diagnostic test					197(21.2%)	97(17.1%)	68(26.6%)	32(29.9%)
			(3) syphilis rapid diagnostic test	304(12.8%)	69(7.2%)	149(16.2%)	86(32.4%)	194(20.9%)	106(18.7%)	60(23.5%)	28(26.2%)
3. Provide adequate childbirth care	**Equipment**	The proportion of facilities with the following equipment to perform CEmONC (obstetric-related)	(1) delivery pack	767(50.6%)	0(0%)	549(97.2%)	218(88.6%)	283(30.5%)	0(0%)	198(77.6%)	85(79.4%)
			(2) cord clamp	714(46.8%)	0(0%)	505(89.4%)	209(87.1%)	314(33.8%)	0(0%)	218(85.5%)	96(89.6%)
			(3) manual vacuum extractor	313(12.1%)	0(0%)	137(17.6%)	176(70.8%)	51(5.5%)	0(0%)	20(7.8%)	31(28.9%)
			(4) vacuum aspiration kit or D&C kit	326(10.9%)	0(0%)	138(14.5%)	188(76.6%)	100(10.8%)	0(0%)	55(21.6%)	45(42%)
			(5) forceps (large)	640(40.6%)	0(0%)	441(76.7%)	199(83.9%)	50(5.4%)	0(0%)	17(6.7%)	33(30.8%)
			(6) forceps (medium)	707(46.1%)	0(0%)	499(88%)	208(87.1%)	49(5.3%)	0(0%)	20(7.9%)	29(27.1%)
	Medicines and commodities	The proportion of facilities with the following medicines	(1) parenteral antibiotics	575(34.4%)	0(0%)	388(64%)	187(79%)	179(19.3%)	0(0%)	109(42.8%)	70(65.3%)
			(2) parenteral anticonvulsants (diazepam)	358(14.7%)	0(0%)	175(22.4%)	183(76.8%)	112(12.1%)	0(0%)	67(26.3%)	45(41.9%)
			(3) parenteral oxytocin	760(50.5%)	0(0%)	547(97.4%)	213(86.7%)	257(27.7%)	0(0%)	173(67.9%)	84(78.4%)
	Staff and guidelines	The proportion of facilities that have the following staff	(1) a health worker who can perform C/S	166(3.5%)	0(0%)	0(0%)	166(65.6%)	54(5.8%)	0(0%)	0(0%)	54(50.4%)
			(2) an anesthetist	152(3.2%)	0(0%)	0(0%)	152(60.4%)	43(4.6%)	0(0%)	0(0%)	43(40.1%)
		The proportion of facilities with the following guidelines	(1) national guidelines for BEmONC								
			(2) national guidelines for CEmONC					124(13.4%)	0(0%)	88(34.5%)	36(33.6%)
4. Provide adequate preterm newborn care	**Equipment**	The proportion of facilities with the following equipment for neonatal resuscitation	(1) suction bulb or penguin sucker	393(22.3%)	0(0%)	252(40.4%)	141(61.2%)	325(35%)	0(0%)	226(88.6%)	99(92.5%)
			(2) stethoscope (in general)	771(51.1%)	0(0%)	551(98%)	220(91.9%)	335(36.1%)	0(0%)	242(94.9%)	93(86.8%)
			(3) newborn masks, self-inflating bag	718(47.7%)	0(0%)	511(91.5%)	207(86.2%)	207(22.3%)	0(0%)	122(47.8%)	85(79.5%)
		The proportion of facilities with equipment for thermal care	(1) incubator	141(4.5%)	0(0%)	42(4.7%)	99(43.6%)	59(6.4%)	0(0%)	24(9.5%)	35(32.7%)
			(2) other external heat source	530(33.6%)	0(0%)	354(63.2%)	176(72.8%)	160(17.2%)	0(0%)	90(35.3%)	70(65.4%)
		The proportion of facilities with equipment for respiratory care, including safe oxygen use	(1) pulse oximeter	770(42%)	211(28.1%)	340(50.4%)	219(91.8%)	155(16.7%)	58(10.2%)	54(21.2%)	43(40.1%)
			(2) oxygen concentrator	307(11.7%)	37(4.1%)	145(14.7%)	125(52.3%)	100(10.8%)	23(4.1%)	40(15.7%)	37(34.6%)
			(3) filled oxygen cylinder	507(22.5%)	85(8.5%)	237(30.3%)	185(78.7%)	149(16.1%)	36(6.3%)	55(21.7%)	58(54.2%)
			(4) oxygen distribution system	128(3.2%)	11(1%)	7(0.6%)	110(45.4%)	32(3.5%)	5(0.9%)	11(4.4%)	16(14.9%)
	Medicines and commodities	The proportion with commodities for monitoring blood glucose	(1) glucometer	348(19.4%)	94(11.4%)	150(24.9%)	104(42.6%)	463(49.8%)	227(40%)	159(62.3%)	77(71.9%)
			(2) glucometer strips	325(17.4%)	82(10%)	138(21.9%)	105(42.9%)	424(45.6%)	201(35.4%)	146(57.2%)	77(71.9%)
		The proportion with commodities for infection management	(1) hand-washing soap	1297(88.5%)	595(86.2%)	507(91.7%)	195(81.8%)	492(52.9%)	305(53.8%)	133(52.1%)	54(50.5%)
			(2) disposable latex gloves	1433(95.8%)	651(93.8%)	554(97.9%)	228(94.2%)	831(89.5%)	497(87.7%)	235(92.2%)	99(92.5%)
	Staff and guidelines	The proportion of facilities with at least one health worker who has received training about the following in the past 24 months	(1) IMPAC[1]	87(4.5%)	4(0.7%)	54(7.7%)	29(10.2%)	257(27.8%)	76(13.5%)	109(42.8%)	72(67.3%)
			(2) CEmONC[2]	98(4.4%)	5(1.2%)	57(6.8%)	36(12.5%)	218(23.5%)	59(10.4%)	91(35.7%)	68(63.5%)
			(3) Routine care for labor and normal delivery	180(11.1%)	7(1%)	119(20.4%)	54(18.9%)	258(27.9%)	75(13.3%)	111(43.6%)	72(67.3%)
		The proportion of facilities with the following guidelines	guidelines on the management of preterm labor					60(6.4%)	0(0%)	40(15.6%)	20(18.6%)

[1]Integrated Management of Pregnancy and Childbirth. [2]Comprehensive Emergency Obstetric and Newborn Care. : data unavailable

Supplemental Table 4. Facility structural readiness for 35 indicators by country and facility level (continued)

Four readiness categories based on WHO criteria		The proportion of facilities with the indicators available		Sub-Saharan Africa							
				DRC 2017-2018				Ethiopia 2021-2022			
				Overall	Level 1	Level 2	Level 3	Overall	Level 1	Level 2	Level 3
1. Assess GA accurately	**Equipment**	The proportion of facilities with a functional ultrasound machine in use		450(10.7%)	1(12.5%)	8(1.2%)	441(36.2%)	344(4.5%)	16(1.2%)	38(6.1%)	290(84.9%)
2. Identify maternal infections	**Equipment**	The proportion with the equipment	thermometer	1102(76.2%)	0(0%)	377(74.6%)	725(85.9%)	568(21%)	0(0%)	262(83.5%)	306(91%)
	Diagnostics	The proportion of facilities with the following diagnostics	(1) hematology analyzer	179(5.4%)	1(12.5%)	8(2%)	170(14.1%)	364(5.7%)	17(1%)	68(12.4%)	279(82.2%)
			(2) HIV rapid diagnostic test	654(44.2%)	4(28.1%)	189(39.3%)	461(58.5%)	616(29.1%)	62(10.5%)	258(85.6%)	296(80.1%)
			(3) syphilis rapid diagnostic test	218(11.8%)	1(12.5%)	53(9.9%)	164(16.9%)	238(11.1%)	24(5.2%)	107(29.1%)	107(28.2%)
3. Provide adequate childbirth care	**Equipment**	The proportion of facilities with the following equipment to perform CEmONC (obstetric-related)	(1) delivery pack	1240(87.5%)	0(0%)	437(87.2%)	803(94.5%)	605(22.5%)	0(0%)	276(89.5%)	329(96.9%)
			(2) cord clamp	1160(79.1%)	0(0%)	409(80.1%)	751(81.9%)	625(23.4%)	0(0%)	292(93.4%)	333(97.9%)
			(3) manual vacuum extractor	273(7.2%)	0(0%)	28(5.1%)	245(13.4%)	518(16.5%)	0(0%)	205(62.8%)	313(92.8%)
			(4) vacuum aspiration kit or D&C kit	729(36.4%)	0(0%)	134(26.4%)	595(65.9%)	385(10%)	0(0%)	124(36.2%)	261(70.4%)
			(5) forceps (large)	127(5.9%)	0(0%)	31(5.4%)	96(7.6%)	617(23.9%)	0(0%)	286(95.4%)	331(97.4%)
			(6) forceps (medium)	112(5.2%)	0(0%)	21(4.6%)	91(7.1%)	611(23.4%)	0(0%)	281(93.4%)	330(96.4%)
	Medicines and commodities	The proportion of facilities with the following medicines	(1) parenteral antibiotics	549(36.4%)	0(0%)	174(34.3%)	375(44.4%)	489(16.4%)	0(0%)	204(64.6%)	285(75.7%)
			(2) parenteral anticonvulsants (diazepam)	785(55.4%)	0(0%)	253(52.7%)	532(66.6%)	351(10.4%)	0(0%)	121(39.3%)	230(61.6%)
			(3) parenteral oxytocin	1110(77.3%)	0(0%)	394(77.5%)	716(82.4%)	611(22.8%)	0(0%)	283(90.7%)	328(96.7%)
	Staff and guidelines	The proportion of facilities that have the following staff	(1) a health worker who can perform C/S	725(20.5%)	0(0%)	0(0%)	725(77.3%)	312(2.2%)	0(0%)	0(0%)	312(83.5%)
			(2) an anesthetist	486(12.3%)	0(0%)	0(0%)	486(46.4%)	311(2.2%)	0(0%)	0(0%)	311(82.8%)
		The proportion of facilities with the following guidelines	(1) national guidelines for BEmONC					350(11.5%)	0(0%)	147(45%)	203(55%)
			(2) national guidelines for CEmONC	411(24.7%)	0(0%)	118(23.2%)	293(30.5%)	162(4.3%)	0(0%)	45(15.5%)	117(33%)
4. Provide adequate preterm newborn care	**Equipment**	The proportion of facilities with the following equipment for neonatal resuscitation	(1) suction bulb or penguin sucker	1099(80.4%)	0(0%)	388(80%)	711(87.1%)	577(21.3%)	0(0%)	261(84.3%)	316(93.6%)
			(2) stethoscope (in general)	1144(81.3%)	0(0%)	412(81.5%)	732(86.3%)	612(23.1%)	0(0%)	290(92.1%)	322(95.1%)
			(3) newborn masks and self-inflating bag	561(26.9%)	0(0%)	102(21%)	459(44.6%)	593(21.6%)	0(0%)	262(85.2%)	331(97.4%)
		The proportion of facilities with equipment for thermal care	(1) incubator	114(3%)	0(0%)	3(0.6%)	111(9.7%)	232(4.5%)	0(0%)	60(14.4%)	172(47.1%)
			(2) other external heat source	411(18.2%)	0(0%)	62(12.4%)	349(35.3%)	382(9.4%)	0(0%)	118(32.7%)	264(79.5%)
		The proportion of facilities with equipment for respiratory care, including safe oxygen use	(1) pulse oximeter	78(2.8%)	1(12.5%)	2(0.4%)	75(8.6%)	318(26.8%)	23(31.1%)	85(21%)	210(64.9%)
			(2) oxygen concentrator	105(2.4%)	2(14.4%)	2(0.5%)	101(6.7%)	184(11.2%)	11(11.3%)	38(6.8%)	135(46.5%)
			(3) filled oxygen cylinder	73(1.8%)	2(14.4%)	1(0.3%)	70(4.8%)	200(13%)	12(15.7%)	43(7.9%)	145(49%)
			(4) oxygen distribution system					80(4.8%)	3(7.2%)	12(2.6%)	65(17.7%)
	Medicines and commodities	The proportion with commodities for monitoring blood glucose	(1) glucometer	761(34%)	3(27.7%)	76(18.2%)	682(77%)	564(21%)	38(4.1%)	202(68.8%)	324(95.6%)
			(2) glucometer strips	674(29.6%)	3(27.7%)	63(15.6%)	608(67.4%)	542(19.3%)	35(3.8%)	188(62.5%)	319(94.4%)
		The proportion with commodities for infection management	(1) hand-washing soap	686(48.4%)	7(57.8%)	228(45.6%)	451(55.6%)	487(45.3%)	116(42.7%)	160(51.8%)	211(63.3%)
			(2) disposable latex gloves	1256(90.2%)	10(100%)	453(88.5%)	793(93.9%)	761(69.4%)	160(61.5%)	283(93%)	318(94.1%)
	Staff and guidelines	The proportion of facilities with at least one health worker who has received training about the following in the past 24 months	(1) IMPAC[1]	423(34.5%)	1(41.7%)	107(33.8%)	315(35.6%)	108(2.4%)	5(0.4%)	41(6.6%)	62(24.7%)
			(2) CEmONC[2]	401(29.6%)	1(41.7%)	93(28.6%)	307(31.2%)	112(2%)	4(0.3%)	38(5.6%)	70(19.3%)
			(3) Routine care for labor and normal delivery	415(33.6%)	1(41.7%)	107(33.5%)	307(33.8%)	126(2.8%)	7(1.1%)	44(6.5%)	75(20.6%)
		The proportion of facilities with the following guidelines	guidelines on the management of preterm labor	232(11.4%)	0(0%)	46(8.8%)	186(19%)	248(7.2%)	0(0%)	86(27.1%)	162(43.2%)

