Technical University of Munich
TUM School of Medicine and Health

Telemedicine to Address Barriers to Follow up Care Among Women Undergoing Cesarean Section in Rural Rwanda

Theoneste Nkurunziza

Complete reprint of the dissertation approved by the TUM School of Medicine and Health

of the Technical University of Munich for the award of the

Doktor der Philosophie (Dr. Phil.)

Chair: Prof.Dr. Michael Laxy

Examiners:

1. Prof. Dr. Stefanie Klug
2. Prof. Dr. Eva Kantelhardt

The dissertation was submitted to the Technical University of Munich on 15.02.2024

and accepted by the TUM School of Medicine and Health on 07.08.2024.

TABLE OF CONTENTS

List of Tables ... iii
List of Figures ... iii
DECLARATION ... iv
ACKNOWLEDGMENTS ... v
PREFACE ... vii
LIST OF ABBREVIATIONS ... ix
SUMMARY IN ENGLISH ... xi
SUMMARY IN GERMAN ... xiii
CHAPTER I: INTRODUCTION ... 1
1.1 Overview ... 1
1.2 History and indication of cesarean section ... 1
1.3 Global access to CS ... 2
1.3.1 CS access in SSA and in Rwanda ... 2
1.4 Global burden and SSI risks associated with CS ... 3
1.4.1 Definition of SSI ... 3
1.4.2 SSI risks associated with CS ... 4
1.4.3 Global burden of SSI ... 5
1.5 Post-cesarean SSI monitoring ... 6
1.5.1 Challenges of post-discharge follow up ... 9
1.5.2 Opportunities for solving the post-discharge follow-up challenges. ... 10
1.6 Rwanda and Rwanda's health system ... 13
1.7 Critique of current research ... 15
1.8 Rationale of the thesis ... 15
1.8.1 Rationale of Publication one ... 16
1.8.2 Rationale of publication two ... 17
1.9 Aims of the thesis ... 17
1.10 Research questions ... 18
CHAPTER II: METHODOLOGY ... 19
2.1 Methods for study one ... 19
2.2 Methods for study two ... 20

CHAPTER III: RESULTS 22
3.1 Publication one 22
3.2 Publication two 33
CHAPTER IV: DISCUSSION 43
4.1 Findings overview and discussion 43
4.2 Policy implications and recommendations 46
4.2.1 Reminder notifications on the eve of the scheduled follow-up clinic 46
4.2.2 Telemedicine implementation by CHW with GP assistance 47
4.2.3 Targeted supports for women at risk of lost-to-follow-up 47
4.3 Thesis strengths and limitations 48
4.4 Future studies 50
CHAPTER 5: CONCLUSIONS 51
REFERENCES 52
Reprint Permissions 66

List of Tables

Table 1.1: *Postpartum care visit timeline and content for women delivering by cesarean birth in rural Rwanda*...…………………………………….…………………….....8

List of Figures

Figure 1.1: *Conceptual framework for post-discharge follow-up of women with CS…..10*

Figure 1.2: *Rwandan health system and administrative structure* ………………….……..14

DECLARATION

I undersigned, Theoneste Nkurunziza, declare that this is my original work. This dissertation is summarizing two of my publications and is submitted in fulfillment of the requirements for the doctoral of philospohy degree.This work was conducted under the supervision of Professsor Stefanie Klug, Head of Chair of Epidemiology at the Technical University of Munich (TUM) and Professor BethanyHedt-Gauthier, Associate Professor of Biostatistics at Harvard Medical School (HMS) Department of Global Health and Social Medicine.It received support from both institutions and from Partners In Health/Inshuti Mu Buzima (PIH/IMB), Kigali, Rwanda. However, the content is solely the responsibility of the author and does not necessarily represent the official views of these institutions.

I acknowledge plagiarism is wrong, and therefore I declare that the work presented in this dissertation, except where appropriate references are cited, is entirely my own. To prove the originality of this work, if necessary, I agree to submit it to an official plagiarism test.

Theoneste Nkurunziza

Munich, 15.02.2024

ACKNOWLEDGMENTS

Undertaking this PhD program has been a truly challenging and life-changing experience for me. Many people have accompanied and supported me throughout this journey and doctoral thesis, and I want to thank them.

I want to extend my sincere thanks to my academic supervisor at the TUM, University Professor Dr. Stefanie Klug. When I contacted Prof. Dr. Klug with questions or guidance regarding my research or writing, she was always open to my inquiries, despite her very busy schedule. Prof. Dr. Klug consistently allowed me to be in charge of my thesis throughout the writing process, though she steered me in the right direction as needed. It was an inspiration to write my thesis because of her incredible knowledge, dedication, and work.

As well, I want to thank my mentor and co-supervisor, Prof. Dr. Bethany Hedt-Gauthier, the Associate Professor of Global Health and Social Medicine at HMS, for her dedication to building my research capacity. Prof. Hedt-Gauthier has been mentoring and coaching me throughout my previous research works and during this project. I am grateful for her advice and inspiration in implementation research and global surgery. In addition, her expertise in quantitative methods was invaluable to me. Along with Prof. Hedt-Gauthier, I also want to express my gratitude to other Principles Investigators of the mHealth and Telemedicine research projects, Dr. Robert Riviello, the Associate Professor of Global Health and Social Medicine and of Surgery at HMS and Head of Division of Trauma, Burns, and Critical Care at Brigham and Women’s Hospital; and Dr. Fredrick Kateera, the Chief Medical Officer at PIH/IMB. In addition to securing funds for both projects, their scientific and technical support, and leadership led to the successful study implementation. I thank them for their encouragement, capacity-building opportunities, inspiration to aim higher, and for allowing me to use the projects' data for this thesis.

I appreciate all the support received from the leadership of PIH/IMB during my employment and implementation of both projects. I received support from administrative and finance offices and from Research Department whenever I ran into a trouble spot, and I am thankful for that.

I want to thank the leadership and staff members of Kirehe District Hospital and Kirehe administrative district for their acceptance to host the research projects and their collaboration and active participation in both projects. It was a humbling experience to learn from every health care worker and administrator in Kirehe and their support was essential for the successful completion of this research.

Special thanks go to the study community health workers (CHWs) who made the implementation of the study possible and to village CHW who helped connect with study participants and guided our field staff during their home visits.

I also want to express my appreciation to Vestine, the women whose painful experience ignited my interest to global surgery. Her courage and resilience during her difficult times send the message of hope and optimism even during despair and hardship situations.

Many thanks to everyone involved in both research projects, especially from the challenging beginning. It was a pleasure working with Dr. Kristin Sonderman, Dr. Magdalena Gruendl, Mr. Ramadhan Bahati, Mr. Edson Nihiwacu and lately Dr. Elizabeth Miranda just to name a few. They were all very friendly and dedicated to the project success. Particularly, I express my profound gratitude to Dr. Gruendl for inspiring me and using her network that led me to the interest and connections at the TUM.

Big thanks to all colleagues and TUM staff at the Chair of Epidemiology who have supported my work from the very beginning and during the past four years. I am very happy and grateful for the incredible support I received from the Graduate Center at the Department of Sport and Health Sciences.

Finally, I must express my very profound gratitude to my family and friends for their moral support. Throughout my years of study and through the process of researching and writing my thesis, they provided me with unfailing backing and continuous encouragement. This accomplishment would not have been possible without them. Thank you.

PREFACE

Vestine is a shy and reserved woman in her thirties, whom I met during my work in 2013 as she was admitted to Kigali University Teaching Hospital, CHUK. At this time, I served as the Right to Healthcare (RTHC) Program Manager (from 2008 to 2016). Through this program, my team and I helped provide clinical, social, and financial support to poor patients to access specialized care in national and international referral hospitals. These patients were from district hospitals supported by PIH/IMB, namely Butaro, Kirehe, and Rwinkwavu.

Under this program, the majority of patients had favorable clinical outcomes. On the other hand, some patients had delays in accessing healthcare or received poor quality care, resulting into devastating outcomes. This situation is very common in low-resources settings. This unjust outcome motivated my goal to serve the vulnerable and strive for social justice.

Vestine's traumatizing history is one of many examples. Vestine lost her baby boy due to the distress he endured throughout the first delivery attempts at the health center and the delay in reaching the hospital for cesarean delivery. After her discharge, she was expected to visit her nearest health center for wound care. However, while grieving her baby, she did not comply with the follow-up plan. She developed a surgical site infection (SSI) that did not respond to treatment until she was transferred to CHUK for management by a specialist. An obstetrician-gynecologist performed an exploratory laparotomy, revealing a necrotic uterus. Her uterus necrosis and peritonitis resulted in subtotal hysterectomy among other treatments. Hysterectomy takes away the ability to conceive. And thus, Vestine will not have a biological child. This is a distressing outcome because in Rwanda children are considered as power and hope for the future and social protection for the elderly.

Vestine's negative outcome, and the experiences of many others that would lead to what Farmer (2003) called "stupid deaths" inspired me to write about the RTHC program and patients' challenges. First, I presented findings at local meetings and called for improvement by stakeholders and policy action; I then moved to regional and international conferences to engage in scientific debates. My first scientific work explored referral patterns and predictors of referral delays for patients with traumatic injuries from three district hospitals (Nkurunziza et al., 2016). This study highlighted the delay in referral recommendations as one many factors influencing referral delays. My interest in caesarean sections came from those bad experiences with poorly performed caesarean sections and delays in access to appropriate healthcare for those with post-operative complications. Additionally, challenges treating multi-drug resistant SSI, resulting in poor outcomes and increased socioeconomic burdens, furthered this interest.

My experience with cases like that of Vestine motivated my attention to explore viable solutions to the challenges of global surgery, such as applying mobile health to address barriers to access health care.

LIST OF ABBREVIATIONS

ASM: *Animatrice de santé Maternelles* (Maternal Health Monitor)

BC: Before Christ

CBHI: Community-Based Health Insurance

CDC: Centers for Disease Control and Prevention

CHWs: Community Health Workers

CHUK: *Centre Hospitalier Universitaire de Kigali* (Kigali University Teaching Hospital)

CPA: Complementary Package of Activities

CS: Cesarean section

GP: General Practitioner

HIV/AIDS: Human Immunodeficiency Virus/ Acquired Immunodeficiency Syndrome

HIV: Human Immunodeficiency Virus

HMS: Harvard Medical School

IPV: Intimate Partner Violence

LIC: Low-income countries

LMICs: Low-and middle-income countries

mHealth: Mobile health

NISR: National Institute of Statistics of Rwanda

NRH: National Referral Hospitals

PNC: Postnatal Care

POD: Postoperative day

PRH: Provincial Referral Hospitals

RTHC: Right to Health Care

sCHW: Study Community Health Workers

SMS: Short Message Service

SSA: Sub-Saharan Africa

SSI: Surgical site infection

TUM: Technical University of Munich

WHO: World Health Organization

SUMMARY IN ENGLISH

Cesarean section (CS) is the most performed surgical procedure in district hospitals in low- and middle-income countries. After discharge from the hospital, patients often experience hardships in accessing follow-up care and are at risk of postoperative complications, such as surgical site infections (SSIs). Most SSIs develop after patient discharge and may go undetected. Mobile health (mHealth) technologies decentralize postoperative follow-up addressing some of these challenges. However, factors of post-discharge follow-up are complex and not thoroughly studied, and mHealth for SSI diagnosis has not been studied in rural Africa. This doctoral thesis identified factors of return to the follow-up clinic after discharge and determined the feasibility and accuracy of telemedicine-based SSI diagnosis among women who had undergone a CS in rural Rwanda.

Publication one reported on a study conducted at Kirehe District Hospital, which included women aged 18 or older who underwent CS between March and October 2017. All enrolled women received discharge counseling and a voucher to cover transportation costs. The study outcome was the return to the study follow-up clinic. We used logistic regression backward stepwise selection to identify enablers and barriers to post-discharge follow-up return, with a significance level of $\alpha=0.05$.

Of 746 who underwent CSs, 586 were enrolled. The majority had access to a mobile phone, and 73.2% were discharged by postoperative day (POD) 3. Male and female data collectors enrolled 84.1% and 15.9% of participants, respectively. Ninety-four percent of participants attended their first appointment. Overall, 9.6% of participants did not return to the follow-up clinic. Enablers of returning to follow-up care were receiving a reminder call and receiving counseling from a female data collector. Barriers to return to follow-up care were the lack of health insurance and higher transport cost. These findings suggest that mHealth interventions such as reminder calls or notifications and social protection interventions targeting uninsured and patients facing transportation hardship could increase follow-up rates among women who undergo CS.

Publication two reported on a prospective study involving women who underwent CS at Kirehe District Hospital between September 2019 and March 2020. A study CHW (sCHW) visited the participant's home at POD10 (± 3 days), took pictures of the surgical wound using a smartphone application, and sent the images to a general practitioner (GP) in Kigali. The GP determined the SSI diagnosis based on the image and shared it with the sCHW. The following day the participants were physically examined by a different GP, whose SSI diagnosis was considered the gold standard in our analyses. We calculated the sensitivity and specificity of telemedicine-based SSI diagnosis and described the intervention process indicators.

Of 787 participants enrolled, the sCHW located and visited 91.4% of participants' homes. All of them accepted the intervention. Overall, the intervention was successfully implemented for 79.2% of the study participants. SSI was diagnosed in 4.2% and 5.4% of participants through telemedicine and physical examination, respectively. The sensitivity of telemedicine-based SSI diagnosis was 36.8%, with a specificity of 97.6%. The positive predictive value of the telemedicine-based diagnosis was 46.7%, while the negative predictive value was 96.4%. These findings confirm the feasibility of telemedicine intervention implemented by CHW in rural Rwanda or similar settings. The high negative predictive value of telemedicine can be leveraged to reduce unnecessary post-discharge follow-ups. Further studies are needed to improve telemedicine SSI diagnosis accuracy.

The thesis highlighted the importance of mHealth interventions in adherence to follow-up care, particularly among disadvantaged populations in low-income settings. It ascertained that mHealth interventions, such as reminder calls or notifications, could increase the return to post-discharge follow-up care. Barriers to this follow-up, such as transport costs and a lack of health insurance, should be addressed through targeted social protection and empowerment interventions. Further, these vulnerable women can benefit from home-based mHealth-CHW interventions like telemedicine. This thesis demonstrated that these interventions are feasible in rural settings. Further studies should explore the reasons for the gender-matching role in the uptake of follow-up care and strategies to improve telemedicine SSI diagnosis accuracy.

SUMMARY IN GERMAN

ZUSAMMENFASSUNG AUF DEUTSCH

Der Kaiserschnitt ist der am häufigsten durchgeführte chirurgische Eingriff in Distriktkrankenhäusern (DHs) in Ländern mit niedrigem und mittlerem Einkommen. Nach der Entlassung aus dem Krankenhaus haben die Patientinnen oft Schwierigkeiten, die Nachsorge in Anspruch zu nehmen, und riskieren postoperative Komplikationen wie Wundinfektionen (SSI). Die meisten SSI entwickeln sich nach der Entlassung des Patienten und können unentdeckt bleiben. Mobile Gesundheitstechnologien (mHealth) dezentralisieren die postoperative Nachsorge und gehen einige dieser Herausforderungen an. Die Faktoren der Nachsorge nach der Entlassung sind jedoch komplex und nicht gründlich untersucht, und mHealth für die SSI-Diagnose wurde im ländlichen Afrika nicht untersucht. In dieser Doktorarbeit wurden die Faktoren für die Rückkehr in die Nachsorgeklinik nach der Entlassung ermittelt und die Durchführbarkeit und Genauigkeit der telemedizinischen SSI-Diagnose bei Frauen, die sich einem Kaiserschnitt unterzogen hatten, im ländlichen Ruanda bestimmt.

In der ersten Publikation wird über eine Studie berichtet, die am Kirehe District Hospital durchgeführt wurde und an der Frauen ab 18 Jahren teilnahmen, die sich zwischen März und Oktober 2017 einem Kaiserschnitt unterzogen hatten. Alle teilnehmenden Frauen erhielten eine Entlassungsberatung und einen Gutschein zur Deckung der Transportkosten. Das Studienergebnis war die Rückkehr in die Nachsorgeklinik der Studie. Wir verwendeten eine logistische Regression mit schrittweiser Rückwärtsselektion, um Befähiger und Hindernisse für die Rückkehr in die Nachsorgeklinik nach der Entlassung zu identifizieren, mit einem Signifikanzniveau von 0,05.

Von 746 Patienten, die sich einer CS unterzogen, wurden 586 in die Studie aufgenommen. Die meisten hatten Zugang zu einem Mobiltelefon, und 73,2 % wurden am dritten postoperativen Tag entlassen. 84,1 % der Teilnehmer wurden von männlichen und 15,9 % von weiblichen Datensammlern erfasst. Vierundneunzig Prozent erschienen

zu ihrem ersten Termin. Insgesamt kehrten 9,6 % der Teilnehmer nicht in die Nachsorgeklinik zurück. Erleichternd für die Wiederaufnahme der Nachsorge waren Erinnerungsanrufe und die Beratung durch eine weibliche Datenerfasserin. Hindernisse für die Wiederaufnahme der Nachsorge waren das Fehlen einer Krankenversicherung und höhere Transportkosten. Diese Ergebnisse deuten darauf hin, dass mHealth-Maßnahmen wie Erinnerungsanrufe oder -benachrichtigungen und Maßnahmen des sozialen Schutzes, die auf nicht versicherte Patienten und Patientinnen mit schwierigen Transportbedingungen abzielen, die Nachsorgequote bei Frauen, die sich einer CS unterziehen, erhöhen könnten.

In der zweiten Publikation wird über eine prospektive Studie mit Frauen berichtet, die sich zwischen September 2019 und März 2020 in der Kirehe District Hospital einer CS unterzogen. Eine CHW der Studie (sCHW) besuchte die Teilnehmerin am POD10 (± 3 Tage) zu Hause, machte mit einer Smartphone-Applikation Fotos von der Operationswunde und schickte die Bilder an einen Allgemeinmediziner (GP) in Kigali. Der Hausarzt stellte die SSI-Diagnose und teilte sie dem sCHW mit. Am folgenden Tag wurden die Teilnehmer von einem anderen Arzt untersucht, dessen SSI-Diagnose in unseren Analysen als Goldstandard angesehen wurde. Wir berechneten die Sensitivität und Spezifität der telemedizinisch gestellten SSI-Diagnose und beschrieben die Indikatoren des Interventionsprozesses.

Von 787 Teilnehmern, die an der Studie teilnahmen, wurden 91,4 % der Teilnehmer zu Hause aufgesucht und untersucht. Alle Teilnehmer nahmen die Intervention an. Insgesamt war die Intervention bei 79,2 % der Studienteilnehmer erfolgreich. SSI wurde bei 4,2 % der Teilnehmer durch Telemedizin und bei 5,4 % durch körperliche Untersuchung diagnostiziert. Die Sensitivität der telemedizinischen SSI-Diagnose lag bei 36,8 %, die Spezifität bei 97,6 %. Der positive prädiktive Wert der telemedizinischen Diagnose lag bei 46,7 %, der negative prädiktive Wert bei 96,4 %. Diese Ergebnisse bestätigen die Durchführbarkeit einer telemedizinischen Intervention durch CHW in ländlichen Gebieten Ruandas oder in ähnlichen Situationen. Der hohe negative Vorhersagewert der Telemedizin kann genutzt werden, um unnötige

Nachuntersuchungen nach der Entlassung zu reduzieren. Weitere Studien sind erforderlich, um die Genauigkeit der telemedizinischen SSI-Diagnose zu verbessern.

In der Dissertation wurde die Bedeutung von mHealth-Interventionen für die Einhaltung der Nachsorge hervorgehoben, insbesondere bei benachteiligten Bevölkerungsgruppen in einkommensschwachen Gebieten. Es wurde festgestellt, dass mHealth-Interventionen, wie z. B. Erinnerungsanrufe oder Benachrichtigungen, die Rückkehr zur Nachsorge nach der Entlassung erhöhen könnten. Hindernisse für diese Nachsorge, wie Transportkosten und fehlende Krankenversicherung, sollten durch gezielte soziale Absischerung- und Empowerment-Maßnahmen angegangen werden. Außerdem können diese gefährdeten Frauen von häuslichen mHealth-CHW-Maßnahmen wie Telemedizin profitieren. Diese Doktorarbeit hat gezeigt, dass diese Maßnahmen in ländlichen Gebieten durchführbar sind. Weitere Studien sollten die Gründe für die geschlechtsspezifische Rolle bei der Inanspruchnahme der Nachsorge und Strategien zur Verbesserung der Genauigkeit der telemedizinischen SSI-Diagnose untersuchen.

CHAPTER I: INTRODUCTION

1.1 Overview

Cesarean section (CS) is a surgical procedure for delivering babies. While the procedure can be lifesaving for both mother and child, it is not without risks. Despite these risks, CS rates have been increasing globally.

Apart from medical indications for CS, socioeconomic and cultural factors influence CS rates and outcomes. In addition, social and economic inequities in low- and middle-income countries (LMICs) have challenged postoperative follow-up of women who undergo CS. SSIs are common in these settings. Fortunately, mobile health (mHealth) applications have enabled remote postoperative follow-up care in high-income countries, reducing geographical and financial barriers. Such applications can be considered for LMICs. This chapter discusses the background of the CS, the overview on global SSI, SSI monitoring and the Rwandan health system.

1.2 History and indication of cesarean section

The term cesarean section is derived from the Latin word "***caedere***," which means "to cut" (Moore, 2003). It is a surgical procedure involving the cutting of both the abdominal and uterine walls to deliver the baby (Rosenberg& Trevathan, 2018). This procedure, originally known as "***Lex Regia"***, dates back 715 years before Christ (BC). In ancient times it was performed to save the baby from a dying mother or to separate them when both mother and child died before or during delivery. This practice was stipulated by the then Roman law codified by King Numa Pompilius (715–673 BC] (Moore, 2003; Antoine &Young, 2021). However, some mothers survived the procedure, which was then considered to save either the mother, baby, or both (Moore, 2003). Today, CS is decided as an alternative to impossible or endangering vaginal delivery. It saves either the neonate or the mother in jeopardy, or both (WHO, 2021).

Although vaginal delivery has significantly better outcome than CS (Harrison et al, 2017), CS may be necessary for various reasons. The indications include fetal distress, abnormal position of the baby, severe maternal medical conditions, multiple births, or a previous cesarean delivery (Morton et al., 2020). In these situations, a CS can be the safest and most effective way to deliver the baby while ensuring the health and well-being of both mother and baby (Lucas et al., 2000). According to the level of urgency, CS are classified as 1) emergency: in case of an immediate threat to the life of a woman or fetus; 2) urgent: in case of maternal or fetal compromise which is not immediately life-threatening, 3) scheduled: needing early delivery but no maternal or fetal compromise, and 4) elective: delivery timed to suit woman or staff (Lucas et al., 2000). This urgency classification is also applied in Rwandan public hospitals. Previous CS and acute fetal distress are the most common indications of CS in Rwanda (Mazimpaka et al., 2020).

1.3 Global access to CS

The World Health Organization (WHO) modified its previous recommendation of CS rate between 10-15%, and now recommends only medically necessary CS (Betrȧn et al., 2016b). As of 2020 CSs represented 21% of all childbirths globally (up from 7% in 1990) and present enormous clinical benefits (WHO,2021). Increased access to CS is linked to declines in neonatal and maternal mortalities (Althabe et al., 2006). This increase is estimated to prevent 109,762–163,513 maternal deaths and 279,584 – 803,129 neonatal deaths if countries with low CS rate (≤ 7%) increased this rate to 7 - 19% (Molina et al., 2015). Further, there is an association between CS rates and countries' income levels, with high-income countries having higher CS rates than low-income countries (LICs) (Alipour et al., 2022).

1.3.1 CS access in SSA and in Rwanda

CS coverage is disproportionately distributed, varying from 5% in sub-Saharan Africa (SSA) to as high as 43% in Latin America and the Caribbean (WHO,2021). It is projected that global CS rate will increase to 28.5% by 2030. While the Eastern Asia will be leading with 63.4%, SSA will still lag with 7.1% (Betrȧn et al.,2021). Although the CS rate is low in SSA, it is the most-performed surgical procedure, accounting for 80% of the surgical volume (Sway et al., 2019). These surgical procedures are mainly performed in District Hospitals (Galukande et al., 2010; Petroze et al., 2012). Overall, the poorest countries, accounting for one-third of the global population, access only 6.3% of all global surgeries (Weiser et al. 2016).

In SSA, access to CS presents a double challenge. On one side, CS tends to be underutilized to help those most in need mainly due to fears CS (Akintayo et al., 2014). This fear of CS is due to inappropriate knowledge and myths, religious beliefs, community and peer pressure, CS complications, and the economic burden related to CS and post-operative care, to name a few (Richard, Zongo, & Ouattara, 2014; Litorp et al., 2015). On the other side, CS are overutilized by those who have great access to resources (Harrison et al., 2017). This overutilisation is a result of the convenience of CS for health professionals and women (Betran et al., 2016), and due to fear of losing their precious baby during labor and delivery (Akintayo et al., 2014).

Like the rest of SSA, Rwanda's CS rate increased from 2.2% in 2000 to 15.6% in 2019 (Kibe et al.,2022). However, a significantly higher CS rate was observed in private health facilities (60.6%), and private facilities have about four times higher CS rate as compared to public health facilities (Kibe et al.,2022). Compared to urban areas, rural areas have a lower CS rate (13% versus 25%). These rates increasing with higher education and wealth. Majority of women with high socioeconomic status reside in Kigali, the capital city (National Institute of Statistics of Rwanda [NISR], 2021).

1.4 Global burden and SSI risks associated with CS

1.4.1 Definition of SSI

According to the Centers for Disease Control and Prevention (CDC), SSI is defined as an infection occurring within 30 days from the operative procedure in the part of the body where the surgery took place. SSI can be incisional or organ/space SSI. Incisional

SSI is classified into superficial (involving the skin and subcutaneous tissue) and deep SSI (involving fascial and muscle layers) (CDC,2010).

CS benefits also come with medical and economic disadvantages, particularly in LMICs. The results obtained from the Mascarello et al. (2017) meta-analysis indicated that women who deliver by CS have a triple increase in infection risk.

1.4.2 SSI risks associated with CS

Post caesarean SSI development depends on individual factors, pregnancy and intrapartum-related factors, and caesarean procedure-related factors. The maternal preoperative condition, age and physical condition, her weight, living in a rural area, pregestational diabetes, previous CS, and recurrent miscarriages are individual factors of SSI (Rubin, 2006). The SSI development is also attributed to poor peri- and postoperative care and mainly to post-discharge factors (Woelber et al., 2016) such as the patient's environment, health literacy, or financial and geographic barriers to healthcare. Particularly in low-income settings, the environment in which a mother who underwent CS must live after discharge exposes her to developing SSI. Poor water, sanitation, and hygiene environment, poor living conditions (Tusting et al., 2020), household duties, poor wound care, and to some extent, lack of wound care are widespread in SSA (Findeisen et al., 2019; Powell et al., 2021). These factors are worsened by poor or absence of post-discharge education, ignoring the importance of post-discharge care, and financial and travel hardships related to returning to follow-up care (Findeisen et al., 2019; Powell et al., 2021; Tanner et al., 2013; Nkurunziza et al., 2019). Of note, these challenges imply the necessity of active surveillance through post-discharge follow-up for timely detection and treatment of CS complications.

1.4.3 Global burden of SSI

The SSI burden is extensive, from clinical to economic, and from individuals to national and global health systems (Findeisen et al., 2019; Sullivan et al., 2017). SSI is associated with increased patient morbidity and mortality. SSI accounts for 38% of death among patients with SSI (Astagneau et al.,2001). It causes a significant increase in the clinical burden associated with surgery. SSI leads to prolonged hospitalization and treatment, reoperation, and readmission (Badia et al., 2017; Gibson, Tevis, & Kennedy, 2014). This burden is endured by the health systems and the patient's family. Health system becomes overloaded and face higher medical bills and families bears the burden of prolonged hospitalization, absenteeism and unproductivity and significantly increased medical bills. Consequently, these bills may go unpaid or lead to impoverishment (Sochet, et al., 2017).

1.4.3.1 SSI clinical burden in LMICS

LMICs endure a more significant SSI burden. In a review of 26 studies, Sway et al. (2019) found that SSI rates in SSA ranged from 7% to 48%. This high prevalence makes SSI the most common and costly healthcare-acquired infection (Monahan et al., 2020; Mehtar et al., 2020). SSI alone accounts for more than 30% of the costs associated with hospital-acquired infections (Sullivan et al., 2017). Furthermore, SSI management is more challenging in these settings. This challenge is mainly due to antibiotic resistance, poor health facilities infrastructure, inadequate quality of wound care, misfortunate living environment, and lack of timely access to healthcare (Shears, P. 2007; Ntakirutimana et al, 2020; Velin et al., 2021; Tanner et al., 2013). Although the reported SSI prevalence is already high, the more considerable burden of SSI is not accounted for because 60% of SSIs develop after a patient is discharged from the hospital (Woelber et al., 2016). As a result, these SSIs go undetected and thus untreated due to the lack of active surveillance and standard post-operative follow-up (di Oliviera et al., 2007; Løwer et al., 2013).

1.4.3.2 SSI economic burden in LMICs

Economic burden of post-cesarean SSI to patients, families, health insurance, and health systems is enormous. Mori et al. (2020) found that the CS costs range between USD 56 and USD 562 in SSA. In Rwanda, CS costs 122.16 USD (interquartile range: 102.9 to 148.1 USD) from a patient perspective, of which 63% occur after a patient's discharge (Niyigena et al, 2022). SSI development is associated with the increased health expenditures. In average, the healthcare cost for patients with SSI is approximately twice that of those without an SSI (Broex et al., 2009). The additional cost of SSI in LMICs range from $174 to as high as $29,610 per patient (Monahan et al., 2020). The cost burden and impact of SSI in LMICs are higher due to the limited resources and healthcare infrastructure needed for prevention and control of infection and antibiotic resistance. Countries that invested less health spending per capita suffer more of SSI economic impacts. SSI costs worsen economies of already impoverished individuals and families (Mehtar et al., 2020). Therefore, reducing SSI in LMICs is a priority for improving global health and surgical outcomes (Ademuwiya et al., 2021).

Contrary to LICs, high income countries leverage the advances in medical and telecommunication technologies to trim down SSI through proper per- and post-operative care and post-discharge follow-up, even remotely (Abelson et al., 2017; Gunter et al., 2016a; Løwer et al., 2013). For example, a multicentre study by Jang et al. (2022) found that SSIs occur in 1.8% of cesarean procedures in the United States. Similarly, a systematic review and meta-analysis reported 1-4% SSI incidence rates in Europe (Mengistu et al., 2023). This incidence is much lower compared to SSA that records as high as 48% (Sway et al., 2019).

1.5 Post-cesarean SSI monitoring

Postoperative evaluation through inspection of the cesarean incision is an essential component of SSI monitoring. In addition to symptoms such as fever and pain on the surgical site, this evaluation detects the predictive signs of SSI such as purulent discharge, induration, tenderness, or erythema on surgical site. Most SSI develop silently and become clinically apparent between POD5 and POD10 (National Collaborating Centre for Women's and Children's Health (UK), 2008). By this time, most women have already been discharged from the hospital. Therefore, it is paramount to establish a clear post-discharge follow-up plan and counsel women on alarming signs and symptoms (Kateera et al, 2022). Early treatment significantly prevents further advance of post-operative complications and severe consequences (Fitzwater & Tita, 2014).

According to the WHO (2014) recommendation, mothers and neonates should benefit from an effective follow-up after delivery to ensure maternal and neonatal optimal outcomes. It also helps prevent complications, and if any, treat them early. This general post-partum follow-up is recommended on day 3 (48–72 hours) –likely on discharge, between days 7–14, and six weeks after delivery.

As adapted from the WHO guidelines, the Rwandan postpartum guidelines recommended that postnatal care (PNC) be conducted within 48 hours after birth, followed by subsequent visits on the third day (PNC 2), the seventh day (PNC 3), and at six weeks after birth (PNC 4) to ensure that both the mother and baby are healthy and progressing well (Ministry of Health [Rwanda], 2016) (Table 1.1). PNC 2 and 3 are conducted at home because the risk of infection is greater if brought to the facility, and the burden is high for new mothers (Williams et al., 2019). However, there are no guidelines for those who have given birth through CS although they require special surgical follow-up.