[1]Integrated Management of Pregnancy and Childbirth. [2]Comprehensive Emergency Obstetric and Newborn Care. : data unavailable

Supplemental Table 4. Facility structural readiness for 35 indicators by country and facility level (continued)

Four readiness categories based on WHO criteria		The proportion of facilities with the indicators available		Sub-Saharan Africa							
				Malawi 2013-2014				Senegal 2018 and 2019			
				Overall	Level 1	Level 2	Level 3	Overall	Level 1	Level 2	Level 3
1. Assess GA accurately	**Equipment**	The proportion of facilities with a functional ultrasound machine in use		65(10%)	4(3.8%)	7(1.5%)	54(76%)	1(0.2%)	0(0%)	1(0.2%)	0(0%)
2. Identify maternal infections	**Equipment**	The proportion with the equipment	thermometer	453(69.6%)	0(0%)	390(82.6%)	63(88.6%)	495(69.9%)	0(0%)	436(80.2%)	59(96.4%)
	Diagnostics	The proportion of facilities with the following diagnostics	(1) hematology analyzer	57(8.8%)	8(7.7%)	6(1.3%)	43(60.8%)	139(16.1%)	7(28.9%)	80(10.5%)	52(52.2%)
			(2) HIV rapid diagnostic test	391(60.6%)	57(55.4%)	288(61.2%)	46(64.6%)	548(78.7%)	40(40.5%)	461(86.2%)	47(72.7%)
			(3) syphilis rapid diagnostic test	96(14.8%)	17(16.4%)	54(11.4%)	25(35.2%)	487(68.8%)	37(39.5%)	410(77.6%)	40(30.2%)
3. Provide adequate childbirth care	**Equipment**	The proportion of facilities with the following equipment to perform CEmONC (obstetric-related)	(1) delivery pack	486(74.8%)	0(0%)	418(88.7%)	68(95.7%)	579(83.7%)	0(0%)	521(97.8%)	58(96%)
			(2) cord clamp	482(74.1%)	0(0%)	416(88.2%)	66(92.9%)	568(82.1%)	0(0%)	509(95.8%)	59(96.4%)
			(3) manual vacuum extractor	221(33.9%)	0(0%)	165(34.8%)	56(78.8%)	96(11%)	0(0%)	57(7.6%)	39(71.5%)
			(4) vacuum aspiration kit or D&C kit	131(20.1%)	0(0%)	97(20.4%)	34(48%)	343(49.4%)	0(0%)	303(55.7%)	40(79.1%)
			(5) forceps (large)	448(69%)	0(0%)	390(82.8%)	58(81.7%)	521(73.5%)	0(0%)	464(85%)	57(94.9%)
			(6) forceps (medium)	434(66.9%)	0(0%)	379(80.5%)	55(77.5%)	533(75.6%)	0(0%)	474(87.5%)	59(96.4%)
	Medicines and commodities	The proportion of facilities with the following medicines	(1) parenteral antibiotics	299(46.1%)	0(0%)	244(51.9%)	55(77.4%)	362(51.3%)	0(0%)	316(60.7%)	46(51.1%)
			(2) parenteral anticonvulsants (diazepam)	433(66.6%)	0(0%)	371(78.6%)	62(87.2%)	363(51.6%)	0(0%)	317(58.1%)	46(83.6%)
			(3) parenteral oxytocin	514(79.2%)	0(0%)	449(95.3%)	65(91.4%)	451(62.3%)	0(0%)	402(74.5%)	49(52.2%)
	Staff and guidelines	The proportion of facilities that have the following staff	(1) a health worker who can perform C/S	57(8.7%)	0(0%)	0(0%)	57(80.1%)	49(3.5%)	0(0%)	0(0%)	49(48.7%)
			(2) an anesthetist	47(7.2%)	0(0%)	0(0%)	47(66%)	51(3.6%)	0(0%)	0(0%)	51(50.4%)
		The proportion of facilities with the following guidelines	(1) national guidelines for BEmONC	266(40.9%)	0(0%)	231(48.9%)	35(49.1%)				
			(2) national guidelines for CEmONC	148(22.8%)	0(0%)	117(24.8%)	31(43.6%)	304(41.9%)	0(0%)	269(47.5%)	35(64.5%)
4. Provide adequate preterm newborn care	**Equipment**	The proportion of facilities with the following equipment for neonatal resuscitation	(1) suction bulb or penguin sucker	399(61.5%)	0(0%)	346(73.6%)	53(74.5%)	480(66.4%)	0(0%)	434(76.9%)	46(84.9%)
			(2) stethoscope (in general)	423(65.2%)	0(0%)	369(78.4%)	54(76.1%)	369(51.1%)	0(0%)	314(56.7%)	55(92.2%)
			(3) newborn masks and self-inflating bag	483(74.4%)	0(0%)	418(88.7%)	65(91.4%)	477(67.4%)	0(0%)	419(77.1%)	58(94.9%)
		The proportion of facilities with equipment for thermal care	(1) incubator	37(5.7%)	0(0%)	8(1.7%)	29(41.1%)	41(6.6%)	0(0%)	18(3%)	23(59.4%)
			(2) other external heat source	78(12%)	0(0%)	31(6.5%)	47(66.3%)	407(58.4%)	0(0%)	350(65.9%)	57(94.2%)
		The proportion of facilities with equipment for respiratory care, including safe oxygen use	(1) pulse oximeter	60(9.3%)	9(8.8%)	25(5.3%)	26(36.9%)	68(8.2%)	2(1.2%)	22(2.5%)	44(85.1%)
			(2) oxygen concentrator	99(15.2%)	9(8.5%)	54(11.4%)	36(50.7%)	61(7.5%)	1(0.6%)	23(2.9%)	37(73.4%)
			(3) filled oxygen cylinder	47(7.3%)	7(6.8%)	16(3.4%)	24(34%)	99(12.4%)	5(10.9%)	44(6%)	50(85.7%)
			(4) oxygen distribution system	27(4.2%)	2(1.9%)	15(3.2%)	10(14.2%)	60(8.5%)	1(9.1%)	16(2.1%)	43(78.4%)
	Medicines and commodities	The proportion commodities for monitoring blood glucose	(1) glucometer	151(23.4%)	32(31.2%)	58(12.3%)	61(85.8%)	532(79.7%)	48(72.9%)	446(81.1%)	38(77.7%)
			(2) glucometer strips	129(20%)	24(23.4%)	48(10.1%)	57(80.2%)	537(82%)	46(71%)	446(84%)	45(82.5%)
		The proportion of facilities with commodities for infection management	(1) hand-washing soap	313(48.7%)	57(55.4%)	211(44.9%)	45(63.5%)	334(48.2%)	36(44.9%)	263(50.1%)	35(34.6%)
			(2) disposable latex gloves	622(96.4%)	96(93%)	458(97.2%)	68(95.8%)	584(86.7%)	55(81.7%)	480(91.5%)	49(44.4%)
	Staff and guidelines	The proportion of facilities with at least one health worker who has received training about the following in the past 24 months	(1) IMPAC[1]	137(21.2%)	3(2.9%)	103(21.9%)	31(44.2%)	223(37.8%)	10(19%)	190(41.8%)	23(21.3%)
			(2) CEmONC[2]	133(20.6%)	5(4.8%)	97(20.6%)	31(44.3%)	170(27.5%)	9(17.5%)	141(29.6%)	20(18.6%)
			(3) Routine care for labor and normal delivery	214(33.2%)	3(2.9%)	166(35.3%)	45(64.1%)	236(43.5%)	10(46.1%)	205(45.4%)	21(18.8%)
		The proportion of facilities with the following guidelines	guidelines on the management of preterm labor	226(34.7%)	0(0%)	190(40.2%)	36(50.6%)	130(18%)	0(0%)	107(17.7%)	23(57.6%)