Table 1.1: *Postpartum care visit timeline and content for women delivering by cesarean birth in rural Rwanda*

PNC #	PNC 1	PNC 2	PNC 3	PNC 4
Timing	At discharge	2 days after discharge	7-14 Days after delivery	6 weeks after delivery
Eligible	All women	For patients discharged with wound dressings	All women	All women
Location	Hospital with GPs	Health center with healthcare providers; with CHW if no complications	Based on progress of recovery—Referral to hospital with GPs or health center with nurses; with CHW if no complications.	Health center with nurses
Activities	• Assess general well-being and possible complications. • Counseling on nutrition, hygiene, family planning, and exercise. • Counseling on normal. recovery vs danger signs • Any topics patient wishes to address.	• Assess wound healing, replace wound dressing. • Assess pain level and management. • Assess for other complications including pregnancy and previous health complications. • Newborn check-up (umbilical cord healing, breastfeeding troubleshooting, child immunization schedule) • Continue discussion on family planning. • Any topics patient wishes to address.	• Assess for danger signs. • Check wound healing for patients with sutures, remove sutures (at hospital only). • Evaluate for postpartum depression (using a validated screening tool), psychosis, and severe psychiatric illness. • Evaluate for signs of IPV. • Evaluate home conditions (if a home visit). • Newborn check-up (infant weight gain, breastfeeding troubleshooting, child immunization schedule). • Continue discussion on family planning. • Any topics patient wishes to address	• Check wound healing. • Assess recovery & general well-being. • Preventive care (cervical smear, chronic disease management with GP. • Evaluate for postpartum depression and generalized anxiety disorder (using a validated screening tool), psychosis, and severe psychiatric illness. • Evaluate for signs of IPV and home conditions. • Continue discussion on family planning. • Child vaccination schedule • Any topics patient wishes to address.

Note**:** From "Safe recovery after cesarean in rural Africa: Technical consensus guidelines for post-discharge care" by Kateera et al., *Int J Gynecol Obstet*., 2023;160(1), p.19. (https://doi.org/10.1002/ijgo.14284). Copyright 2023 by F. Kateera

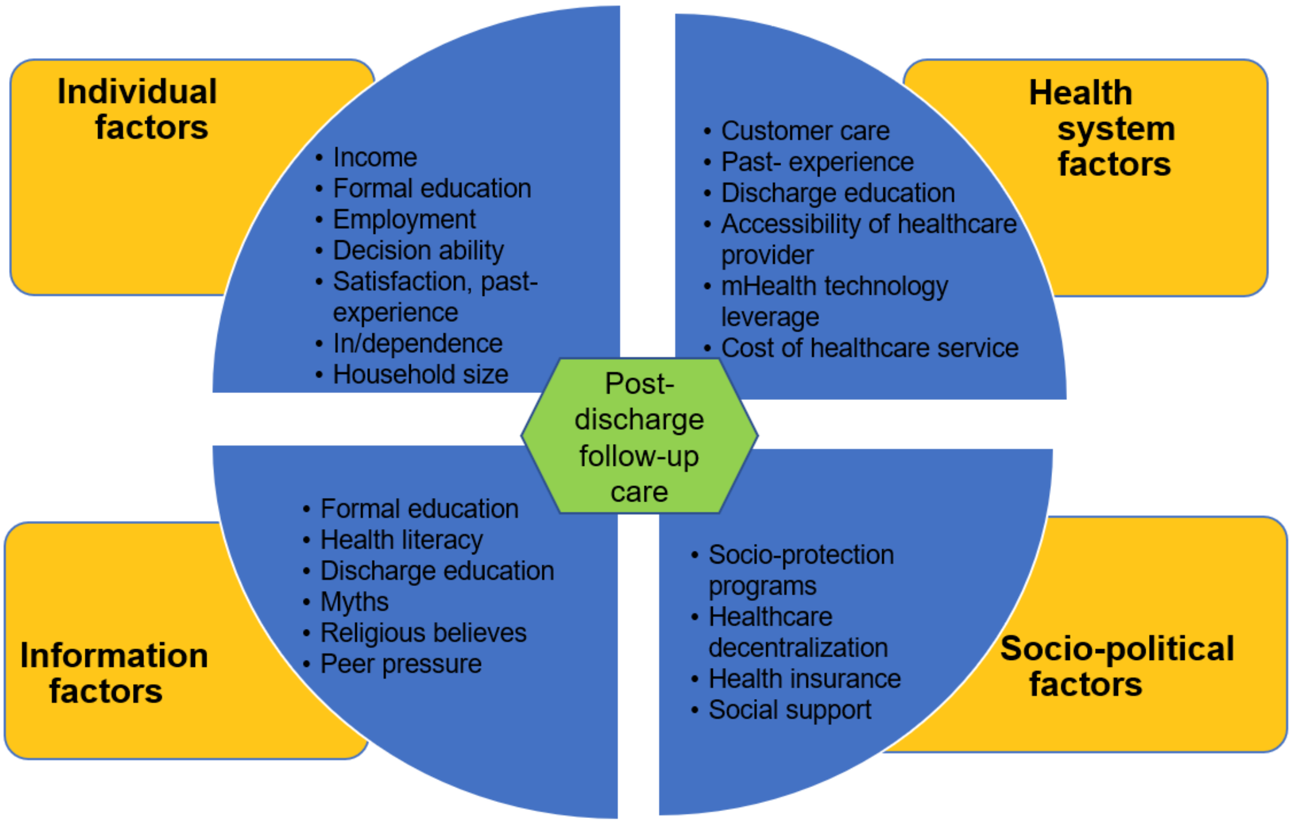
IPV: intimate partner violence

1.5.1 Challenges of post-discharge follow up

Many challenges impede women from appropriately following post-discharge care, but the list is not exhaustive (Figure 1.1). First, there are challenges from individual patients relating to lack of required knowledge on wound monitoring and danger signs, and in case of wound concerns, patients have a challenge with communication with their providers (Sanger et al., 2014). Further, unsatisfactory customer care, inconsistency or lack of information, misperception, or absence of cesarean complications, accumulated medical and indirect costs, dependency of women on their husbands, husband's education and occupation, insufficient household income, and large family size were identified as factors that can hinder patients from returning to a health care facility for post-discharge follow up (Adams et al., 2018; Powell et al., 2021).

Second, there are challenges related to the healthcare system. Factors that influence the uptake of post-discharge follow-up by surgical patients include geographical distance to a healthcare facility and financial challenges such as care and transportation costs (Grimes, 2011; Nkurunziza et al.,2019). In addition, women reported a lack of or flawed discharge education, poor explanation of diagnosis, patients not actively participating in their surgical journey, and bad experiences of a patient through the delivery process as factors demotivating them from returning to health facility (Powell et al., 2021; Kang et al., 2020). Lastly, CHWs who normally provide maternal and children follow-up care and serve as a link between their community and the health system are not trained to monitor women with cesarean wounds (Haver et al., 2015).

Figure 1.1: *Conceptual framework for post-discharge follow-up of women with CS*



Note: There are inter-relationships between individual, health system, informational and socio-political factors influencing access to post-discharge care.

The figure was designed by the author as a visual display of factors of post-discharge follow-up as described in the manuscript.

1.5.2 Opportunities for solving the post-discharge follow-up challenges.

1.5.2.1 Home-base care by community health workers' network

Rwanda's integrated CHWs in the decentralization of health care delivery, built its network coordination from the national level up to the village, and currently employs mobile technologies to assist them in their work. As a result, Rwanda recorded a tremendous reduction in maternal and infant mortality and improved children growth achieving the Millennium Development Goals for Health (Abbott et al., 2017).

Particularly, *Animatrice de santé Maternelles* (ASM), present in each village, support pregnant women from early signs of pregnancy to accompanying them to the health facility for labor to post-partum home visits for early danger signs detection and timely referral if needed. To that effect, they are initially trained in community-based maternal and neonatal health care and receive refresher training after six months (Haver et al., 2015).

1.5.2.2 Maternal health voucher program

The available data indicate the role of the maternal health voucher programs in increasing maternal health services utilization and improving maternal outcomes in South Asia (Jehan et al., 2012). A typical case study of success in this aspect is the maternal voucher program in Bangladesh. The benefit package of the voucher scheme includes incentivizing antenatal care check-ups, delivery at the health facility or skills attendant-assisted delivery at home, and postnatal care check-ups up to six postnatal weeks. In addition, this scheme covers transportation costs (Ahmed &Khan, 2011). According to a systematic review of 28 voucher programs by Bellows and colleagues (2013), these programs have successfully increased access to quality maternal and newborn health services for disadvantaged women and recommended them as they can contribute to the national-level impact in the population. This program empowers women and improves household living conditions and increases the use of health services (Ahmed& Khan, 2011; Nguyen et al., 2012). Further, it contributes to reducing inequities in accessing maternal and newborn health services among disadvantaged populations (Sapkota, Bhusal, & Acharya, 2021). Similar results were obtained in a quasi-experimental study using maternal health voucher in Kenya (Dennis et al., 2018). However, there is no such a program in Rwanda.

1.5.2.3 Mobile health (mHealth) technologies in healthcare delivery.

mHealth connects patients and healthcare providers through short message service (SMS), phone calls, mobile apps, and computer-assisted through machine learning algorithms (Pillay & Motsoaledi, 2018; Triantafyllidis & Tsanas, 2019).

mHealth technologies have the potential to revolutionize healthcare delivery. mHealth enables patients and providers to communicate more efficiently, improve patient outcomes through remote monitoring and disease management, increase access to healthcare in underserved areas, and reduce healthcare costs through streamlined processes and reduced hospital readmissions (Cowie et al., 2021; Dawes et al., 2021; Crocker, Crocker, & Greenwald, 2012). Further, these technologies increase the patient's participation in their care and decision, decrease the healthcare delivery cost while increasing the productivity of medical practitioners, and subsequently improve the efficiency and effectiveness of operations of healthcare delivery (De La Cruz Monroy & Mosahebi, 2019; Iyawa, Herselman, & Botha, 2016; Gjellebæk et al., 2020).

The benefits of mHealth include effortless education and awareness, remote data collection, remote monitoring, tracking of priority diseases and outbreaks in real-time, improving diagnosis abilities, treatment support, improving access to healthcare relieving geographical and financial barriers, and remote communication and training for healthcare practitioners (Vital Wave Consulting, 2009). Telemedicine optimizes patient outcomes improving time and cost utilization, which makes the doctor and patient more effective and reduces missing appointments (Haleem et al., 2021). However, implementing and adopting mHealth technologies must be done thoughtfully, considering privacy concerns, data security, and regulatory compliance (Kreitmair, Cho, & Magnus, 2017).

Rwanda started implementing mHealth projects in 2012, initially with Rapid SMS, an mHealth monitoring system implemented by CHWs and the Ministry of Health for maternal and child health services (Hategeka et al., 2019); In 2016, Babyl (known in the United Kingdom as Babylon) was inaugurated to conduct medical or nurse consultations and related laboratory tests and medical prescription online (Griffiths et al., 2020). These already available mHealth applications and strides made in information and technologies reflect the Rwanda's political will and telecommunication environment conducive for telemedicine interventions uptake in Rwanda.

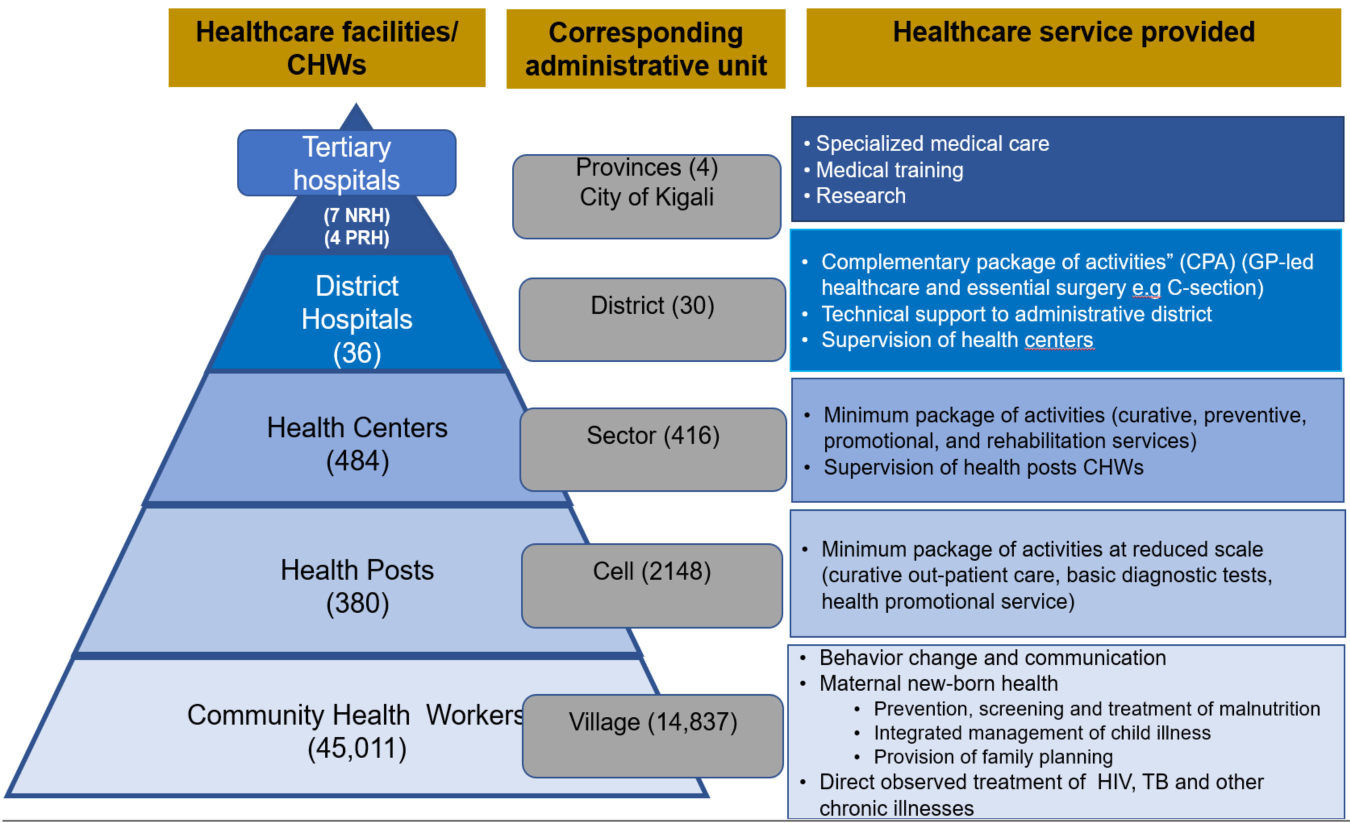
1.6 Rwanda and Rwanda's health system

Rwanda is a small landlocked country (26,338 km^2) located between Central and East Africa. According to the latest National Institutes of Statistics (2022), the size of the resident population is 13,246,394; mainly (72.1%) residing in rural areas, young, with primary education (89.3%) and living on subsistence agriculture (69 % of households). Sixty-one percent of households have access to electricity (51.3% in rural areas), and 77% of rural households have access to an improved source of water. Among the population, aged 21 years and above, 62.9% own mobile phones. According to World Bank (2023) data, 55% of the Rwandan population lives in poverty.

Rwanda has a three-tiered health-system delivery system (Figure 1.2). The first and nearest level of care is the health center operated by nurses. The second level of care is the District Hospital staffed with general practitioners (GP) who manage general health conditions, surgical emergencies and perform minor and some major surgical interventions, mainly CS. The tertiary level of care is referral hospitals staffed with medical specialists who receive transferred patients for further diagnosis and specialized management of complicated cases. In addition to this health system, community-based healthcare delivery is possible thanks to the CHWs network described above.

The Rwandan health system implements a four-level premium community-based health insurance (CBHI) system based on Rwanda's socioeconomic assessment system (Binagwaho et al., 2014). The poorest quartile of society is categorized in category one, whose premiums and medical bills are covered by the government; and wealthiest quartile is in category four. Those in category two to four pay their annual premiums and copays. CBHI covers a basic and tertiary package of services and drugs in public health facilities (Figure 1.2). Rwanda has made strides in e-health, leveraging technology to enhance health service delivery and improve health outcomes (Maeder, 2021). For example, the development of an electronic medical record system greatly improved the efficiency and effectiveness of healthcare delivery by allowing healthcare providers to access patient information and medical history in real-time (Amoroso et al., 2010).

Figure 1.2: *Rwandan health system and administrative structure*



Note: This figure was designed by the author using data from Ministry of health and Government of Rwanda website: https://www.gov.rw/government/administrative-structure.

NRH: National Referral Hospitals; PRH: Provincial Referral Hospitals; CPA: Complementary Package of Activities

1.7 Critique of current research on post-discharge follow-up after CS

The available literature on post-discharge follow-up of cesarean patients has a limitation of focusing on high-income countries, and few from low-income countries focused on urban settings. Further, most studies based their data on in-hospital data (Aiken et al, 2013; Petherick et al, 2006). By not standardizing post-discharge follow-up, most infection surveillance systems undermine the burden of surgical complications such as SSI, which go undetected and untreated (Aiken et al, 2013; Petherick et al, 2006; Forrester et al, 2018).