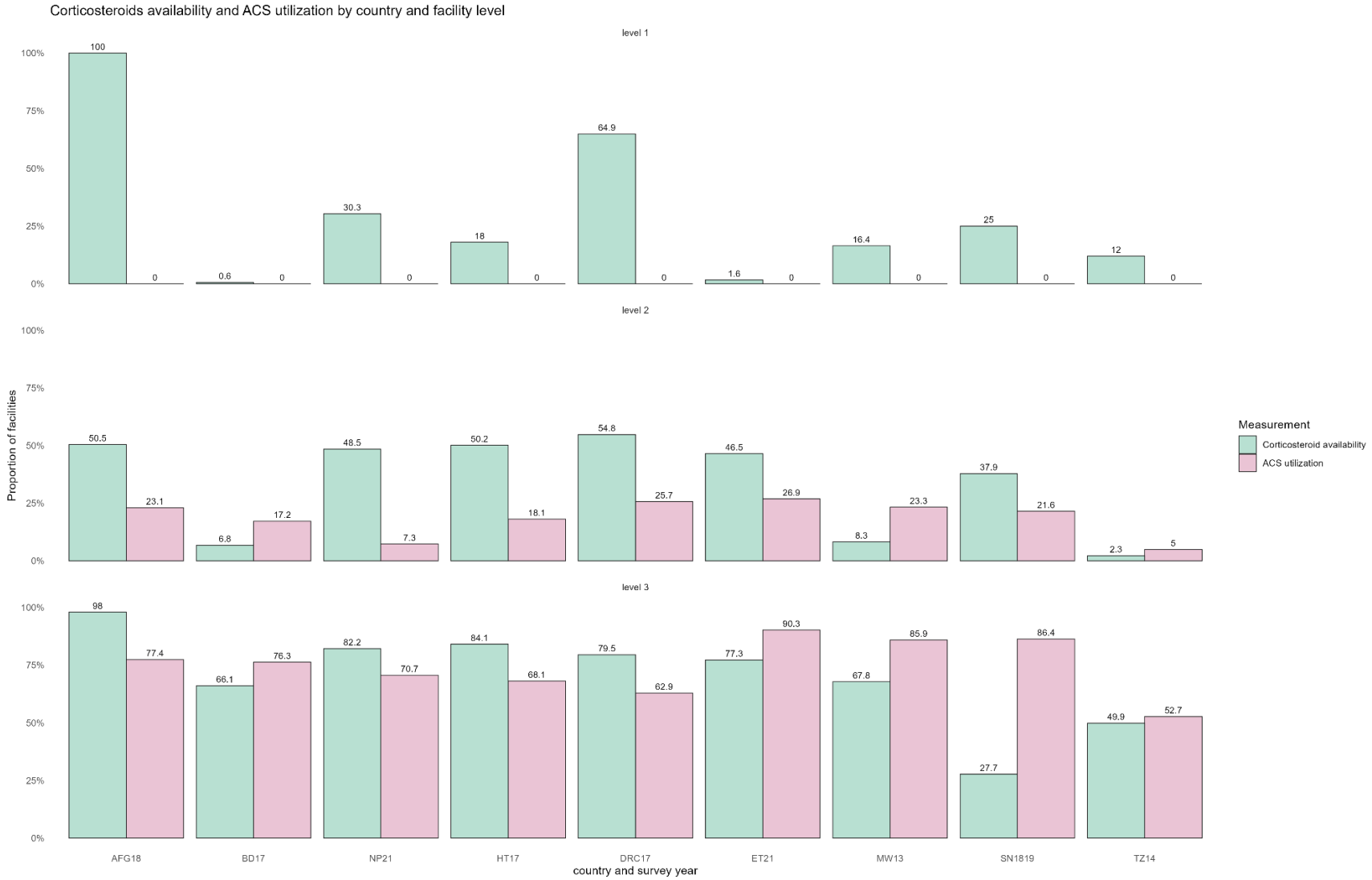
[1]Integrated Management of Pregnancy and Childbirth. [2]Comprehensive Emergency Obstetric and Newborn Care. : data unavailable

Supplemental Table 4. Facility structural readiness for 35 indicators by country and facility level (continued)

Four readiness categories based on WHO criteria		The proportion of facilities with the indicators available		Sub-Saharan Africa			
				Tanzania 2014-2015			
				Overall	Level 1	Level 2	Level 3
1. Assess GA accurately	**Equipment**	The proportion of facilities with a functional ultrasound machine in use		223(4.6%)	6(2.9%)	23(1%)	194(65.1%)
2. Identify maternal infections	**Equipment**	The proportion of facilities with the equipment	thermometer	654(56.6%)	0(0%)	417(62.7%)	237(84.6%)
	Diagnostics	The proportion of facilities with the following diagnostics	(1) hematology analyzer	233(6.7%)	12(10.1%)	52(3%)	169(58.2%)
			(2) HIV rapid diagnostic test	879(82.1%)	76(77.4%)	573(82.6%)	230(83%)
			(3) syphilis rapid diagnostic test	455(40%)	50(41.1%)	275(39.5%)	130(45.4%)
3. Provide adequate childbirth care	**Equipment**	The proportion of facilities with the following equipment to perform CEmONC (obstetric-related)	(1) delivery pack	838(74.4%)	0(0%)	575(83.2%)	263(97.1%)
			(2) cord clamp	711(64.7%)	0(0%)	487(72.4%)	224(83.3%)
			(3) manual vacuum extractor	176(4.7%)	0(0%)	26(2.2%)	150(54.5%)
			(4) vacuum aspiration kit or D&C kit	197(6.6%)	0(0%)	77(5.1%)	120(45.7%)
			(5) forceps (large)	821(72.1%)	0(0%)	568(80.7%)	253(93.3%)
			(6) forceps (medium)	896(82.2%)	0(0%)	634(92.5%)	262(96.9%)
	Medicines and commodities	The proportion of facilities with the following medicines	(1) parenteral antibiotics	363(28.4%)	0(0%)	211(30.7%)	152(54.4%)
			(2) parenteral anticonvulsants (diazepam)	580(48.9%)	0(0%)	369(53.9%)	211(76.7%)
			(3) parenteral oxytocin	818(69.8%)	0(0%)	562(77.9%)	256(93.2%)
	Staff and guidelines	The proportion of facilities that have the following staff	(1) a health worker who can perform C/S	238(4.4%)	0(0%)	0(0%)	238(83.6%)
			(2) an anesthetist	215(3.9%)	0(0%)	0(0%)	215(74.3%)
		The proportion of facilities with the following guidelines	(1) national guidelines for BEmONC	368(25%)	0(0%)	249(27.3%)	119(43.2%)
			(2) national guidelines for CEmONC	134(7.9%)	0(0%)	79(8.1%)	55(20.7%)
4. Provide adequate preterm newborn care	**Equipment**	The proportion of facilities with the following equipment for neonatal resuscitation	(1) suction bulb or penguin sucker	652(57.4%)	0(0%)	427(63.9%)	225(80.7%)
			(2) stethoscope (in general)	732(64%)	0(0%)	490(71.4%)	242(86.4%)
			(3) newborn masks, neonatal size self-inflating bag	772(67.4%)	0(0%)	512(75%)	260(94.8%)
		The proportion of facilities with equipment for thermal care	(1) incubator	97(2.4%)	0(0%)	17(1.1%)	80(28%)
			(2) other external heat source	188(5.6%)	0(0%)	41(3.4%)	147(52.5%)
		The proportion of facilities with equipment for respiratory care, including safe oxygen use	(1) pulse oximeter	84(2.8%)	8(10.1%)	9(0.4%)	67(25.3%)
			(2) oxygen concentrator	159(5.2%)	11(12.2%)	45(2.1%)	103(38.7%)
			(3) filled oxygen cylinder	105(3.7%)	8(11.1%)	20(1%)	77(29.7%)
			(4) oxygen distribution system	51(2.1%)	5(5.5%)	12(0.9%)	34(12.9%)
	Medicines and commodities	The proportion of facilities with commodities for monitoring blood glucose	(1) glucometer	453(19.3%)	40(42.2%)	181(12%)	232(86%)
			(2) glucometer strips	395(17.8%)	35(39.3%)	147(11%)	213(78.4%)
		The proportion of facilities with medicines and commodities for infection management	(1) hand-washing soap	697(63.5%)	67(64.1%)	434(63.1%)	196(70%)
			(2) disposable latex gloves	996(94%)	98(94.1%)	640(94%)	258(94.9%)
	Staff and guidelines	The proportion of facilities with at least one health worker who has received training about the following in the past 24 months	(1) IMPAC[1]	228(16%)	3(5.1%)	138(16.6%)	87(31.5%)
			(2) CEmONC[2]	252(14.7%)	2(5%)	146(14.6%)	104(36.8%)
			(3) Routine care for labor and normal delivery	308(20.1%)	6(9.2%)	185(20.2%)	117(42.6%)
		The proportion of facilities with the following guidelines	guidelines on management of preterm labor	153(10.2%)	0(0%)	83(10.7%)	70(24.9%)