There is a gap in knowledge about barriers to post-discharge follow-up care among women who undergo CS in rural areas. After discharge, in addition to the huge costs these women bear during their hospitalization, they face travel hardships due to long distances from hard-to-reach areas where transport is limited and expensive (Powell et al, 2020; Niyigena et al., 2022). These hardships to return to health facilities worsen the already existing poverty. To the best of our knowledge, no study has explored the enablers of return to post-discharge follow-up care for women who under CS from resource-limited rural settings.

Particularly to mobile technologies, which are still new in SSA, a systematic review by Njoroge and colleagues (2017) found that most mHealth projects focused on infectious diseases such as HIV/AIDS and were largely implemented in urban areas. We are unaware of any studies on telemedicine for remote SSI diagnosis implemented by CHWs with support from a doctor in real-time or using telemedicine as a surveillance method for SSI in SSA rural settings.

1.8 Rationale of the thesis

The majority of SSIs develop after a patients discharge and go undetected due to lack post-discharge surveillance (Løwer et al., 2013). Factors of return to post-discharge care are complex and multifaceted. Most studies that explored these factors were based in urban settings. Further, data regarding the facilitators and barriers to follow-up care encountered by women who undergo CS in low-resource settings are scarce.

In the context of telecommunication technology advances, telemedicine presents opportunities for remote post-discharge follow-up. Available data from high-income countries demonstrated that telemedicine is effective to that effect (Gjellebæk et al., 2020). In Rwanda, access to mobile phones and improved network infrastructure have created opportunities to implement mHealth interventions. Seventy-one percent of Rwanda's population own a mobile phone, and 99% have access to mobile networks (NISR, 2018).

Another opportunity is presented by a community of CHWs. Each village in Rwanda has three CHWs. They are integrated into health care decentralization, linking their communities to the health system, and using mobile technologies to assist them. As a result, maternal and infant mortalities were significantly reduced, and children's growth was improved (Abbott et al., 2017). However, to the best of our knowledge no study explored the use of CHW-led mHealth in improving access to follow-up healthcare after surgical patients' discharge from hospitals in rural Africa. This thesis explored telemedicine use to address barriers to follow-up care among women undergoing CS in rural Rwanda.

1.8.1 Rationale of Publication one

The post-discharge follow-up is essential to optimise the clinical outcome of both the mother and the baby. However, the rate of postnatal check-ups is low. The NISR (2015) report showed that only 43% of women have a least one check-up after delivery. Particularly, women who undergo CS in rural settings return to unfavourable environment and have additional risk of developing SSI (Ntakirutimana et al, 2020; Robb et al, 2020). Factors influencing post-discharge follow-up for surgical patients are not fully studied. Therefore, we undertook the present study to fill this gap and explored barriers and facilitators of the return to follow-up care among women who undergo CS in rural Rwanda.

1.8.2 Rationale of publication two

Majority of SSIs go undetected because they develop after a patient discharge and patients face barriers to return to healthcare. Yet, in developed countries, telemedicine technologies have been effective in the post-discharge follow-up of surgical patients (Gunter et al., 2016a). In LMICs, telemedicine interventions have been implemented successfully mainly in maternal and children health and follow-up for infectious diseases (Njoroge et al., 2017). Nevertheless, the use of telemedicine for postoperative patients' follow-up in rural Africa has not been explored. To this end, we appraised the feasibility and accuracy of telemedicine implemented by CHW to diagnose SSI in rural Rwanda.

1.9 Aims of the thesis

In this thesis, to inform strategies for effective post-discharge follow-up care in the rural context, we aimed to explore the use of telemedicine to address barriers to follow-up care among women undergoing cesarean section in rural Rwanda.

First, we ascertained the prevalence of women who did not return for post-operative follow-up after receiving CS in rural Rwanda. Second, we identified enablers and barriers to returning to the hospital after discharge among women who had undergone CS in rural Rwanda.

Thirdly, we assessed the feasibility of an mHealth-CHW home-based telemedicine intervention to diagnose SSIs in women who have undergone CS in rural Rwanda; and

Finally, we determined the diagnostic accuracy of the telemedicine-based SSI diagnosis compared to physical examination-based diagnosis.

1.10 Research questions

Referring to the low rate of post-discharge follow-up among postpartum women in Rwanda, the following research questions motivated and guided this doctoral project:

- What is the prevalence of women who do not return for postoperative follow-up after receiving CS in rural Rwanda?
- What are the enablers and barriers to post-discharge follow-up among women who have undergone a CS in rural Rwanda?
- Is the mHealth-CHW telemedicine intervention for SSI diagnosis in rural Rwanda feasible?
- What is the accuracy of the telemedicine-based SSI diagnosis compared to the physical examination-based SSI diagnosis?

CHAPTER II: METHODOLOGY

2.1 Methods for study one

For publication one (Nkurunziza et al.,2022a), the study included all women 18 years or older who delivered via CS at Kirehe District Hospital between March 23 and October 18, 2017. We excluded patients who could not potentially return due to any third factor. This is the case of patients from the Mahama Refugee Camp, patients from outside the Kirehe District Hospital's catchment area, and patients who were readmitted or remained in the hospital by postoperative day (POD) 7.

A study-trained data collector provided discharge counseling to all enrolled women, including information about their follow-up plans. In addition, we provided a voucher that could be redeemed at Kirehe District Hospital to cover the transport cost and compensate the women for their time spent participating in the study. This voucher ensured that transportation fees would not be a financial barrier for study participants returning to Kirehe District Hospital. Study participants were scheduled to return to the hospital SSI screening clinic on POD 10 (± 3 days). A reminder call was made to study participants the day before their scheduled appointment. At a study clinic, data collectors assessed participants' attendance status and entered clinical data as a GP screened participants for SSI. Any patient who missed her first clinic appointment was contacted and given a second appointment. We described study participants demographic and clinical characteristics and reported frequencies and proportions. The study outcome was the return to the study follow-up clinic, defined as attending the first or the second study clinic appointment. To determine the enablers and barriers related to post-discharge follow-up return, we employed a backward stepwise logistic regression with a significance level of α=0.05.

2.2 Methods for study two

Publication two (Nkurunziza et al., 2022b) resulted from a prospective study that involved women who underwent CS at Kirehe District Hospital between September 22, 2019 and March 16, 2020. Exclusion criteria included patients from the Mahama Refugee Camp, those who were still in the hospital on POD10, and those who had been readmitted at the time of their scheduled research follow-up visits. All recruited women received discharge counseling from a study-trained data collector and details on their follow-up schedule and planned study procedures. In addition, the study staff called a study participant and her village CHW for a reminder one day before the home visit.

At POD10 (± 3 days), the study team organized the moto transport for the sCHW travel to the scheduled participant's home. When she arrived in the village, she was oriented by the village-based CHW. During her visit, the sCHW used a Samsung Galaxy J8 smartphone with the Wound Screener application, which standardizes image capture and quality, to take pictures of the surgical wound. Using WhatsApp, the sCHW sent the image to a GP in Kigali. The GP determined if an SSI was present and texted the sCHW with the findings, ideally within one hour. Additionally, the sCHW recorded process indicators such as the ability to locate patients' homes, patients' acceptance of wound examination and image capture, patients' willingness to share electronically transmitted data with a doctor, successful transmission of wound images to a doctor, receipt and timeliness of a doctor's diagnosis, and any difficulties encountered.

Every participant was requested to attend a study clinic at Kirehe District Hospital the following day for a physical examination by a different GP. During the visit, a Kirehe-based GP conducted a physical examination, administered SSI screening questions, and then determined if the patient had an SSI. The SSI diagnosis referred to the CDC definition. This physical examination-based SSI diagnosis was considered the gold standard in our analysis of accuracy.

The study team gave each participant cash in exchange for a voucher to help with travel expenses. The whole telemedicine intervention was deemed effective if the sCHW received a response from a GP within one hour after sending the wound image. For study two, we assessed the intervention process indicators and calculated the sensitivity and specificity of telemedicine-based SSI diagnosis.

CHAPTER III: RESULTS

3.1 Publication one

Authors: Theoneste Nkurunziza, Robert Riviello, Frederick Kateera, Edson Nihiwacu, Jonathan Nkurunziza, Madgalena Gruendl, Stafanie J. Klug, Bethany L. Hedt-Gauthier

Title: Enablers and Barriers to Post-Discharge Follow-Up Among Women Who Have Undergone a Caesarean Section: Experiences From A Prospective Cohort in Rural Rwanda.

Journal: BMC Health Services Research.

DOI: https://doi.org/10.1186/s12913-022-08137-5

Summary:

Of 746 women who underwent CS, 586 were enrolled in the study. Majority were farmers (86.7%, n=508), with primary education (70.0%, n=410), and earning less than 31.8 Euro/month (92.7%, n=543). At least 86.4% (n=506) had access to a mobile phone. By POD 3 the majority of patients (73.2%, n=423) were discharged. In the study, the majority of participants (84.1%, n=493) were enrolled and consented by male data collectors. As a result of reminders, 93.6% of patients (n=367) attended their first appointment. Of those 194 not reached by the first reminder phone call, 136 (70.1%) returned to the first appointment clinic. Overall, 56 participants (9.6%) were not reached at all on the phone call and did not returned follow-up clinic.

Being called and reminded of their appointment (OR=16.47, 95%CI:7.07–38.38) and having a female data collector counseling study participants(OR=9.85, 95%CI:1.43–37.59) were associated with higher return to follow-up clinic. Patients without health insurance (OR=0.03, 95%CI:0.03–0.23) and paying greater than 10.6 Euro as transport cost had reduced odds of returning to follow-up clinic (OR=0.14, 95%CI:0.04- 0.50).

Nkurunziza *et al.*
BMC Health Services Research (2022) 22:733
https://doi.org/10.1186/s12913-022-08137-5

BMC Health Services Research

RESEARCH | Open Access

Enablers and barriers to post-discharge follow-up among women who have undergone a caesarean section: experiences from a prospective cohort in rural Rwanda

Theoneste Nkurunziza[1,2*], Robert Riviello[3,4], Frederick Kateera[1], Edison Nihiwacu[1], Jonathan Nkurunziza[1], Magdalena Gruendl[2], Stefanie J. Klug[2] and Bethany Hedt-Gauthier[3]

Abstract

Background: Caesarean sections account for roughly one third of all surgical procedures performed in low-income countries. Due to lack of standardised post-discharge follow-up protocols and practices, most of available data are extracted from clinical charts during hospitalization and are thus sub-optimal for answering post-discharge outcomes questions. This study aims to determine enablers and barriers to returning to the hospital after discharge among women who have undergone a c-section at a rural district hospital in Rwanda.

Methods: Women aged ≥ 18 years who underwent c-section at Kirehe District Hospital in rural Rwanda in the period March to October 2017 were prospectively followed. A structured questionnaire was administered to participants and clinical data were extracted from medical files between March and October 2017. At discharge, consenting women were given an appointment to return for follow-up on postoperative day 10 (POD 10) (± 3 days) and provided a voucher to cover transport and compensation for participation to be redeemed on their return. Study participants received a reminder call on the eve of their scheduled appointment. We used a backward stepwise logistic regression, at an $\alpha = 0.05$ significance level, to identify enablers and barriers associated with post-discharge follow-up return.

Results: Of 586 study participants, the majority (62.6%) were between 21–30 years old and 86.4% had a phone contact number. Of those eligible, 90.4% returned for follow-up. The predictors of return were counselling by a female data collector (OR = 9.85, 95%CI:1.43–37.59) and receiving a reminder call (OR = 16.47, 95%CI:7.07–38.38). Having no insurance reduced the odds of returning to follow-up (OR = 0.03, 95%CI:0.03–0.23), and those who spent more than 10.6 Euro for transport to and from the hospital were less likely to return to follow-up (OR = 0.14, 95%CI:0.04- 0.50).

Conclusion: mHealh interventions using calls or notifications can increase the post-discharge follow-up uptake. The reminder calls to patients and discharge counselling by a gender-matching provider had a positive effect on return to care. Further interventions are needed targeting the uninsured and patients facing transportation hardship. Additionally, association between counselling of women patients by a female data collector and greater return to follow-up needs further exploration to optimize counselling procedures.

*Correspondence: theonkrz@gmail.com

[1] Partners In Health/Inshuti Mu Buzima, KG 9 Avenue 46, PO Box 3432, Kigali, Rwanda
Full list of author information is available at the end of the article

© The Author(s) 2022. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

Keywords: Post-discharge care, Global surgery, Sub-Saharan Africa, mHealth, Surgical site infections, Follow-up

Introduction

Caesarean sections (c-sections) are the most commonly performed major surgical procedure globally and account for roughly a third of all surgical procedures performed in low-income countries (LICs)[1]. Over the past two decades, there has been an increase in c-section rates from 6.7% to 19.1% globally, with a more modest increase (6.0%) observed in LICs [2]. However, increased access to c-sections in sub-Saharan Africa (SSA) has been linked to reductions in maternal and neonatal mortality rates [3–5].

For optimal maternal and child outcomes, the World Health Organization (WHO) recommends general post-partum follow-up on day 3 (48–72 h), between days 7–14, and at six weeks after delivery [6]. This could lead to early detection and treatment of complications [7]. However, in LICs, some patients face geographical and financial barriers as they strive to return for follow-up care [8]. In a systematic review on factors affecting postpartum follow-up, dependency of women on their husbands, lack of information, absence of complications, unsatisfactory customer care, husband's education and occupation, and large family size and household income were identified as impeding the decision to return to care [9].

Particular to women who undergo c-section, surgical site infections (SSI) are very common after their discharge [10, 11]. Reasons behind this can be poor living conditions, poor sanitation, patient's poor information, delay in seeking or accessing healthcare, poor quality of wound care just to name a few [12, 13]. SSIs introduce a higher morbidity, mortality, and social economic burden on patients and health systems [14–16]. The SSI prevalence and related burden is higher in low-resourced settings [17], such as SSA countries, that report rates of post-caesarean SSI as high as 41.9% [18]. Due to the lack of active surveillance and standard follow-up after a patient is discharged from the hospital, these SSI rates are likely underestimated [19] since 60% of SSIs develop after a patient discharge [20].

In Rwanda, the caesarean section delivery rate in is 14.9% [21]. The community-based health insurance (CBHI) is implemented nationwide to facilitate access to healthcare because majority (55%) of the population is living in poverty [22]. The yearly premiums for this scheme range from 3.2 Euro to 7.6 Euro per head referring to the Ubudehe category. This is the 4-level socio-economic classification system of the population based on household welfare status, whereby Ubudehe category 1 are the poorest and category 4 the wealthiest [23]. Category 1 patients have their entire medical bills subsidized by the government.

Moreover, in addition to implementing WHO postnatal care guidelines [24], general maternal care initiatives were put in place. For example, the Ending Preventable Maternal Mortality initiative aimed to decrease maternal mortality to 70 per 100,000 live births by 2030 [25, 26], and community health workers (CHWs)' programme. The network of CHWs plays a critical role in maternal and neonatal care during the prenatal and postnatal period in their local communities[27]. However, these CHWs are not trained to support surgical follow-up [28, 29].

In spite of those efforts implemented to increase access to healthcare and improve maternal and child outcomes, the 2015 Rwandan National Institutes of Statistics (NISR) report shows that the same socio-economic and geographical barriers to post-partum follow-up care faced by other LICs are prevalent in Rwanda [30]. This results into only 43% of women receiving at least the first post-partum visit [18] and increases the odds of developing SSI and delaying its diagnosis and treatment [31]. To the best of our knowledge, little was done in regards to the particular and additional needs of caesarean patients prone to SSI after their discharge. Further, little is known about their post-discharge follow-up, particularly in rural areas where patients face long distances, difficult-to-access terrains, and financial restrictions to access healthcare. As part of our prospective cohort study among women who undergo a c-section in rural Rwanda, we invited women and supported them with transportation vouchers and reminder calls to return for a study-specific follow-up visit at postoperative day (POD) 10 (±3 days) at a rural district hospital in Rwanda. Here, we report the enablers and barriers for returning for follow-up to inform strategies for effective postoperative care seeking in this context.

Methods

Study setting

This prospective study included women who underwent c-section between March and October 2017 at Kirehe District Hospital (KDH) in rural Rwanda. KDH is managed by the Rwandan Ministry of Health (RMoH) and receives technical and financial support from Partners In Health/Inshuti Mu Buzima (PIH/IMB), a US-based, non-governmental health organization. At KDH, c-sections are mainly performed by general practitioners (GP) and are the most prevalent surgical intervention. KDH has a full-time obstetrician gynecologist on its staff under PIH/IMB support who provides mentorship to available GPs and manages the most complex obstetric and gynecologic cases.