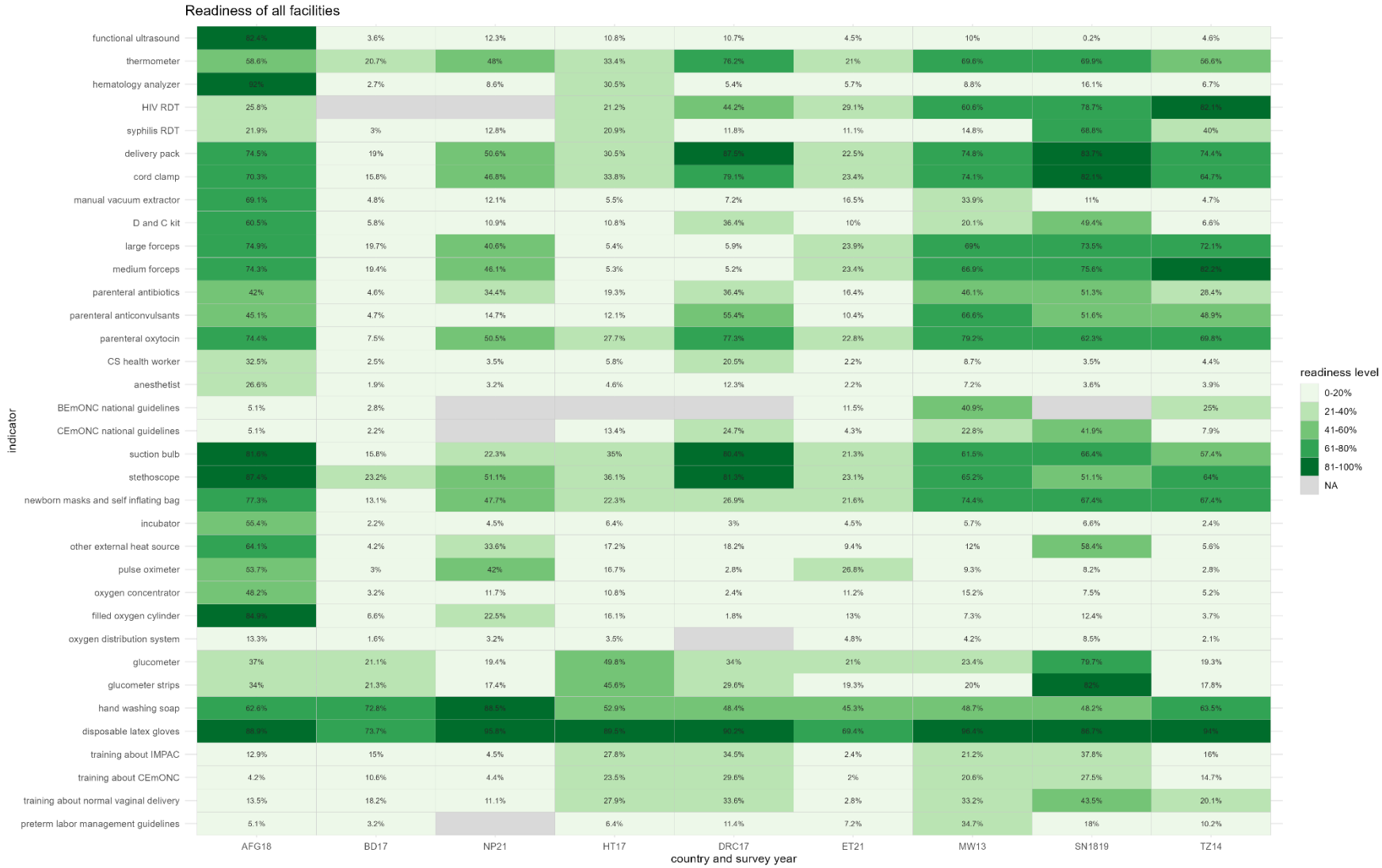
[1]Integrated Management of Pregnancy and Childbirth. [2]Comprehensive Emergency Obstetric and Newborn Care. : data unavailable

Supplemental Figure 1. ACS utilization and corticosteroid availability by facility level



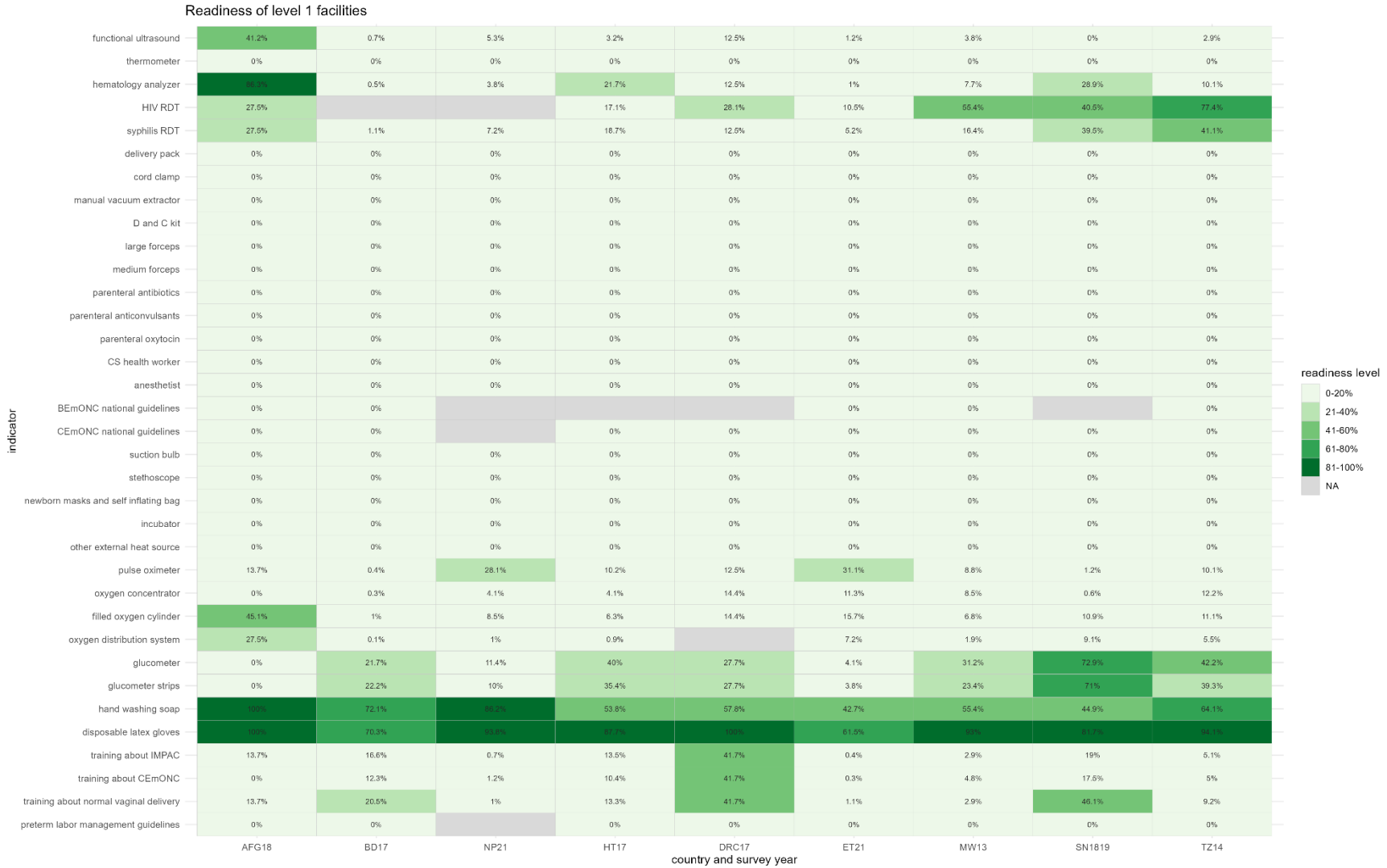
AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017-2018; DRC17: the Democratic Republic of the Congo 2017-2018; ET21: Ethiopia 2021-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015

Supplemental Figure 2. Heatmap of facility readiness for all facilities by country



AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017; DRC17: the Democratic Republic of the Congo 2017-2018; ET21: Ethiopia 20121-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015; RDT: rapid diagnostic test; BEmONC: Basic Emergency Obstetrics and Newborn Care; CEmONC: Comprehensive Emergency Obstetrics and Newborn Care; IMPAC: Integrated Management of Pregnancy and Childbirth; NA: not applicable

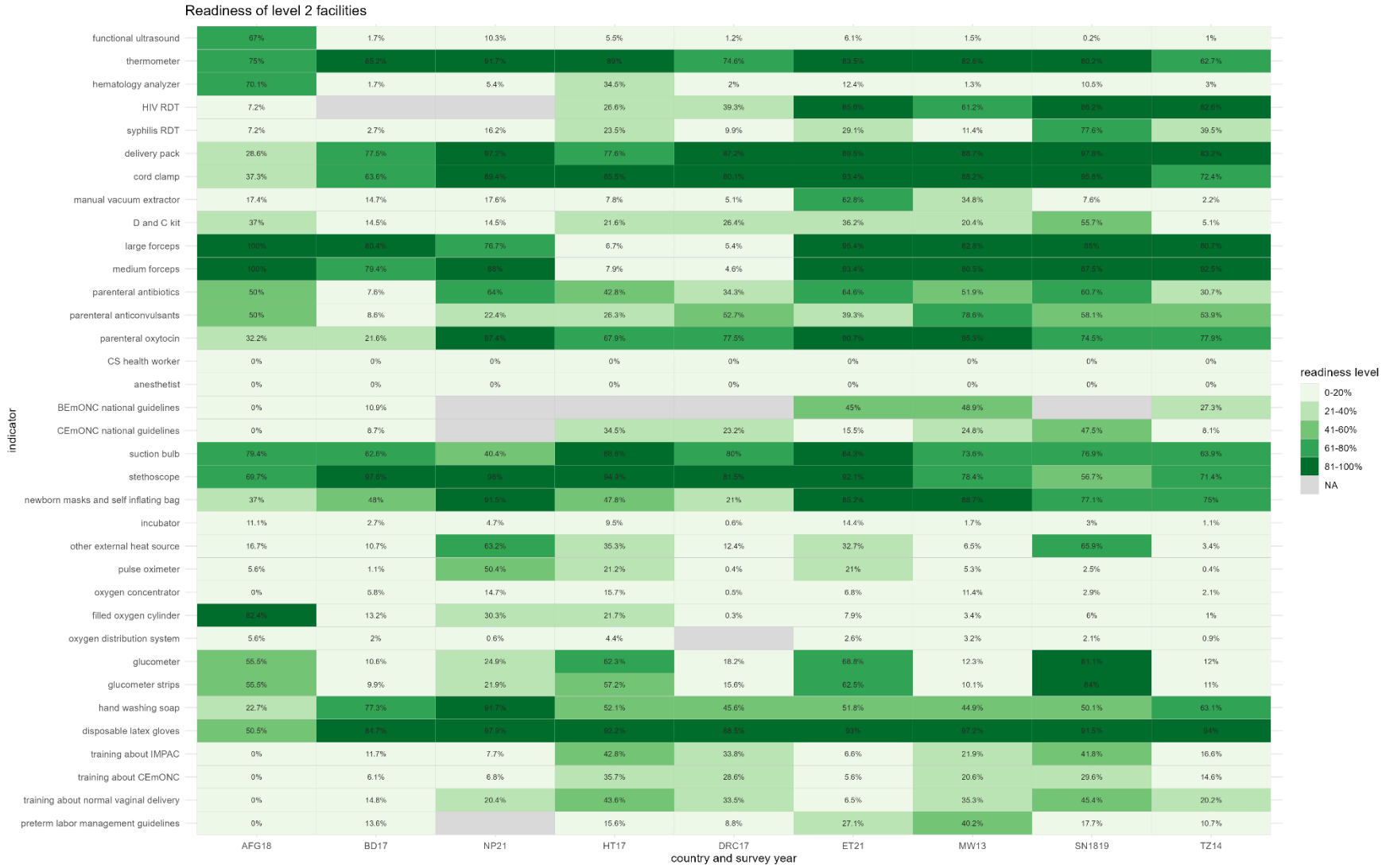
Supplemental Figure 3. Heatmap of facility readiness for level 1 facilities by country



AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017; DRC17: the Democratic Republic of the Congo 2017-2018; ET21: Ethiopia 20121-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015;

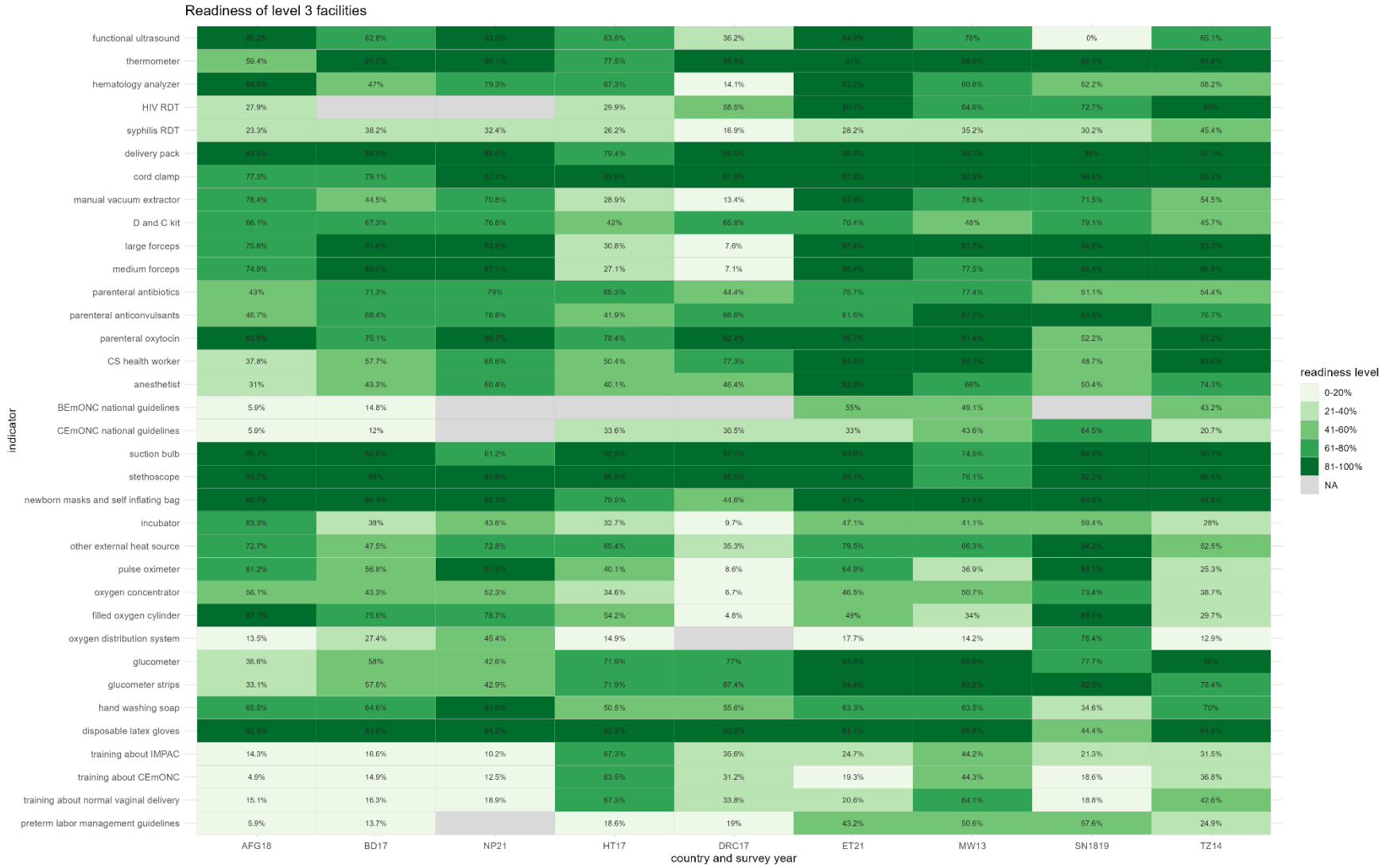
RDT: rapid diagnostic test; BEmONC: Basic Emergency Obstetrics and Newborn Care; CEmONC: Comprehensive Emergency Obstetrics and Newborn Care; IMPAC: Integrated Management of Pregnancy and Childbirth; NA: not applicable

Supplemental Figure 4. Heatmap of facility readiness for level 2 facilities by country



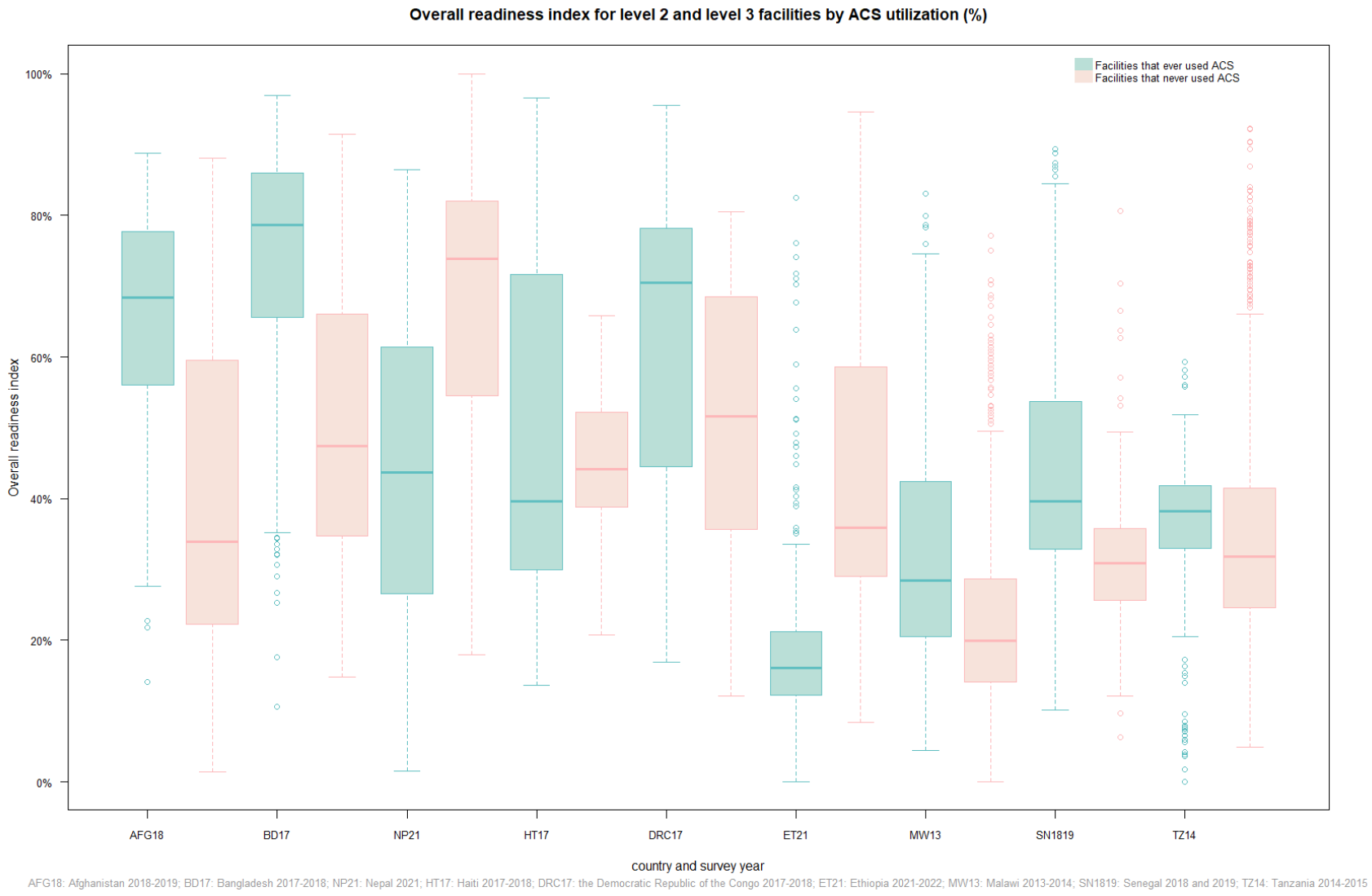
AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017; DRC17: the Democratic Republic of the Congo 2017-2018; ET21: Ethiopia 20121-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015; RDT: rapid diagnostic test; BEmONC: Basic Emergency Obstetrics and Newborn Care; CEmONC: Comprehensive Emergency Obstetrics and Newborn Care; IMPAC: Integrated Management of Pregnancy and Childbirth; NA: not applicable

Supplemental Figure 5. Heatmap of facility readiness for level 3 facilities by country