In the Rwandan health care system, patients present first to the nearest health center for primary health care, basic evaluation, and treatment by nurses. These nurses transfer any cases requiring management by a GP to the district hospitals. District hospitals in Rwanda provide a secondary level of care, including minor and some major surgical interventions, as well as management of surgical emergencies, such as c-sections. These hospitals are staffed with GPs, nurses, midwives, other paramedical health practitioners, and administrative personnel [32]. District hospitals transfer complex cases in need of management by a specialist to tertiary care facilities, mostly in the capital city, Kigali [33].

A woman who undergoes a c-section is admitted to the postpartum ward for monitoring and postoperative care and, if she does not experience complications, is routinely discharged on POD 3. The decision to discharge the patient is made by a GP who completes a discharge form with notes on the patient's in-hospital management and the plan for post-discharge follow-up. A ward midwife or nurse then counsels the patient and gives discharge instructions, including operative wound care, a follow-up date for her wound dressing change at her nearest health center, details about any post-discharge medications, and neonatal care.

Study design and population

Data used for this study are a subset of data collected in the larger prospective cohort study where consenting adult women (≥ 18 years of age) who underwent c-section at KDH between March 22nd and October 18th, 2017 were enrolled and followed up for SSI detection [34]. This window was selected based on funding availability and implementation logistics but did give us the advantage of covering both the rainy and dry seasons. Patients from Mahama Refugee Camp were excluded given that their return would depend on the camp management. Patients from outside the KDH catchment area were also excluded given that they were likely to follow-up at their nearest health facility. Further, patients who were still hospitalized by POD 7 or readmitted before their follow-up date were also excluded.

Implementation of the study

At discharge, enrolled women received discharge counselling detailing the follow-up plan by study trained data collector. Each study participant was given a return date to the study-specific SSI screening clinic at KDH on POD 10 (± 3 days). To prevent transport costs from being a financial barrier to study participants returning to KDH, we provided a voucher on discharge that would be redeemed upon return to cover the transport costs and compensate the women's time participating in the study. To determine transportation fees, we used the guide set by PIH/IMB in Kirehe based on distance from each district zones to the hospital.

The study clinics were held on Tuesdays and Thursdays. Study participants were called on the eve of their scheduled appointment to remind them of their clinic schedule. When a patient missed her first clinic appointment, she was called again and was given a second appointment on the following study clinic day. At the study clinic, data collectors recorded their attendance status and a GP implemented the SSI screening protocol (results of the SSI screening is reported elsewhere) [31, 34].

Data collection

The study employed five trained data collectors, one female and four males, with clinical backgrounds. The questionnaire that had been developed and tested in Haiti [35] was translated in Kinyarwanda by the local study team and tested on 12 individuals for comprehension in March 2017. It was revised accordingly before the start of the study. The data collectors identified patients who had undergone c-section from the operating room registry and located them in the maternity postoperative room on POD 1. They explained the study aims, benefits and risks of participating in the study to eligible participants, and invited them to voluntarily consent to participate in the study. Those who consented were enrolled as study participants. The data collectors administered a structured questionnaire collecting demographic data from enrolled study participants. Clinical data were extracted from medical files. Study participants' access to a phone was also documented. A patient was confirmed to have access to a phone when she owned one, had a phone available in her household, or she gave the number of a neighbor where she could be reached.

A patient was considered as having comorbidity when she had any of the following underlying disease conditions prior to c-section: HIV/AIDS, diabetes, hypertension and other cardio-vascular disorders. Post-operative complications included any morbidity that occurred after surgery and prior to discharge as assessed by a GP or an obstetrician-gynaecologist and documented in the medical file. The documented complications were haemorrhage, fever, organ disfunction such as respiratory depression or urinary dysfunction, wound dehiscence, return to operating room, and any other post-operative abnormality diagnosed post-operatively during the hospital stay. The total length of hospital stay and post-operative length of stay were calculated by subtracting the date of discharge from the date of admission and date of surgery, respectively.

In addition to demographic and clinical data, we obtained rainfall data corresponding to the study clinic days from the Rwandan Metrological Agency. This agency uses satellite and has six stations in Kirehe. Each woman had two rainfall data points attached to her study visit. First, we used the data corresponding to the station closest to the participant's residence on the day of her study follow-up visit. Second, we also collected the rainfall data for the station closest to KDH for the day she was attending the study clinic. These data were used to analyze whether the rain had negative effect on participants' return on their appointments. All data were entered into REDCap, a secure web application that can support both online or offline data collection [36].

Analysis and statistics

The primary outcome for this study was the return to the study follow-up visit, defined as coming to the first or the second study clinic appointment. We used descriptive statistics to report study participants demographic and clinical characteristics. We converted Rwandan francs (FRW) to Euro using the 942 FRW/Euro rate, referring to the then average central bank exchange rate [37]. To identify predictors of return to follow-up care, we performed univariable logistic regression to determine variables eligible for a multivariable logistic regression model (Supplementary table S1). Variables significant at an $\alpha = 0.1$ significance level were considered for the reduced model. We built the model using backward stepwise selection, stopping when the remaining covariates were significant at $\alpha = 0.05$ significance level. We report the odds ratios (ORs), 95% confidence intervals (95%CIs) and p-values from the multivariable analysis. All analyses were performed using Stata v15 (College Station, TX: StataCorp LP).

Results

Of 746 women who underwent c-section, 586 (78.6%) were eligible for study enrollment. The majority (62.6%, $n = 338$) were between 21–30 years, married (43.0%, $n = 252$), with primary education (70.0%, $n = 410$), and were insured with CBHI (95.1%, $n = 557$). Most of the women were farmers (86.7%, $n = 508$), earned less than 31.8 Euro/month (92.7%, $n = 543$), and had access to a phone (86.4%, $n = 506$). Of those with recorded information on transport vouchers, 392 (66.9%) were issued between 5.3 and 10.6 Euro (Table 1). Fetal distress was the leading indication of c-Sect. (32.2%, $n = 189$) followed by previous scar (29.5%, $n = 173$). The majority of patients (73.2%, $n = 423$) were discharged by POD 3. The male data collectors enrolled and consented a majority of the study participants (84.1%, $n = 493$). Forty-one (7.0%) of study participants were exposed to rain, either at home or KDH, on their first appointment date or, for those who did not attend their first appointment date, on their second appointment date (Table 2).

Table 1 Demographic characteristics of study participants ($N = 586$)

Variables	Frequency	Percent
Age		
20 years and younger	73	12.5
21–30 years old	367	62.6
31–39 years old	128	21.8
40 years and older	18	3.1
Marital status		
Single	209	35.7
Married	252	43.0
Living with a partner	119	20.3
Separated (divorced or widowed)	6	1.0
Education level		
No education	47	8.0
Primary education	410	70.0
Secondary education or higher	129	22.0
Occupation		
Farmer	508	86.7
Employed, trader	43	7.3
Housewives	35	6.0
Type of insurance		
No insurance	6	1.0
Community-Based Health Insurance (CBHI)	557	95.1
Private insurance	23	3.9
Monthly household income†		
Less than < 31.8 Euro/month	543	92.7
31.8 Euro and above	43	7.3
Does the patient have phone contact?		
No	71	12.1
Yes	506	86.4
Missing	9	1.5
Amount of transportation voucher fees		
Up to 5.30 Euro†	119	20.3
> 5.30–10.60 Euro	392	66.9
Greater than 10.60 Euro	62	10.6
Missing	13	2.2

† = converted from FRW using the 942 FRW/Euro rate referring to the then average central bank exchange rate

Nearly all participants returned to the study follow-up clinic (90.4%, $n = 530$), most (85.8%, $n = 503$) on the date of their first clinic appointment. The phone call reached 72.3% ($n = 424$) of participants to remind them of either of their appointments. Of those reminded, 93.6%

Table 2 Clinical characteristics of study participants ($n=586$)

Variables	Frequency	Percent
Co-morbidity[&]		
No	571	97.4
Yes	15	2.6
Anaesthesia type		
General	14	2.4
Loco-regional	572	97.6
Indication to C-section*		
Foetal distress	189	32.3
Previous scar	173	29.5
Prolonged labour	68	11.6
Malpresentation	80	13.7
Obstructed labour	70	12.0
Cord and membrane dystocia	45	7.7
Hypertensive disorders	7	1.2
Uterine pre/rupture	8	1.4
Hypotonic dysfunction	21	3.6
Other indications	13	2.2
Post-operative complications**		
No	574	98.0
Yes	12	2.0
Total length of stay (LOS)		
Within 3 days	338	57.7
More than 3 days	248	42.3
Post-operative LOS		
Within 3 days	423	73.2
4–7 days	163	27.8
Duration of post-surgery antibiotic therapy		
No post-operative antibiotic	21	3.6
1–3 days	442	75.4
More than 3 days	123	21.0
Counselling data collector		
Male data collectors	493	84.1
Female data collector	86	14.7
Missing	7	1.2
Was it raining on the patient's appointment day?		
No	545	93.0
Yes	41	7.0

[&] Comorbidities included HIV/AIDS, diabetes, hypertension and other cardiovascular disorders

* = Percent total greater that 100% due to possibility of more than 1 indication for a C-section decision

** = Post-operative complications included haemorrhage, fever, organ disfunction such as respiratory depression or urinary dysfunction, wound dehiscence, return to operating room, and any other post-operative abnormality diagnosed post-operatively during the hospital stay

($n=367$) attended their first appointment. Of 194 participants who were not reached by the first reminder phone call, 136 (70.1%) returned to the clinic, all on the first appointment. Of 83 who did not show up at the first visit, 32 (38.6%) were reached by the second reminder call, and 27 of them (84.4%) attended their second appointment. Overall, 56 participants (9.6%) were not reached at all on the phone call and did not attend the clinic (Fig. 1).

In the reduced model of the multivariable analysis, having a female data collector enrolling and counselling study participants was associated with higher return to care compared to male counterparts (OR = 9.85, 95%CI:1.43–37.59). Study participants who were called and reminded of their appointment had 16-times greater odds of returning to their follow-up clinic (95%CI: 7.07–38.38). Study participants who had no insurance were 97% less likely to return to their follow-up clinic as compared to those who had CBHI (OR:0.03, 95%CI: 0.03-0.23). Study participants who were expected to spend more than 10.6 Euro for a round-trip ticket to return to the follow-up clinic were 86% less likely to return (OR = 0.14, 95%CI:0.04–0.50) (Table 3). Marital status, education level, type of insurance, and post-operative length of stay were included in the regression model but did not remain significant until the final model.

Discussion

In this study, we identified several factors associated with the participants' return to the study follow-up visit. Counselling before hospital discharge and a reminder call on the eve of the follow-up appointment were associated with higher return to follow-up. In contrast, higher costs of transportation and lack of health insurance were associated with reduced likelihood of return for the follow-up visit.

A reminder call on the eve of the follow-up appointment was associated with 16-fold higher chance of return. This reflects the role of mobile health technologies in improving the follow-up of surgical patients after their discharge from the hospital. Phone calls have been shown to be feasible and effective in the post-discharge follow-up and care of obstetric patients in Tanzania [38], and has been shown to optimize follow-up in other non-obstetric settings [39–42]. In this study, more than 80% gave phone contact on which they can be reached, consistent with the reported 71% of households owning cell phones in Rwanda [43]. Our reminder calls reached approximately 70% of study participants. This high phone coverage and the effectiveness of the reminder call should be leveraged in follow-up care activities. Nevertheless, given the burden that reminder calls could present to the already overwhelmed healthcare facilities and providers, less burdensome mHealth tools can be employed. Automated SMS notifications a day before their scheduled clinic could be an alternative with similar effect [44]. This would have an added benefit of reaching those who would otherwise be inaccessible during the call time.

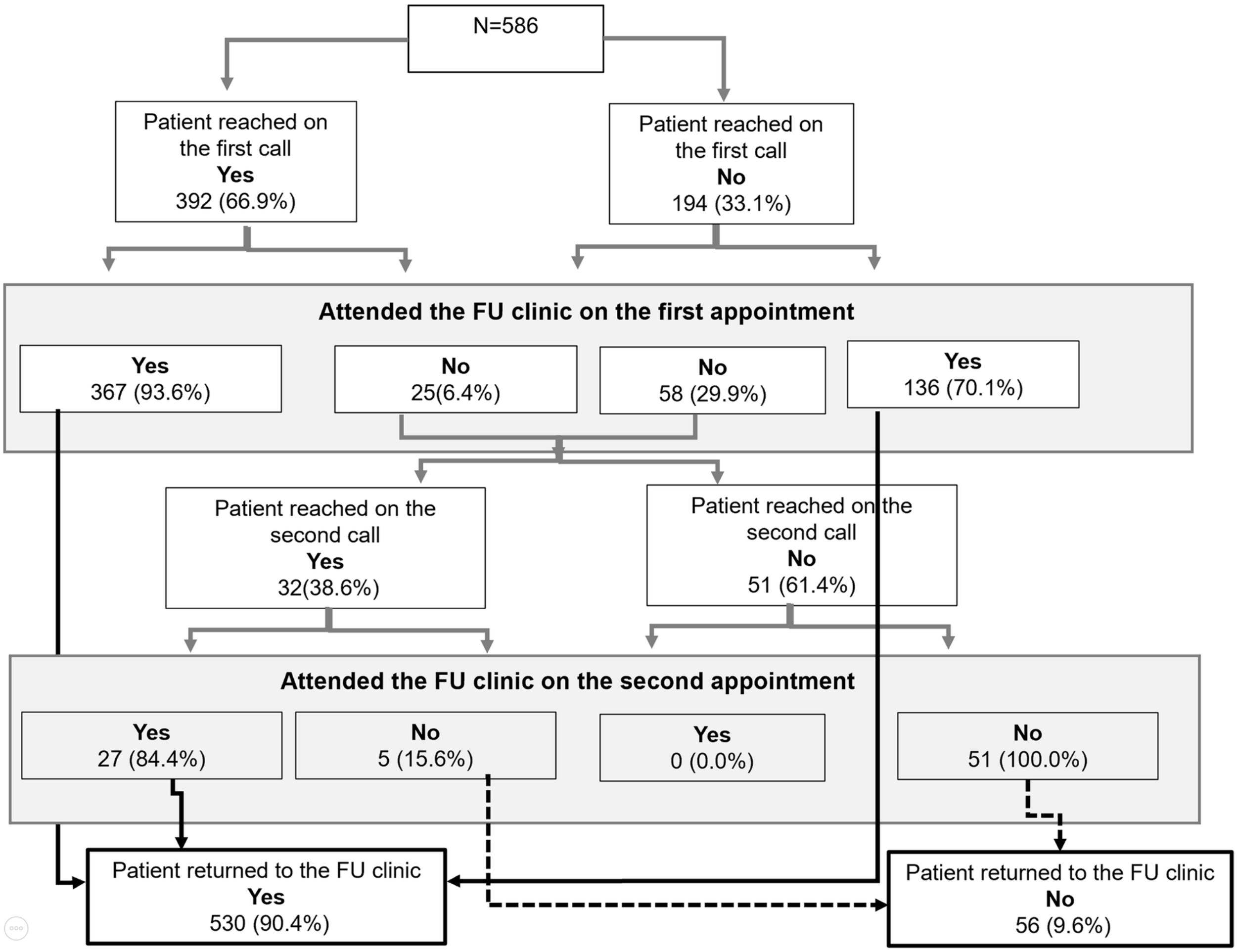


Fig. 1 Flowchart of the study implementation and follow-up rates. Dotted lines represent women who did not return to follow-up clinic. Full lines display those who returned to care

While we attempted to mitigate financial barriers via a transportation voucher, the amount of transportation voucher fees, which served as a proxy of transportation cost from the patient's home to the hospital, emerged as a significant predictor associated with lower follow-up rates. This implied that the higher the cost of transport, and therefore likely the farther the patient residence, the less likely the patient is to return to follow-up in this rural setting. Further, our study was conducted at a district hospital, the second level of Rwanda healthcare system, which have GPs on its staff; which required participants to travel further distance as compared to distance from home to health centers. Decentralized follow-up of these surgical patients at the nearest health facility may increase follow-up rates; however, as reported in a recent qualitative study [45], health center follow-up is also reported to be both financially and physically burdensome. While our use of vouchers may have offset some of the financial burden, the funding was reimbursed on arrival – a challenge if women could not front the costs – and did not remove physical challenges of travel postpartum and postoperative.

Patients without health insurance had almost no chance to return to the follow-up clinic. Particular to this study clinic, no fees were charged for the service. Yet uninsured patients failed to attend the clinic. For this rural setting, we believe that these were the vulnerable patients particularly from *Ubudehe* category 2 who are not subsidized by the government, and most prone to significantly have lower adherence to health insurance [46]. We attribute their failure to return to impoverishing out-of-pocket incurred at the hospital. Our findings support available data whereby while health insurance increases health service utilization and provides financial protection, that lack of insurance has negative effects on both [47–49]. This suggests that there is a vicious cycle of lack of insurance leading to impoverishment by healthcare costs, and vice-versa, as demonstrated by other studies

Table 3 Enablers and barriers of the return to a follow-up clinic after c-section (multivariable regression model) *n* = 567

	FULL MODEL (*n* = 567)			REDUCED MODEL (*n* = 567)		
	OR	**95% CI**	***P***	**OR**	**95% CI**	***P***
Marital status						
Married	1					
Single	0.71	(0.31–1.62)	0.415			
Living with a partner	0.62	(0.25–1.57)	0.314			
Education level						
Primary education	1					
No education	0.34	(0.12–0.99)	0.048			
Secondary education or higher	1.72	(0.45–6.63)	0.429			
Type of insurance						
CBHI	1					
No insurance	0.034	(0.03–0.33)	0.004	0.03	(0.03–0.23)	0.001
Private insurance	0.67	0.65–6.82)	0.733	0.73	(0.07–7.23)	0.789
Amount of transportation voucher fees						
up to 5.3 Euro	1					
> 5.3–10.6 Euro	0.38	(0.13–1.11)	0.078	0.36	(0.13- 1.02)	0.055
Greater than 10.6 Euro	0.13	(0.03–0.52)	0.004	0.14	(0.04- 0.50)	0.003
Post-operative length of stay						
Within 3 days	1					
4- 7 days	0.57	(0.27–1.19)	0.135			
Counseling data collector						
Male data collectors	1					
Female data collector	9.65	(1.22–45.95)	0.031	9.85	(1.43–37.59)	0.020
Was the patient reminded of her appointment?						
No	1					
Yes	17.30	(7.31–40.92)	< 0.001	16.47	(7.07- 38.38)	< 0.001
Was it raining on the patient's appointment day?						
No	1					
Yes	1.47	(0.40–5.41)	0.564			

where poverty was the root cause of uninsured populations in SSA [50]. This group of patients need more attention from healthcare providers to prevent them from being lost-to-follow-up and should benefit from extension of the available social protection programmes.

Discharge counselling by a female data collector was linked to the higher return to care as compared to her male counterparts. Psychological studies suggest that gender-matching improves agreement and emotional bonds that are associated with treatment compliance and retention[51–53]. However, to our knowledge, no study has assessed the gender-matching aspect when it comes to discharge counselling in the context of surgery in SSA. Further studies should explore the rationale behind and benefits of that preference.

Notwithstanding, our cohort has benefited from additional services that could have bettered their return as compared to the current standard of care for national postpartum follow-up. On discharge, study participants received a more detailed counselling by the study data collector regarding their follow-up visit and transport vouchers to facilitate their return. Additionally, they were reminded of their appointment. All these make this cohort unrepresentative of the women who are followed up postoperatively in normal standard of care. Further, according to the Rwandan demographic health survey, only 43% of women benefited from the first visit of standard post-partum care [30]. We suspect that the lost-to-follow-up in post caesarean patients under standard of care may be higher than 10% found in this study and this warrants another study. We believe that our findings would generalize to other women outside of the context of the study if they benefited from the same services since the setting is similar.

Since many changes have taken place after the study was implemented, including the coronavirus pandemic that added burden to healthcare system. We expect that better phone coverage will lead to feasibly reaching more patients by reminder notifications given ongoing efforts to improve access to mobile telephone particularly in rural areas. The current phone ownership in rural area has increased from 54% in 2014 to 67% in 2019 and from 60 to 71% nationally [21, 30].

This study had some limitations to be considered in interpretation. First, the generalization of results is limited given the population that was part of a larger study whose participants received additional services to encourage their return to follow-up clinic. However, the hypotheses generated by this study are relevant to the general population and we suggest further studies to explore the situation and the impact of those add-on services on the return to follow-up care. Second, there was incomplete data on geographical locations and transportation facilities. However, we used the transport fees, following a compensation structure outlined by PIH/IMB at KDH site, as proxy of distance and transport requirements from home to the hospital. Third, there are likely other possible enablers or barriers not considered, such as patient motivation and husband's influence. Fourth, the male–female data collector ratio was 4:1, which resulted into the female data collector counselling proportionately fewer women. We believe that this hypothesis is worth further exploring. Finally, this study took place in one location in Rwanda; however, the structure of KDH and care protocols in the district are similar to other facilities in Rwanda and the region.

Conclusions

The study found overall high return to follow-up in this study population; participant reminders via phone calls may contribute to their return for post-discharge follow-up. For those lost-to-follow-up, our findings on the detrimental effects of travel costs support the case for decentralizing follow-up care. Further, patients from rural communities who do not have health insurance represent the population at risk of lost-to-follow-up and so need more support. The association between discharge counselling by the same gender data collector and greater return to follow-up warrants further exploration. While these results are in the context of study-specific follow-up, and may have direct implication for future prospective studies in rural Africa, we believe these lessons learned can inform strategies for effective follow-up care post c-section more broadly.

Abbreviations

CBHI: Community-based health insurance; CHW: Community health worker; C-section: Caesarean sections; GP: General practitioners; KDH: Kirehe District Hospital; LICs: Low-income countries; LOS: Length of stay; NISR: Rwandan National Institutes of Statistics; PIH/IMB: Partners In Health/Inshuti Mu Buzima; POD: Postoperative day; RNEC: Rwanda National Ethics Committee; SSA: Sub-Saharan Africa; SSI: Surgical site infection; WHO: World Health Organization.

Supplementary information

The online version contains supplementary material available at https://doi.org/10.1186/s12913-022-08137-5.

Additional file 1: Table S1. Univariate logistic regression of predictors of the return to a follow-up clinic after c-section.

Acknowledgements

The authors would like to acknowledge the leadership and staff at KDH and PIH/IMB for their assistance in the implementation of the study, research participants, and the study team. Particular thanks to Kristin Sonderman, Teena Cherian, Irakoze Holy Louise, Bahati Ramadhan, Laban Bikorimana for their diligent work to ensure good quality data collection and data management.

Authors' contribution

Study concept and design: BH, RR, FK, TN, SJK. Acquisition, analysis or interpretation of data: TN, BH, RR, FK, SJK, EN, JN, MG. Drafting of manuscript: TN, EN, JN, MG. Critical revision of manuscript for important intellectual content: TN, RR, FK, EN, JN, MG, BH, SJK. Statistical analysis: TN, BH. Administrative technical or material support: EN, JN, MG. Study supervision: BH & SJK. All authors read and approved the final manuscript.

Funding

The study was funded by the National Institutes of Health grant number R21EB022368. The funder had no role in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript.

Availability of data and materials

The data that support the findings of this study are available from PIH/IMB but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of PIH/IMB.

Declarations

Ethics approval and consent to participate

All methods were carried out in accordance with relevant guidelines and regulations. All study participants signed informed consent prior to study enrolment. To protect patients' privacy, each patient was assigned study ID. Common measures were taken for data protection. Study data were entered directly into a REDCap database using password-protected and encrypted study tablets. This study went through scientific and ethical reviews and was approved by the Rwanda National Ethics Committee (Kigali, Rwanda, No. 848/RNEC/2016) and Partners Human Research Committee (Boston, MA, No 2016P001943/MGH).

Consent for publication

All authors have approved the text for publication. All data from was fully anonymised before analysis, and there are no data from individuals.

Competing interests

The authors declare they have no competing interests.

Author details

[1]Partners In Health/Inshuti Mu Buzima, KG 9 Avenue 46, PO Box 3432, Kigali, Rwanda. [2]Epidemiology Department of Sports and Health Sciences, Technical University of Munich, Munich, Germany. [3]Department of Global Health and Social Medicine, Harvard Medical School, Boston, USA. [4]Center for Surgery and Public Health, Brigham and Women's Hospital, Boston, USA.

Received: 30 March 2022 Accepted: 27 May 2022
Published online: 02 June 2022

References

1. Weiser TG, Haynes AB, Molina G, Lipsitz SR, Esquivel MM, Uribe-Leitz T, et al. Size and distribution of the global volume of surgery in 2012. Bull World Health Organ. 2016;94(3):201-209F.
2. Betran AP, Ye J, Moller A-B, Zhang J, Gulmezoglu AM, Torloni MR. The Increasing Trend in Caesarean Section Rates: Global, Regional and National Estimates: 1990–2014. PLoS ONE. 2016;11(2): e0148343.
3. Collaborators GBD 2015 MM. Global, regional, and national levels of maternal mortality, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1775–812.
4. Molina G, Esquivel MM, Uribe-Leitz T, Lipsitz SR, Azad T, Shah N, et al. Avoidable maternal and neonatal deaths associated with improving access to caesarean delivery in countries with low caesarean delivery rates: an ecological modelling analysis. Lancet. 2015;385(Suppl):S33.
5. Thomas S, Meadows J, McQueen KAK. Access to Cesarean Section Will Reduce Maternal Mortality in Low-Income Countries: A Mathematical Model. World J Surg. 2016;40(7):1537–41.
6. World Health Organization [WHO] & United States Agency for International Development [USAID]. (2015, April). Postnatal Care for Mothers and Newborns Highlights from the World Health Organization 2013 Guidelines. Geneva: WHO. https://www.who.int/docs/default-source/mca-documents/nbh/brief-postnatal-care-for-mothers-and-newborns-highlights-from-the-who-2013-guidelines.pdf. Accessed 13 Jul 2017.
7. Tsai PS, Hsu CS, Fan YC, Huang CJ. General anaesthesia is associated with increased risk of surgical site infection after Caesarean delivery compared with neuraxial anaesthesia: A population-based study. Br J Anaesth. 2011;107(5):757–61.
8. Grimes CE, Bowman KG, Dodgion CM, Lavy CBD. Systematic Review of Barriers to Surgical Care in Low-Income and Middle-Income Countries. World J Surg. 2011;35:941–50.
9. Adams YJ, Smith BA. Integrative Review of Factors That Affect the Use of Postpartum Care Services in Developing Countries. J Obstet Gynecol neonatal Nurs JOGNN. 2018;47(3):371–84.
10. Ward VP, Charlett A, Fagan J, Crawshaw SC. Enhanced surgical site infection surveillance following caesarean section: experience of a multicentre collaborative post-discharge system. J Hosp Infect. 2008;70(2):166–73.
11. Ferraro F, Piselli P, Pittalis S, Ruscitti LE, Cimaglia C, Ippolito G, Puro V. Surgical site infection after caesarean section: space for post-discharge surveillance improvements and reliable comparisons. New Microbiol. 2016;39(2):134–8.
12. Robb KA, Habiyakare C, Kateera F, Nkurunziza T, Dusabe L, Kubwimana M, Powell B, Koch R, Gruendl M, Ngamije P, Riviello R. Variability of water, sanitation, and hygiene conditions and the potential infection risk following cesarean delivery in rural Rwanda. J Water Health. 2020;18(5):741–52.
13. Tanner J, Padley W, Davey S, Murphy K, Brown B. Patient narratives of surgical site infection: implications for practice. J Hosp Infect. 2013;83(1):41–5.
14. Findeisen A, Arefian H, Doenst T, Hagel S, Pletz MW, Hartmann M, et al. Economic burden of surgical site infections in patients undergoing cardiac surgery. Eur J cardio-thoracic Surg Off J Eur Assoc Cardio-thoracic Surg. 2019;55(3):494–500.
15. Jenks PJ, Laurent M, McQuarry S, Watkins R. Clinical and economic burden of surgical site infection (SSI) and predicted financial consequences of elimination of SSI from an English hospital. J Hosp Infect. 2014;86(1):24–33.
16. Sullivan E, Gupta A, Cook CH. Cost and Consequences of Surgical Site Infections: A Call to Arms. Surg Infect. 2017;18(4):451–4. https://doi.org/10.1089/sur.2017.072.
17. Allegranzi B, Bagheri Nejad S, Combescure C, Graafmans W, Attar H, Donaldson L, et al. Burden of endemic health-care-associated infection in developing countries: systematic review and meta-analysis. Lancet. 2011;377(9761):228–41.
18. Sway A, Nthumba P, Solomkin J, Tarchini G, Gibbs R, Ren Y, Wanyoro A. Burden of surgical site infection following cesarean section in sub-Saharan Africa: a narrative review. Int J Womens Health. 2019;11:309–18.
19. De Oliveira AC, Carvalho DV. Evaluation of underreported surgical site infection evidenced by post-discharge surveillance. Rev Lat Am Enfermagem. 2007;15(5):992–7.
20. Woelber E, Schrick EJ, Gessner BD, Evans HL. Proportion of Surgical Site Infections Occurring after Hospital Discharge: A Systematic Review. Surg Infect. 2016;17(5):510–9.
21. National Institute of Statistics of Rwanda(NISR) [Rwanda], Ministry of Health (MOH) [Rwanda], and ICF. 2021. Rwanda Demographic and Health Survey 2019–20 Final Report. Kigali, Rwanda, and Rockville, Maryland, USA: NISR and ICF.
22. World Bank. The World Bank In Rwanda: overview. 2018. http://www.worldbank.org/en/country/rwanda/overview. Accessed 28 September 2018.
23. Ezeanya-Esiobu, Chika. The rise of homegrown ideas andgrassroots voices: New directions in social policy in Rwanda, UNRISD Working Paper, 2017; No.2017–6, United Nations Research Institute for Social Development (UNRISD), Geneva.
24. Republic of Rwanda Ministry of Health Maternal and Child Health Division National Postnatal Care Guideline for Mother and Newborn. 2016.
25. Rwanda Ministry of Health. Maternal Newborn and child strategic plan 2018–2024. MoH. 2018. https://www.moh.gov.rw/fileadmin/user_upload/Moh/Publications/Strategic_Plan/Rwanda_MNCH_StrategicPlan_June_costed_v2Draft.pdf. Accessed 8 May 2022.
26. United Nations Population Fund (UNFPA) [Rwanda]. Collective efforts in strengthening midwifery education are positively contributing to saving lives and ending preventable maternal deaths. UNFPA. 2021. https://rwanda.unfpa.org/en/news/collective-efforts-strengthening-midwifery-education-are-positively-contributing-saving-lives. Accessed 10 May 2022.
27. Mugeni C, Levine AC, Munyaneza RM, Mulindahabi E, Cockrell HC, Glavis-Bloom J, et al. Nationwide implementation of integrated community case management of childhood illness in Rwanda. Glob Heal Sci Pract. 2014;2(3):328–41.
28. Williams P, Napier H, Mugeni C, & Crigler L. Rwanda's Community Health Worker Program. CHW Central. 2020. https://chwcentral.org/rwandas-community-health-worker-program/. Accessed 30 Apr 2022
29. Haver J, Brieger W, Zoungrana J, Ansari N, Kagoma J. Experiences engaging community health workers to provide maternal and newborn health services: Implementation of four programs. Int J Gynecol Obstet. 2015;130:S32–9. https://doi.org/10.1016/j.ijgo.2015.03.006.
30. National Institute of Statistics of Rwanda, Ministry of Health (MoH), ICF International. Rwanda Demographic and Health Survey 2014–15. Rockville, Maryland, USA:NISR, MOH, and ICF International.; 2015.
31. Nkurunziza T, Kateera F, Sonderman K, Gruendl M, Nihiwacu E, Ramadhan B, et al. Prevalence and predictors of surgical site infections: a prospective cohort study of women undergoing caesarean section at a rural district hospital in Rwanda. Br J Surg. 2019;106:e121–8.
32. Government of Rwanda, Ministry of Health. Service packages for health facilities at different levels of service delivery. 2011 p. 34–7.
33. Government of Rwanda, Ministry of Health. HSSP III Rwanda Health Sector Strategic Plan 2012–2018. Kigali: Government of Rwanda; 2012. http://www.diplomatie.be/oda/18553_PROGDESCR_HSSP_III_FINAL_VERSION.pdf.
34. Cherian T, Hedt-Gauthier B, Nkurunziza T, Sonderman K, Gruendl MA, Nihiwacu E, et al. Diagnosing Post-Cesarean Surgical Site Infections in Rural Rwanda: Development, Validation, and Field Testing of a Screening Algorithm for Use by Community Health Workers. Surg Infect (Larchmt). 2020;21(7):613–20.
35. Matousek A, Paik K, Winkler E, Denike J, Addington SR, Exe C, Louis RR, Riviello R. Community health workers and smartphones for the detection of surgical site infections in rural Haiti: a pilot study. Lancet. 2015;385(Suppl 2):S47. https://doi.org/10.1016/S0140-6736(15)60842-X.
36. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)–a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009;42(2):377–81.
37. National Bank of Rwanda. Exchange Rate.Historical data. https://www.bnr.rw/currency/exchange-rate/?tx_bnrcurrencymanager_master%5Baction%5D=archive&tx_bnrcurrencymanager_master%5Bcontroller%5D=Currency&cHash=9b3b8a3170a02e5876e4a1be17720fec. Accessed 13 June 2017.
38. Nguhuni B, De Nardo P, Gentilotti E, Chaula Z, Damian C, Mencarini P, et al. Reliability and validity of using telephone calls for post-discharge surveillance of surgical site infection following caesarean section at a tertiary hospital in Tanzania. Antimicrob Resist Infect Control. 2017;6:43.