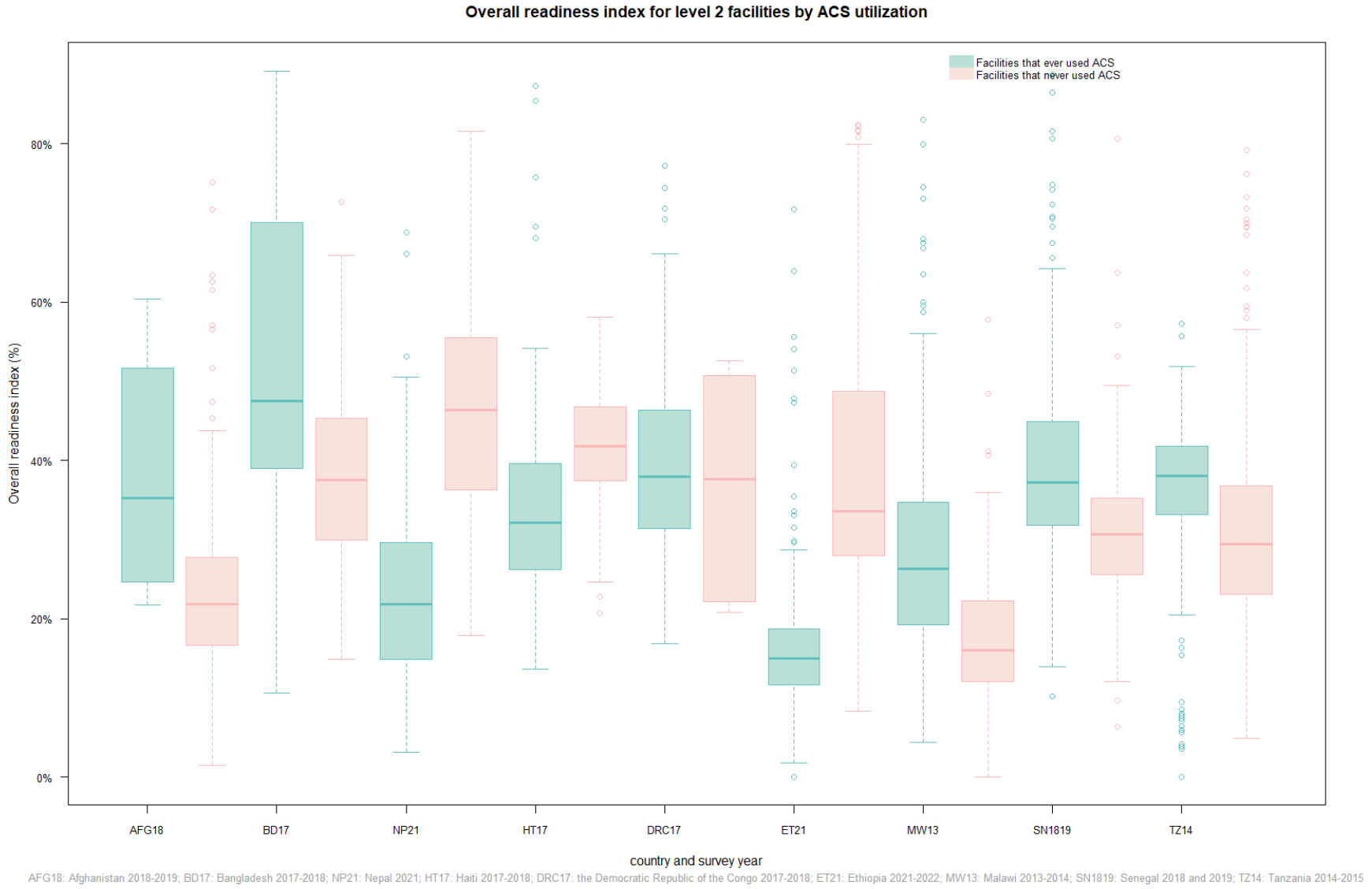
AFG18: Afghanistan 2018-2019; BD17: Bangladesh 2017-2018; NP21: Nepal 2021; HT17: Haiti 2017; DRC17: the Democratic Republic of the Congo 2017-2018; ET21: Ethiopia 20121-2022; MW13: Malawi 2013-2014; SN1819: Senegal 2018 and 2019; TZ14: Tanzania 2014-2015; RDT: rapid diagnostic test; BEmONC: Basic Emergency Obstetrics and Newborn Care; CEmONC: Comprehensive Emergency Obstetrics and Newborn Care; IMPAC: Integrated Management of Pregnancy and Childbirth; NA: not applicable

Supplemental Figure 6. Differences in overall readiness indexes by antenatal corticosteroid utilization for level 2 and level 3 facilities*

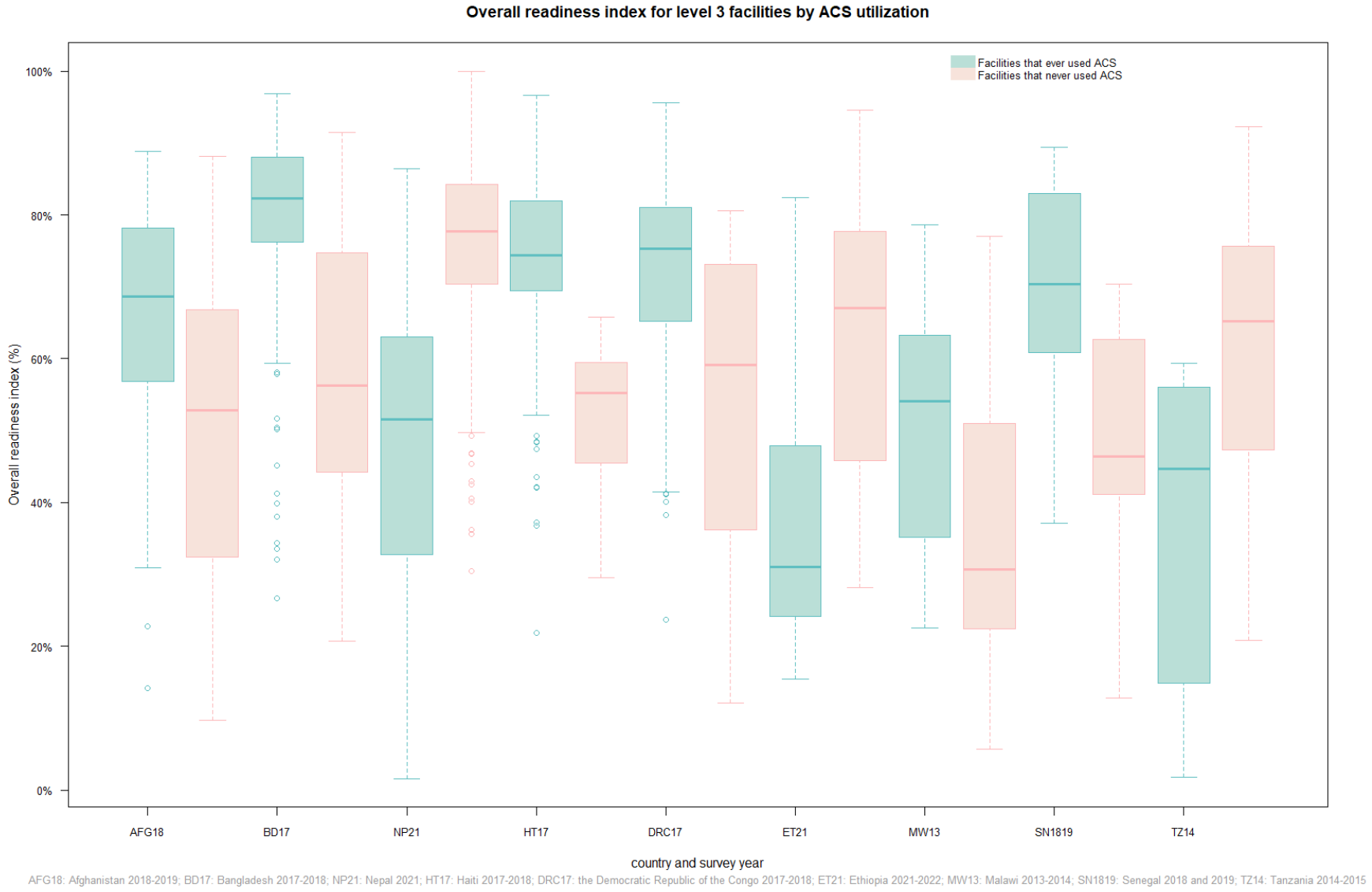


* Level 1 facilities were excluded as none of the level 1 facilities across nine countries had provided ACS.

Supplemental Figure 7. Differences in overall readiness indexes by antenatal corticosteroid utilization for level 2 facilities



Supplemental Figure 8. Differences in overall readiness indexes by antenatal corticosteroid utilization for level 3 facilities



Appendix B. Chapter 3 Supplemental tables and figures

Supplemental Table 5. Development of standardized categorization of facility managing authority types

Standardized categories of managing authority types[1]		**1) Public**	**2) Private for-profit**	**3) Private not-for-profit/mission or faith-based**	**4) Others**
Country-specific categorization for managing authority types[2]	Afghanistan 2018-2019	public/government	private for-profit	private not-for-profit	-
	Nepal 2021	public/government	private for-profit	private not-for-profit, mission-based facilities	-
	Haiti 2017	public/government	private for-profit	private not-for-profit	mixed
	Malawi 2013-2014	public/government	private for-profit	private not-for-profit, mission-based facilities	Christian Health Association of Malawi, Company
	Tanzania 2014-2015	public/government	private for-profit	mission-based facilities	parastatal
	Ethiopia 2021-2022	public/government, other government (military, federal, etc.)	private for-profit	private not-for-profit, mission-based facilities	-
	Bangladesh 2017-2018	public/government, local government	private for-profit	private not-for-profit	-
	DRC 2017-2018	public/government	private for-profit	private not-for-profit, mission-based facilities	-
	Senegal 2018 & 2019	public/government	private for-profit	private not-for-profit	-

[1] We developed the standardized categorization for managing authority types across nine countries.
[2] The country-specific categorizations were obtained from surveys of each country.