39. Hurt K, Walker R, Campbell J, Egede L. mHealth Interventions in Low and Middle-Income Countries: A Systematic Review. Glob J Health Sci. 2016;8(9):54429.
40. Karageorgos G, Andreadis I, Psychas K, Mourkousis G, Kiourti A, Lazzi G, et al. The Promise of Mobile Technologies for the Health Care System in the Developing World: A Systematic Review. IEEE Rev Biomed Eng. 2019;12:100–22.
41. Malherbe LF. Cataract surgery and non-attendance: RCT to determine the effect of a SMS reminder system and financial impact in a developing country [Internet]. University of Cape Town; 2017. http://hdl.handle.net/11427/27434. Accessed 4 October 2017.
42. Von Allmen RS, Tinner C, Schmidli J, Tevaearai HT, Dick F. Randomized controlled comparison of cross-sectional survey approaches to optimize follow-up completeness in clinical studies. Puebla I, editor. PLoS One. 2019; 14(3):e0213822.
43. National Institute of Statistics of Rwanda. Rwanda Poverty Profile Report, 2016/17 [Internet]. Kigali, Rwanda; 2018. https://www.statistics.gov.rw/publication/eicv-5-rwanda-poverty-profile-report-201617 Accessed 30 March 2021.
44. Robotham D, Satkunanathan S, Reynolds J, Stahl D, Wykes T. Using digital notifications to improve attendance in clinic: systematic review and meta-analysis. BMJ Open. 2016;6: e012116. https://doi.org/10.1136/bmjopen-2016-012116.
45. Powell BL, Nkurunziza T, Kateera F, Dusabe L, Kubwimana M, Koch R, et al. Synthesizing postpartum care pathways, facilitators, and barriers for women after cesarean section: a qualitative analysis from rural Rwanda. Journal of Global Health Reports. 2021;5: e2021043. https://doi.org/10.29392/001c.23615.
46. Mukangendo M, Nzayirambaho M, Hitimana R, Yamuragiye A. Factors Contributing to Low Adherence to Community-Based Health Insurance in Rural Nyanza District. Southern Rwanda J Environ Public Health. 2018;2018:2624591.
47. Spaan E, Mathijssen J, Tromp N, McBain F, Have AT, Baltussen R. The impact of health insurance in Africa and Asia: a systematic review. Bull World Health Organ. 2012;90:685–92.
48. Atake EH. Does the type of health insurance enrollment affect provider choice, utilization and health care expenditures? BMC Health Serv Res. 2020;20(1):1003.
49. Kullgren JT, McLaughlin CG. Beyond affordability: the impact of nonfinancial barriers on access for uninsured adults in three diverse communities. J Community Health. 2010;35(3):240–8.
50. Atake EH. Health shocks in Sub-Saharan Africa: are the poor and uninsured households more vulnerable? Health Econ Rev. 2018;8:26. https://doi.org/10.1186/s13561-018-0210-x.
51. Bhati KS. Effect of Client-Therapist Gender Match on the Therapeutic Relationship: An Exploratory Analysis. Psychol Rep. 2014;115(2):565–83.
52. Behn A, Davanzo A, Errázuriz P. Client and therapist match on gender, age, and income: Does match within the therapeutic dyad predict early growth in the therapeutic alliance? J Clin Psychol. 2018;74(9):1403–21.
53. Landes SJ, Burton JR, King KM, Sullivan BF. Women's preference of therapist based on sex of therapist and presenting problem: An analog study. Couns Psychol Q. 2013;26(3–4):330–42.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions

3.2 Publication two

Authors: Theoneste Nkurunziza, Wendy Williams, Fredrick Kateera, Robert Riviello, Anne Niyigena, Elizabeth Miranda, Laban Bikorimana, Jonathan Nkurunziza, Lotta Velin, Andrea S. Goodman, Alex Matousek, Stefanie J. Klug, Erick Gaju, Bethany L. Hedt-Gauthier

Title: mHealth-Community Health Worker Telemedicine Intervention for Surgical Site Infection Diagnosis: a Prospective Study Among Women Delivering Via Caesarean Section in Rural Rwanda

Journal: BMJ Global Health

DOI: http://dx.doi.org/10.1136/bmjgh-2022-009365

Summary:

Of the 787 study participants, the majority were farmers (84.8%, n=667), with primary education (67.3%, n=529), and in *Ubudehe* category 2 (51.7%, n=406). Most had CBHI (94.3%, n=742) and were discharged from the hospital by POD3 (76.9%, n=605).

During the study home visits (POD10), the sCHW located 91.4% (n=719) of women's homes. All visited women (100%, n=719) allowed the sCHW to examine them, take their wound photo and share it with the Kigali-based GP via WhatsApp. Of the 719 images captured, 686 (95.4%) were successfully sent to the GP, and 623 (86.7%) had the GP's SSI diagnosis returned within one hour. Overall, 79.2% (n=623) of participants had the full mHealth-CHW intervention successfully completed for all steps, including receipt of diagnosis within one hour. Including photo-based SSI diagnoses received after one hour, 30 of 715(4.2%) women were SSI positive. The GP diagnosed 38 SSIs (5.4%) through physical examination of 707 women at the POD11 study visit. For those with both telemedicine-based and physical exam SSI diagnoses (n=694), the sensitivity and specificity were 36.8% (95% CI:22.6%, 53.8%) and 97.6% (95% CI:96.1%, 98.5%),

respectively. The positive predictive value for the telemedicine-based SSI-diagnosis was 46.7% (n=14) and negative predictive value was 96.4% (n=640).

BMJ Global Health

mHealth-community health worker telemedicine intervention for surgical site infection diagnosis: a prospective study among women delivering via caesarean section in rural Rwanda

Theoneste Nkurunziza ,[1,2] Wendy Williams,[3] Fredrick Kateera,[1] Robert Riviello,[4,5,6] Anne Niyigena,[1] Elizabeth Miranda ,[6,7] Laban Bikorimana,[1] Jonathan Nkurunziza,[1] Lotta Velin ,[6,8] Andrea S Goodman,[9] Alex Matousek,[10] Stefanie J Klug,[2] Erick Gaju,[11] Bethany L Hedt-Gauthier[6,9]

To cite: Nkurunziza T, Williams W, Kateera F, *et al.* mHealth-community health worker telemedicine intervention for surgical site infection diagnosis: a prospective study among women delivering via caesarean section in rural Rwanda. *BMJ Global Health* 2022;**7**:e009365. doi:10.1136/bmjgh-2022-009365

Handling editor Seye Abimbola

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bmjgh-2022-009365).

Received 14 April 2022
Accepted 12 July 2022

Check for updates

© Author(s) (or their employer(s)) 2022. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

For numbered affiliations see end of article.

Correspondence to
Theoneste Nkurunziza;
theonkrz@gmail.com

ABSTRACT

Background Surgical site infections (SSIs) cause a significant global public health burden in low and middle-income countries. Most SSIs develop after patient discharge and may go undetected. We assessed the feasibility and diagnostic accuracy of an mHealth-community health worker (CHW) home-based telemedicine intervention to diagnose SSIs in women who delivered via caesarean section in rural Rwanda.

Methods This prospective cohort study included women who underwent a caesarean section at Kirehe District Hospital between September 2019 and March 2020. At postoperative day 10 (±3 days), a trained CHW visited the woman at home, provided wound care and transmitted a photo of the wound to a remote general practitioner (GP) via WhatsApp. The GP reviewed the photo and made an SSI diagnosis. The next day, the woman returned to the hospital for physical examination by an independent GP, whose SSI diagnosis was considered the gold standard for our analysis. We describe the intervention process indicators and report the sensitivity and specificity of the telemedicine-based diagnosis.

Results Of 787 women included in the study, 91.4% (n=719) were located at their home by the CHW and all of them (n=719, 100%) accepted the intervention. The full intervention was completed, including receipt of GP telemedicine diagnosis within 1 hour, for 79.0% (n=623). The GPs diagnosed 30 SSIs (4.2%) through telemedicine and 38 SSIs (5.4%) through physical examination. The telemedicine sensitivity was 36.8% and specificity was 97.6%. The negative predictive value was 96.4%.

Conclusions Implementation of an mHealth-CHW home-based intervention in rural Rwanda and similar settings is feasible. Patients' acceptance of the intervention was key to its success. The telemedicine-based SSI diagnosis had a high negative predictive value but a low sensitivity. Further studies must explore strategies to improve accuracy, such as accompanying wound images with clinical data or developing algorithms using machine learning.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Telemedicine applications have been effective in the follow-up of surgical patients in high-income countries.

⇒ Telemedicine interventions have been implemented successfully in low and middle-income countries, but their use for postsurgical patients' follow-up in those countries, particularly in rural Africa, has not been explored.

WHAT THIS STUDY ADDS

⇒ In a prospective study of 787 women, 719 were located at their home and all accepted the telemedicine intervention implemented by trained community health workers with remote support of a general practitioner.

⇒ The full telemedicine intervention including receipt of the surgical site infection (SSI) diagnosis by a general practitioner within 1 hour was completed for nearly four out of five women.

⇒ While the telemedicine-based specificity for diagnosis of SSI was high, its sensitivity was low.

INTRODUCTION

Caesarean section (c-section) is the most commonly performed surgical procedure in sub-Saharan Africa (SSA) and accounts for the majority of the surgical volume at district hospitals.[1 2] C-section rates vary widely in the region, ranging from 1.0% to 41.9% but averaging 12.4% of total births.[3] Thus, concerns about limited access to and potential overuse of c-sections remain. While access to c-sections is critical for reducing maternal and neonatal mortality, increases in c-section rate correlate with rising cases of surgical site infections (SSIs).[4 5]

BMJ Glob Health: first published as 10.1136/bmjgh-2022-009365 on 28 July 2022. Downloaded from http://gh.bmj.com/ on January 24, 2024 by guest. Protected by copyright.

BMJ Glob Health: first published as 10.1136/bmjgh-2022-009365 on 28 July 2022. Downloaded from http://gh.bmj.com/ on January 24, 2024 by guest. Protected by copyright.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ Home-based follow-up of surgical patients to detect SSI using telemedicine applications is feasible in rural Africa and can be leveraged to improve access to care for these patients.
- ⇒ Telemedicine-based follow-up can help reduce unnecessary clinic visits by surgical patients through remotely ruling out SSI-negative cases, particularly in this context of an overwhelmed health system and the COVID-19 pandemic.
- ⇒ Further studies are needed to improve telemedicine sensitivity through accompanying wound photos with clinical data or through computer-assisted algorithms.

In SSA, SSI rates after c-section range from 7.3% to 48.2%.[3 6] SSIs are also significant contributors to maternal mortality[7] and result in high costs to patients, families and healthcare facilities.[8] Furthermore, SSI rates are likely underestimated because most SSIs develop after patient discharge from the hospital.[9] Due to the lack of active surveillance and standard postoperative follow-up, these infections may go undetected and thus under-reported.[10 11]

Various factors prevent women from returning to follow-up care after discharge. These include geographical and financial barriers,[12 13] low household income and education level, and dependence of women on their husbands.[14 15] However, developments in technology may help reduce these barriers. In high-income countries, mobile health (mHealth) applications have helped decentralise postoperative follow-up care[16–18] and minimise geographical and financial hurdles.[19 20] Telemedicine, which is the use of telephone-based follow-up, has been proven to be especially effective for simple abdominal surgeries,[21] including SSI surveillance after obstetric patient discharge.[22] However, challenges in implementing telemedicine in rural Africa have been documented, including insufficient technical and financial support, inadequate clinical adoption, poor staffing and limited or unstable communication infrastructure.[23]

Similar to the rest of SSA, Rwanda has a high postdischarge SSI rate, previously estimated at 10.9%.[24] Women who have delivered via c-section have reported that geographical distances and the related cost of transportation limit access to postoperative care,[25] and these factors are associated with worse outcomes for neonates,[26 27] and the development of SSIs.[24] Recent advances in telecommunication infrastructure and increased access to mobile phones have created opportunities to implement mHealth interventions in Rwanda. According to national statistics, in 2017, 71% of households reported owning a cell phone and 99% had access to mobile networks.[28] Another resource to leverage in Rwanda is the widely used and highly effective community health worker (CHW) network that has played a critical role in maternal and child care during the prenatal period and following vaginal delivery.[29] Current CHW training, however, does not include post-c-section follow-up care.

Overall, there is conducive environment to implementing mHealth strategies to support CHW-based postoperative follow-up in Rwanda and the region more broadly. This project assesses the feasibility and accuracy of an mHealth-CHW intervention that uses telemedicine to diagnose SSI in rural Rwanda. If proved effective, this intervention would reduce financial and geographical barriers to postdischarge follow-up care and could improve SSI surveillance.

METHODS

Study design and population

This prospective cohort study included all women who were permanent residents in Kirehe District, underwent c-section surgery at Kirehe District Hospital (KDH) between 22 September 2019 and 16 March 2020 and were discharged before postoperative day 10 (POD10). Patients from the Mahama Refugee Camp, those who were still hospitalised on POD10 or those who had been readmitted by the time of their scheduled study follow-up visits were excluded.

Study setting

KDH is a 233-bed facility under management by the Rwandan Ministry of Health and with technical and financial support from Partners In Health/Inshuti Mu Buzima. The hospital is located in the rural Eastern Province of Rwanda and serves a catchment area of 364 000 people,[28] including the 50 000 residents of the Mahama Refugee Camp.[30]

In Rwanda, women in labour present at their nearest health centre. Those with emergency complications are referred to district hospitals to be assessed and managed by a general practitioner (GP), a non-specialist primary care physician, who performs a c-section if necessary. Few district hospitals, such as KDH, have an obstetrician to manage complicated obstetric cases and mentor GPs. After a c-section, patients are admitted to the postoperative ward for monitoring and medication. On average, patients remain admitted for 3 days before being discharged by a GP. On discharge, a patient is instructed to seek follow-up care with a nurse at her nearest health facility for a wound check and dressing change. If an SSI is detected at the health facility, a patient can be treated as an outpatient at the health centre or, for complicated cases, referred to a district hospital for management by a GP. In the case of a deep SSI, involving deep soft tissues such as fascial or muscle layers, patients are transferred to a referral hospital for management by a specialist.

The population of Rwanda is classified into four socioeconomic ‘Ubudehe’ categories that serve as a guide for social protection programmes, such as community-based health insurance (CBHI) and other socioeconomic services.[31] Ubudehe category 1 represents the poorest group, whose medical costs are fully subsidised by the government, while category 4 represents individuals in the highest wealth category, who are expected to cover the majority of their medical expenses either out of pocket or via health insurance.[31] CBHI is a public insurance scheme implemented by the government of Rwanda across the country which uses premium contribution by community members based on Ubudehe categories as a mean for solidarity for affordable access to healthcare.[32]

Participant enrolment

Trained study data collectors approached eligible patients after c-section delivery and prior to discharge. All eligible patients who delivered between 22 September 2019 and 16 March 2020, and who consented to participate in the study were enrolled. However, due to the COVID-19 pandemic, the study was stopped on 17 March 2020, and all subsequent home visits and clinics were cancelled.

Study intervention and follow-up

In Rwanda, CHWs are community volunteers with primary education. They are elected by community members to serve as liaisons between the community and the health system and to provide home-based primary healthcare to residents in their community. For the mHealth-CHW intervention, we used study-specific CHWs (sCHWs); this was at the request of colleagues at the Ministry of Health to avoid disrupting the activities of existing CHWs during the course of the study. The sCHWs were elected through the same procedure as other CHWs and selected to have the same characteristics as typical CHWs. They were all females because of the gender-sensitive duty they were expected to perform. We also hired GPs who were based in Kigali and incentivised two GPs in KDH to help with SSI diagnosis.