Supplemental Table 6. Items included to develop structural readiness tertiles

Readiness items included (number of items = 28)[1]
Equipment (n=16) thermometer, delivery pack, cord clamp, manual vacuum extractor, vacuum aspiratory kit or D&C kit, forceps (large), forceps (medium), suction bulb or penguin sucker, stethoscope, newborn masks and neonatal size self-inflating bag, incubator, other external heat source, pulse oximeter, oxygen concentrator, filled oxygen cylinder, oxygen distribution system **Diagnostics (n=3)** hematology analyzer, HIV rapid diagnostic test, syphilis rapid diagnostic test **Medicines and commodities (n=7)** parenteral antibiotics, parenteral oxytocin, parenteral anticonvulsant, glucometer, glucometer strips, hand-washing soap, disposable latex gloves **Guidelines (n=2)** national guideline for CEmONC[2], guideline on management of preterm labor

[1] Not all surveys included in this study surveyed all these 28 items. Bangladesh 2017-2018 did not survey HIV diagnostic test; Nepal 2021 did not survey HIV diagnostic test, CEmONC, and guidelines on the management of preterm labor; DRC 2017-2018 did not survey oxygen distribution system. Readiness tertile was constructed based on the country-specific number of items surveyed.
[2] CEmONC: Comprehensive Emergency Obstetric and Newborn Care

Supplemental Table 7. Types of staff used to construct binary variables indicating at least one medical doctor, midwife, obstetrician/gynecologist, or specialist

	Types of staff included to construct binary variables				
	At least one medical doctor	**At least one midwife**	**At least one obstetrician/gynecologist**	**At least one pediatrician**	**At least one specialist**
Afghanistan 2018-2019	general medical doctor	registered midwife, community midwife	NA[1]	NA[1]	specialist
Bangladesh 2017-2018	senior consultant (medicine), junior consultant (medicine), residential medical officer (RMO), medical officer (MO)/physician, indoor medical officer (IMO), indoor medical officer (IMO) medicine	nurse midwife, midwife	senior consultant (obgyn[3]), junior consultant (obgyn[3]), indoor medical officer (IMO) obgyn[3]	senior consultant (pediatrician), junior consultant (pediatrician), indoor medical officer (IMO) pediatrician	specialist[2]
Nepal 2021	generalist	nurse (MN, BSC NURSE, BN, PCL, midwife)	gynecologist/obstetrician	pediatrician	specialist[2]
Haiti 2017-2018	generalist	nurse (health nurse, community nurse, midwife)	NA[1]	NA[1]	specialist
DRC 2017-2018	generalist	midwife	NA[1]	NA[1]	specialist
Ethiopia 2021-2022	generalist	midwife (BSc), midwife (diploma)	gynecologist/obstetrician	pediatrician	specialist[2]
Malawi 2013-2014	generalist	registered nurse midwife (BSC), enrolled midwife/nurse midwife technician, enrolled nurse midwife	NA[1]	NA[1]	specialist
Senegal 2018 and 2019	generalist	midwife	NA[1]	NA[1]	specialist
Tanzania 2014-2015	generalist	registered nurse (including nursing officers and midwives)	NA[1]	NA[1]	specialist

[1] Afghanistan, Haiti, DRC, Malawi, Senegal, and Ethiopia did not specifically survey the availability of obstetricians/gynecologists and pediatricians; they surveyed the availability of specialists.
[2] For Bangladesh, Nepal, and Ethiopia, the variable of at least one specialist was constructed based on the variables of at least one obstetrician/gynecologist and at least one pediatrician.
[3] Obstetrics and gynecology

Supplemental Table 8. Country-specific regressions of recent antenatal corticosteroid utilization[1]

	Afghanistan (n=99)			**Bangladesh** (n=810)			**Nepal** (n=800)		
	Adjusted relative risk (aRR)	**95% CI**	**p-value**	**Adjusted relative risk (aRR)**	**95% CI**	**p-value**	**Adjusted relative risk (aRR)**	**95% CI**	**p-value**
Facility characteristic									
Location									
Urban	-[2]	-	-	1.12	1.05 – 1.20	**0.001**	1.02	0.98 – 1.06	0.351
Rural	-[2]	-	-	*ref*			*ref*		
Managing authority type									
Public	*ref*			*ref*			*ref*		
Private for-profit	0.93	0.83 – 1.04	0.216	1.03	0.97 – 1.09	0.293	0.89	0.82 – 0.96	**0.004**
Private not-for-profit	0.99	0.82 – 1.19	0.897	0.97	0.88 – 1.06	0.474	0.92	0.79 – 1.07	0.273
Others	-			-			-		
Structural readiness									
Corticosteroid availability	1.01	0.88 – 1.17	0.852	1.04	0.99 – 1.10	0.143	1.04	1.00 – 1.08	**0.036**
Ultrasound availability	0.87	0.79 – 0.96	**0.005**	1.00	0.95 – 1.06	0.924	1.01	0.96 – 1.07	0.628
Readiness tertile									
High	1.05	0.92 – 1.19	0.488	0.95	0.81 – 1.12	0.540	0.97	0.89 – 1.05	0.466
Medium	0.97	0.85 – 1.10	0.606	0.92	0.79 – 1.08	0.322	0.94	0.87 – 1.02	0.152
Low	*ref*			*ref*			*ref*		
Staffing									
At least one medical doctor	1.03	0.94 – 1.13	0.551	1.04	0.98 – 1.11	0.219	1.01	0.94 – 1.09	0.692
At least one midwife	0.62	0.42 – 0.91	0.015	1.05	0.99 – 1.11	0.088	0.98	0.91 – 1.06	0.690
At least one specialist	1.02	0.90 – 1.16	0.723	1.03	0.96 – 1.10	0.473	1.02	0.94 – 1.11	0.608
CEmONC signal functions									
Provide parenteral antibiotics	1.22	1.04 – 1.44	**0.018**	1.05	1.00 – 1.11	0.071	1.01	0.98 – 1.04	0.446
Provide parenteral oxytocin	0.94	0.83 – 1.07	0.343	1.01	0.96 – 1.07	0.661	0.97	0.92 – 1.02	0.205
Provide parenteral anticonvulsants	1.20	1.03 – 1.40	**0.019**	1.13	1.07 – 1.19	**<0.001**	1.07	1.02 – 1.15	**0.007**
Perform assisted vaginal delivery	0.90	0.77 – 1.05	0.195	1.01	0.97 – 1.05	0.719	1.07	1.01 – 1.14	0.026
Perform manual removal of placenta	1.08	0.83 – 1.40	0.560	1.05	1.00 – 1.11	0.043	0.99	0.95 – 1.02	0.441
Perform removal of retained products	1.14	0.74 – 1.77	0.550	1.09	1.04 – 1.15	**<0.001**	1.05	1.01 – 1.09	**0.012**
Perform neonatal resuscitation	1.29	1.10 – 1.51	**0.002**	1.06	1.01 – 1.11	**0.013**	1.03	0.99 – 1.06	0.098
Perform Cesarean sections	1.59	1.38 – 1.84	**<0.001**	1.02	0.95 – 1.10	0.607	1.23	1.08 – 1.41	**0.002**
Provide blood transfusion	0.91	0.82 – 1.01	0.066	1.07	1.01 – 1.14	**0.026**	1.07	0.96 – 1.20	0.234

[1] Modified Poisson regressions (Poisson regression with a robust error variance) were used to obtain adjusted relative risks (aRR).
[2] Location (urban versus rural) was removed from the model as most of the facilities in Afghanistan were urban.

Supplemental Table 8. Country-specific regressions of recent antenatal corticosteroid utilization (continued)[1]

	Haiti (n=361)			DRC (n=1329)			Ethiopia (n=640)		
	Adjusted relative risk (aRR)	**95% CI**	**p-value**	**Adjusted relative risk (aRR)**	**95% CI**	**p-value**	**Adjusted relative risk (aRR)**	**95% CI**	**p-value**
Facility characteristic									
Urban versus rural									
Urban	1.02	0.95 – 1.09	0.653	1.01	0.96 – 1.05	**0.794**	1.05	0.99 – 1.10	0.104
Rural	*ref*			*ref*			*ref*		
Managing authority type									
Public	*ref*			*ref*			*ref*		
Private for-profit	0.94	0.87 – 1.02	0.152	0.94	0.89 – 1.00	**0.036**	0.92	0.86 – 0.99	**0.020**
Private not for-profit	1.05	0.97 – 1.14	0.198	0.96	0.93 – 1.00	0.039	0.99	0.90 – 1.09	0.872
Others	1.02	0.95 – 1.10	0.595	-			-		
Structural readiness									
Corticosteroid availability	1.05	0.98 – 1.13	0.168	1.02	0.98 – 1.06	0.400	0.98	0.94 – 1.02	0.410
Ultrasound availability	1.07	0.98 – 1.17	0.144	1.08	1.03 – 1.13	**0.002**	0.99	0.93 – 1.05	0.726
Readiness tertile									
High	1.16	1.00 – 1.34	0.044	1.18	1.12 – 1.24	**<0.001**	1.11	1.03 – 1.20	**0.008**
Medium	1.11	0.96 – 1.29	0.158	1.05	1.00 – 1.10	**0.037**	1.11	1.04 – 1.19	**0.003**
Low	*ref*			*ref*			*ref*		
Staffing[5]									
At least one medical doctor	0.96	0.89 – 1.04	0.357	1.09	1.02 – 1.18	**0.017**	1.05	0.97 – 1.14	0.259
At least one midwife	1.01	0.93 – 1.09	0.857	1.03	0.98 – 1.07	0.220	1.05	1.00 – 1.10	0.053
At least one specialist	1.00	0.93 – 1.08	0.937	1.05	0.99 – 1.11	0.093	1.01	0.96 – 1.06	0.635
CEmONC signal functions									
Provide parenteral antibiotics	0.95	0.87 – 1.03	0.222	1.02	0.97 – 1.06	0.528	0.97	0.84 – 1.11	0.623
Provide parenteral oxytocin	0.99	0.89 – 1.10	0.835	1.03	0.94 – 1.13	0.492	1.09	0.91 – 1.31	0.353
Provide parenteral anticonvulsants	1.13	1.06 – 1.22	**<0.001**	1.06	1.02 – 1.10	**0.004**	1.15	1.07 – 1.25	**<0.001**
Perform assisted vaginal delivery	0.99	0.93 – 1.06	0.761	0.94	0.90 – 0.99	**0.020**	0.97	0.84 – 1.11	0.627
Perform manual removal of placenta	1.05	0.98 – 1.12	0.180	1.07	1.02 – 1.13	**0.010**	1.10	0.98 -1.23	0.102
Perform removal of retained products	1.05	0.98 – 1.12	0.140	1.02	0.98 – 1.06	0.255	1.05	0.95 – 1.15	0.356
Perform neonatal resuscitation	1.06	1.00 – 1.12	0.068	1.11	1.05 – 1.16	**<0.001**	1.07	0.94 – 1.21	0.327
Perform Cesarean sections	1.19	1.01 – 1.40	**0.036**	1.04	0.97 – 1.12	0.255	1.25	1.12 – 1.40	**<0.001**
Provide blood transfusion	1.09	0.95 – 1.25	0.228	1.06	1.00 – 1.12	**0.041**	1.00	0.90 – 1.10	0.941

[1] Modified Poisson regressions (Poisson regression with a robust error variance) were used to obtain adjusted relative risks (aRR).

Supplemental Table 8. Country-specific regressions of recent antenatal corticosteroid utilization (continued)[1]

	Malawi (n=533)			Senegal (n=591)			Tanzania (n=948)		
	Adjusted relative risk (aRR)	**95% CI**	**p-value**	**Adjusted relative risk (aRR)**	**95% CI**	**p-value**	**Adjusted relative risk (aRR)**	**95% CI**	**p-value**
Facility characteristic									
Urban versus rural									
Urban	1.02	0.95 – 1.10	**0.575**	0.90	0.82 – 1.00	0.052	0.98	0.93 – 1.03	0.427
Rural	*ref*			*ref*			*ref*		
Managing authority type									
Public	*ref*			*ref*			*ref*		
Private for-profit	0.93	0.82 – 1.05	0.242	1.06	0.96 – 1.18	0.229	1.02	0.95 – 1.11	0.563
Private not for-profit	0.99	0.93 – 1.05	0.667	0.94	0.83 – 1.06	0.334	0.96	0.91 – 1.02	0.167
Others	1.02	0.87 – 1.20	0.819	-			0.93	0.77 – 1.12	0.442
Structural readiness									
Corticosteroid availability	1.06	0.97 – 1.16	0.220	1.00	0.96 – 1.05	0.904	1.01	0.94 – 1.08	0.808
Ultrasound availability	1.18	1.02 – 1.37	**0.028**	-[2]			1.14	1.05 – 1.23	**0.003**
Readiness tertile[4]									
High	1.11	1.03 – 1.20	**0.005**	1.14	1.05 – 1.23	**0.001**	1.09	1.03 – 1.15	**0.003**
Medium	1.01	0.95 – 1.07	0.802	0.99	0.93 – 1.06	0.881	1.00	0.98 – 1.03	0.755
Low	*ref*			*ref*			*ref*		
Staffing[5]									
At least one medical doctor	1.21	1.05 – 1.39	**0.009**	1.08	1.00 – 1.17	0.051	1.04	0.96 – 1.12	0.365
At least one midwife	1.02	0.92 – 1.13	0.721	0.99	0.93 – 1.06	0.834	1.01	0.98 – 1.04	0.484
At least one specialist	1.01	0.90 – 1.12	0.915	1.13	1.02 – 1.26	**0.020**	1.01	0.94 – 1.09	0.786
CEmONC signal functions									
Provide parenteral antibiotics	1.07	1.00 – 1.15	0.055	1.00	0.92 – 1.09	0.951	1.02	0.99 – 1.05	0.252
Provide parenteral oxytocin	0.88	0.67 – 1.16	0.372	1.08	1.01 – 1.15	0.033	1.01	0.97 – 1.06	0.598
Provide parenteral anticonvulsants	0.94	0.87 – 1.01	0.110	1.12	1.06 – 1.18	**<0.001**	0.98	0.94 – 1.02	0.327
Perform assisted vaginal delivery	1.01	0.96 – 1.07	0.629	1.05	0.88 – 1.26	0.554	1.01	0.98 – 1.05	0.473
Perform manual removal of placenta	1.07	1.01 – 1.14	**0.019**	1.12	1.07 – 1.18	**<0.001**	1.06	**1.03 – 1.09**	**<0.001**
Perform removal of retained products	1.01	0.96 – 1.07	0.605	1.01	0.94 – 1.09	0.759	1.01	0.97 – 1.04	0.678
Perform neonatal resuscitation	1.15	1.00 – 1.31	**0.044**	1.09	1.01 – 1.17	**0.023**	1.00	0.97 – 1.03	0.868
Perform Cesarean sections	1.07	0.90 – 1.27	0.466	1.05	0.93 – 1.20	0.409	1.05	0.95 – 1.17	0.338
Provide blood transfusion	0.96	0.81 – 1.12	0.588	1.04	0.92 – 1.17	0.580	1.11	1.00 – 1.24	0.057

[1] Modified Poisson regressions (Poisson regression with a robust error variance) were used to obtain adjusted relative risks (aRR).
[2] Ultrasound was removed from the model for Senegal because no facilities in the sample had ultrasound available.

Appendix C. Chapter 4 supplemental tables and figures

Supplemental Table 9. Discussion questions

General questions about ACS
• From your perspective, do you think ACS use in Ethiopia is high or low? What about in your health facility (if applicable)? • In your opinion, what are the main barriers to increasing ACS use in Ethiopia?
Questions about gaps in ACS use in Ethiopia
• Why is ACS sometimes not provided in health centers despite being recommended in the obstetric protocols for women at risk of preterm labor? • In some regions, there are significant gaps between corticosteroid availability and ACS utilization. What might be the reasons for these gaps?
Questions relevant to the 2022 WHO recommendations on ACS use
• ACS use requires accurate GA assessment. What method does your facility usually use to estimate GA? What are the barriers to accurate GA assessment in Ethiopia, and how do those relate to ACS utilization? • The WHO recommendations require the exclusion of chorioamnionitis when giving ACS. How is chorioamnionitis diagnosed in Ethiopia, and could this be a barrier to ACS use?

Appendix D. Chapter 5 supplemental tables and figures

Supplemental Table 10. Proportion of pregnant women who received each of the six and all six care components at first ANC visits in three countries by research sites

ANC quality care components	Ethiopia N=883				Kenya N=896				Kenya N=854			
	East Shewa N=451		Adama Town N=432		Kitui N=459		Kiambu N=437		Nongoma N=436		uMhlathuze N=418	
	Frequency (%)		Frequency (%)		Frequency (%)		Frequency (%)		Frequency (%)		Frequency (%)	
Physical examination												
Blood pressure measurement	252	55.9%	388	89.8%	432	94.1%	429	98.2%	434	99.5%	418	100%
Test and examinations												
Blood test (blood draw or finger prick)	411	91.1%	427	98.8%	446	97.2%	430	98.4%	436	100%	417	99.8%
Urine test	325	72.1%	427	98.8%	399	86.9%	402	92.0%	434	99.5%	416	99.5%
Ultrasound	140	31.0%	243	56.3%	18	3.9%	56	12.8%	2	0.5%	63	15.1%
Counseling												
Signs of pregnancy complications	102	22.6%	171	39.6%	318	47.5%	326	74.6%	220	50.5%	200	47.9%
Preventions												
Iron and folic acid given or prescribed	359	79.6%	354	81.9%	413	90.0%	418	95.7%	377	86.5%	413	98.8%
Completeness of all six care components[1]	20	4.4%	104	24.1%	13	2.8%	37	8.5%	1	0.2%	21	5.0%
Completeness of all five care components[2]	53	11.8%	126	29.2%	183	39.9%	287	65.7%	206	47.3%	195	46.7%

[1] Include blood pressure measurement, blood test, urine test, ultrasound examination, iron and folic acid given or prescribed, counseling on signs of pregnancy complications

[2] Include all the care components except for ultrasound examination.

Supplemental Table 11. Results of mixed effect logistic regressions for low birth weight newborns

	Good quality ANC (received six care components) N = 2444			Good quality ANC (received five care components) N = 2444		
	Odds Ratio (OR)	**95% Confidence Interval (CI)**	***p*-value**	**Odds Ratio (OR)**	**95% Confidence Interval (CI)**	***p*-value**
Received good quality ANC	0.76	0.48 – 1.19	0.231	0.93	0.73 – 1.18	0.527
Socioeconomic and demographic status						
Country						
Ethiopia	*ref*			*ref*		
Kenya	1.00	0.62 – 1.60	0.997	1.05	0.67 – 1.63	0.84
South Africa	**1.71**	**1.38 – 2.12**	**<0.001**	**1.80**	**1.48 – 2.19**	**<0.001**
Age range						
15 to <20 years old	*ref*			*ref*		
≥20 to <35 years old	**0.76**	**0.60 – 0.96**	**0.022**	**0.76**	**0.59 – 0.96**	**0.024**
≥35 years old	1.00	0.63 – 1.59	0.995	0.99	0.62 – 1.57	0.97
Intended pregnancy	1.15	0.78 – 1.68	0.478	1.15	0.79 – 1.69	0.462
Education level						
No education or some primary	*ref*			*ref*		
Complete primary	1.19	0.86 – 1.63	0.295	1.17	0.86 – 1.60	0.315
Complete secondary or higher	0.89	0.54 – 1.47	0.651	0.89	0.54 – 1.46	0.633
Health literacy[1]	0.91	0.75 –1.10	0.313	0.91	0.75 – 1.10	0.311
Wealth						
Poorest	*ref*			*ref*		
Middle	0.87	0.63 – 1.20	0.405	0.88	0.63 – 1.21	0.426
Richest	0.65	0.42 – 1.02	0.059	0.65	0.41 – 1.02	0.062
Trimester of the first ANC visit						
The first trimester[2]	*ref*			*ref*		
The second trimester[2]	0.88	0.68 – 1.14	0.330	0.88	0.69 – 1.13	0.319
The third trimester[2]	0.67	0.31 – 1.47	0.322	0.68	0.31 – 1.48	0.33
Maternal health						
Self-rated own health as very good or excellent[3]	0.92	0.66 – 1.29	0.643	0.92	0.66 – 1.29	0.642
Risk factor at baseline[4]						
No risk factor	*ref*			*ref*		
One risk factor	1.21	0.93 – 1.58	0.151	1.22	0.93 – 1.59	0.144
Two risk factors	1.18	0.66 – 2.12	0.567	1.17	0.66 – 2.09	0.584
Three or more risk factors	1.06	0.48 – 2.31	0.888	1.07	0.49 – 2.31	0.867
Reported any pregnancy danger signs at baseline[5]	0.79	0.50 – 1.25	0.318	0.79	0.51 – 1.24	0.304

[1] Defined as answering six health knowledge questions correctly. The six questions were adopted from the Indian Health and Human Development Survey.
[2] The first trimester is defined as less than 13 weeks of gestation; the second trimester is defined as between 13 to less than 28 weeks of gestation; the third trimester is defined as above 28 weeks of gestation.
[3] Self-rated own health was based on a Likert scale of five levels (excellent, very good, good, fair, and poor)
[4] Risk factors at baseline include any chronic systemic illness(es) known before pregnancy (including diabetes, hypertension, cardiac disease, HIV, mental health disorder, schizophrenia, epilepsy, seizure, renal disorder, asthma, tuberculosis, anemia, hemoglobinopathy, chronic pelvic inflammatory disease, ovarian cyst, fibroids, uterine myoma, genital tract abnormalities, thyroid cancer, thyroid disease, peptic ulcer disease, gestational hypertension in previous pregnancy, a history of stroke), any history of obstetric complications (Cesarean section, stillbirth, preterm birth, neonatal death, and postpartum hemorrhage), and multiple pregnancy known at the first ANC visit
[5] Pregnancy danger signs at baseline include vaginal bleeding, fever, and fainting or loss of consciousness.