The sCHWs visited participants at home at POD10 (±3 days). We chose POD10 because the majority of SSIs develop between POD5 and POD10[33] and due to the importance of timely identification and referral of SSIs. To facilitate the home visit, sCHWs met with the village-based CHW who guided her to the study participant's home. If the local CHW was not available, the sCHW attempted to contact the participant directly via phone when a contact number was available. On the day before the POD10 home visit, study staff would call the participant and village CHW to remind them of the upcoming home visit. If the participant was not accessible by phone, the village CHW was asked to convey the reminder.

During the home visit, the sCHW photographed the incision site using the Wound Screener application on a Samsung Galaxy J8 smartphone. This phone was chosen for its ability to take high-quality photographs in low light and for its relatively low cost. The Wound Screener application was developed specifically for this study,[34] with the goal of standardising image capture and quality.

The sCHW transmitted the photograph to a Kigali-based GP using WhatsApp (WhatsApp, Mountain View, California), an end-to-end encrypted messaging platform. On receipt, the GP made a diagnosis of presence or absence of an SSI and texted the result to the sCHW. The sCHW did not communicate the SSI diagnosis to the participant to avoid bias in the subsequent in-hospital assessment. All participants were asked to attend a special study visit at KDH the following day (approximately POD11 ±3 days) and a monetary voucher was provided by the study staff to cover transportation costs.

Comparability assessment

We referred to the available literature that supports the effectiveness of using mHealth in diagnosing SSI. Gunter and colleagues proved that digital application images were of sufficient quality and deemed usable for SSI diagnosis by physicians in more than 80% of cases.[18] In addition to saving time, cost and travels, telemedicine-based and usual follow-up care were proven to yield comparable outcomes.[18] However, in our context, we expect the utility of image-based diagnoses to be limited to visible superficial or deep SSI, and so will be ineffective in diagnosing organ/space SSI.

Data collection and variables

The study used data collectors with advanced diplomas in nursing and with experience working in the hospital setting. They received training on the study procedures and materials, and on research ethics before the launch of the study. Study data collectors approached eligible study participants and explained the study aim and procedures, and the intervention's design, benefits and risks. They informed them of their duties and rights, including their right to withdraw consent at any time, and invited them to participate in the study. Informed consent was obtained before enrolling any study participant. At the time of enrolment, data collectors administered structured questionnaires to collect demographic and socioeconomic data. These sociodemographic data included age, marital status, education, occupation, insurance, income level, and phone number of the patient, phone number of a family member or, in case the patient does not have personal phone, phone number of a neighbour.

Study staff also extracted clinical data from patients' medical files using data extraction grid designed in REDCap (V.8.10.20), a secure web application certified for medical research studies.[35] Clinical data included medical history such as comorbidity, defined as having any documented underlying disease conditions prior to c-section, namely diabetes, HIV/AIDS, hypertension and other cardiovascular disorders; intraoperative data (antibiotic therapy, intraoperative complications); and postoperative care. The postoperative length of stay was calculated by subtracting date of surgery from date of discharge from hospital.

During the POD10 home visit, the sCHW documented process indicators using paper-based questionnaires. These indicators detailed the feasibility of implementing the intervention, including the ability to find patients' homes, patients' acceptance of wound examination and wound image capture, patients' willingness to share electronically transmitted data with a GP, successful transmission of wound images to a GP, receipt and timeliness of

BMJ Glob Health: first published as 10.1136/bmjgh-2022-009365 on 28 July 2022. Downloaded from http://gh.bmj.com/ on January 24, 2024 by guest. Protected by copyright.

a GP diagnosis and any challenges encountered. These process indicators were then transcribed by the study staff into REDCap. At the POD11 hospital visit, a Kirehe-based GP asked SSI screening questions, performed a physical examination on the patient and determined whether the patient had an SSI as per the Centers for Disease Control and Prevention definition. SSI refers to an infection that occurs after surgery in the part of the body where the surgery took place.[36] This included superficial, deep or organ/space SSI. This GP diagnosis, based on their patient interview and physical examination, was considered the gold standard for the purposes of this study, as this is the current standard of the field for SSI diagnosis in Rwanda. The responses to the GP interview and physical examination were directly recorded in REDCap.

Data management and protection

All data were collected, managed and stored using REDCap. Images shared through WhatsApp had end-to-end encryption and no personal identifiers were transmitted. The photos were deleted from the memory of the phone after being uploaded to a password-protected study server and a password-protected study computer. The Kigali GPs were also instructed to delete all patient photos from their phones after review. Participant data were deidentified using study IDs; we maintained a separate password-protected file matching study ID and participant identifiers.

Data analysis

We described the demographic and clinical characteristics of participants with frequencies and proportions and assessed the feasibility of the mHealth-CHW intervention by reporting the percentage of process indicators successfully completed. The target was for GPs to transmit a diagnosis within 1 hour; the full telemedicine intervention was considered unsuccessful if the response was received more than 1 hour after the image was sent. We reported the sensitivity and specificity of the GP telemedicine diagnosis-based images texted by the sCHW to the GP compared with the diagnosis based on a physical examination conducted by a GP at the hospital. All descriptive analyses, sensitivity and specificity, and predictive value analyses were completed in Stata V.15 (College Station, Texas: StataCorp).

Patient and public involvement

The patients contributed to identifying the issue which inspired the research question and outcome measures. During previous qualitative research in the same setting, patients expressed concerns regarding long distances and financially prohibitive travels to access health facilities and inappropriate postdischarge service. They also signalled their appreciation for services rendered to them by CHWs. The intervention that was implemented in this study was informed by the current literature showcasing advancement in mHealth in high-income countries. We believed that we could leverage the telecommunication advances and well-established CHWs' network available in Rwanda to improve postdischarge follow-up care for postoperative patients, especially women after c-section. We did not involve patients in the design of this study, but they were strong partners in the recruitment and the conduct of the study. The study results were disseminated to the hospital leadership and to CHWs.

RESULTS

Of the 787 women enrolled in the study, the majority were aged 21–30 years (54.5%, n=429), had primary education as their highest level of education (67.3%, n=529), were farmers (84.8%, n=667), were in Ubudehe category 2 (51.7%, n=406) and used CBHI (94.3%, n=742). Nearly all women had no comorbidities (98.3%, n=773) and 76.9% (n=605) were discharged from the hospital by POD3 (table 1).

During the intervention implementation, 91.4% (n=719) of women's homes were located, mostly (89.9%, n=684) through the support of a village CHW (figure 1). All visited women (100%, n=719) agreed to have a physical examination conducted by the sCHW and to have the wound photo taken and shared with the Kigali-based GP via WhatsApp. Of the 719 images captured, 686 (95.4%) were successfully sent to the GP, and 623 (86.7%) had the GP's SSI diagnosis returned within 1 hour. For these, the mean duration between the time the photo was sent and the time of receipt of the SSI diagnosis was 11 min (IQR: 2–29 min). The SSI diagnosis from the GP was received after 1 hour for 92 images (12.8%), and not received at all for four photos (0.6%). The full mHealth-CHW intervention was successfully completed for all steps, including receipt of diagnosis within 1 hour, for 79.2% (n=623) of participants (figure 1).

Of the 715 women for whom the telemedicine SSI diagnosis was received from a GP, 30 SSIs (4.2%) were identified. Of the 707 women screened at the POD11 study visit, the GP diagnosed 38 SSIs (5.4%). For the 694 women who had both POD10 telemedicine diagnoses and POD11 physical examination diagnoses, the sensitivity was 36.8% (95% CI 22.6% to 53.8%) and specificity was 97.6% (95% CI 96.1% to 98.5%). Of those diagnosed as SSI positive based on telemedicine, 46.7% (n=14) were SSI positive according to the GP examination, and of those diagnosed as negative, 96.4% (n=640) were not subsequently diagnosed as having an SSI (table 2).

DISCUSSION

This mHealth-CHW intervention was successfully implemented in rural Rwanda, and while the intervention was effective for ruling out SSIs in postdischarge c-section patients, the overall sensitivity was low. Although telemedicine interventions for postoperative follow-up have demonstrated promise in high-income countries,[16–18] they have not been widely used in SSA or other low and middle-income settings. Our study findings confirmed that these types of interventions could be applied in rural

BMJ Glob Health: first published as 10.1136/bmjgh-2022-009365 on 28 July 2022. Downloaded from http://gh.bmj.com/ on January 24, 2024 by guest. Protected by copyright.

BMJ Glob Health: first published as 10.1136/bmjgh-2022-009365 on 28 July 2022. Downloaded from http://gh.bmj.com/ on January 24, 2024 by guest. Protected by copyright.

Table 1 Demographic and clinical characteristics of study participants (n=787)

Variables	Frequency	%
Age (n=787)		
≤20 years old	126	16.0
21–30 years old	429	54.5
>30 years old	232	29.5
Marital status		
Single or separated (divorced or widowed)	137	17.4
Married	296	37.6
Cohabiting (no legal marriage)	354	45.0
Education level (n=786)		
No education or less than primary education	79	10.1
Primary education	529	67.3
Secondary education or higher	178	22.7
Occupation		
Farmer	667	84.8
Employed/trader	87	11.1
Housewives	33	4.2
Type of insurance		
No insurance	6	0.8
Community-based health insurance (CBHI)	742	94.3
Private insurance	39	5.0
Ubudehe category* (n=785)		
Category 1	89	11.3
Category 2	406	51.7
Categories 3 and 4	290	36.9
Mode of communication for POD10 visit reminder		
Reached on her phone/household phone	354	45.0
Reached through a neighbour's phone	55	7.0
Reached through a CHW	230	29.2
Not reached	148	18.8
Comorbidity†		
No	773	98.2
Yes	14	1.8
Postoperative length of stay		
Within 3 days	605	76.9
More than 3 days and less than 10 days	182	23.1

*Ubudehe category 1 is the socioeconomic category of the poorest while category 4 is the wealthiest.
†Comorbidity includes underlaying diseases such as diabetes, HIV/AIDS and cardiovascular diseases.
CHW, community health worker; POD10, postoperative day 10.

Rwanda and in similar settings, but scalability in different settings is contingent on an established CHW network, national and local health facility leadership support, reliable communications infrastructure and sufficient mobile phone penetration in rural areas. In our study, the challenge of unreliable internet and cell phone coverage was manageable but resulted in delayed GP diagnosis via telemedicine. These challenges have been highlighted elsewhere[23 37 38] and should be taken into account when planning mHealth interventions.

Most patients were accepting of all steps of the mHealth-CHW intervention. This is consistent with other studies demonstrating high acceptability of telemedicine interventions,[39] and is likely influenced by how integrated CHW home visits are in Rwanda's health system. CHWs are locally elected by the community members, respected and strongly committed to providing village-level care. CHWs link the community to the health system[40 41] and therefore are highly trusted, even when implementing new activities.

The telemedicine SSI diagnosis had a low sensitivity but a high specificity, which was similar to findings when evaluating the wound photography for remote postoperative SSI diagnosis in high-income settings.[42] This low sensitivity can be attributed to poor quality of wound image or the ability and confidence of the GP to consistently evaluate the wound status based on images alone, which can change from one to another and from time to time.[43 44] While the sensitivity is low, the high negative predictive value could help reduce unnecessary postoperative clinic visits. This could relieve financial and travel hardships for these vulnerable patients and workload for clinicians, as has been shown in other studies.[18 20 45] This could also reduce the number of unsolicited health facility visits, which is of critical importance now given COVID-19 infection risks.[46]

Although we strived to obtain the best of quality and standardised wound images, the forementioned challenges might have impaired the ability of GP to accurately diagnose SSI. In response to these observed challenges, we upgraded the lighting and quality image camera as part of our iterative quality improvement process. Therefore, prior to scaling such an intervention, we strongly recommend identifying strategies to increase sensitivity. One potential approach would be to include clinical data along with the wound photo.[44] Other strategies we are exploring are including wound images taken at different times after surgery and tracking wound change over time. This would allow comparisons between wound images from POD3 to the POD10 so that the GP can assess how the wound has progressed over time rather than at a static time point. A third strategy is to develop algorithms using artificial intelligence, particularly machine learning.[47] This would require developing large libraries of images and diagnoses to train and evaluate algorithms, but if successful, these algorithms could improve accuracy and remove the person-to-person variability of diagnoses based on image review.[44]

Limitations

We encountered several limitations during this study's implementation that should be considered while interpreting our study findings. First, we did not assess the GP's perception of image quality or the GP's confidence

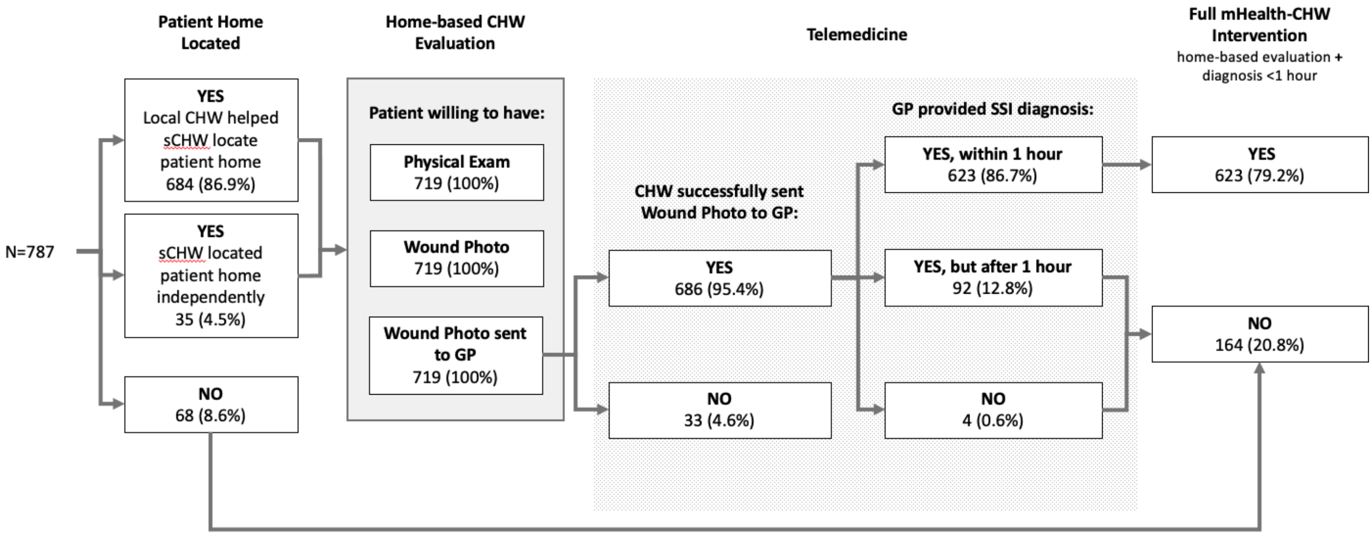


Figure 1 Flow chart of study participants into the study and implementation process indicators. Mean duration in minutes from when the photo was sent to the time of surgical site infection (SSI) diagnosis reception: 11 min (2–29). SSI diagnoses received from general practitioners (GPs) more than 1 hour after their photos being sent were still considered for telemedicine accuracy analyses, though recorded in process indicators by study-specific community health workers (sCHWs) as not successfully sent.

in making diagnoses based on an image alone. The questions to the Kigali-based GP only included a closed question to indicate 'SSI positive' or 'SSI negative', and therefore we did not receive further insights or clarifications that could help improve the mHealth-CHW intervention. Second, the observed SSI rate at KDH declined from 10.9%[24] to 5.4%, and as such, we had fewer than expected cases of SSI. This led to lower than desired precision in our sensitivity estimates.

A third limitation is that the gold standard for SSI diagnosis is a GP physical examination, without isolating pathological organisms through swab or fluid culture. Due to lack of infrastructure for pathology confirmations, this is the main means of SSI diagnosis in this rural hospital, similar to many other rural SSA settings.[48 49] Since we are interested in identifying strategies that imitate a facility visit without the burden of travel, the GP diagnosis is a suitable gold standard in this context. Finally, for logistical reasons, the telemedicine screening and physical examination were 1 day apart. It is possible that during that period, an SSI could have developed, or the wound could have changed considerably. Nevertheless, we assume the likelihood of a change in SSI status or wound appearance to be minimal because all follow-up physical examinations by a GP were performed within 1 day of the telemedicine diagnosis. We also suspect that the effectiveness of the telemedicine-based diagnosis was limited to visible signs of superficial and deep SSI, and thus was unable to detect organ/space SSI.

CONCLUSIONS

This study showed that implementation of an mHealth-CHW postoperative follow-up intervention in rural Rwanda and similar settings is feasible. Health system and community infrastructure, including telephone network coverage, a robust CHW network and buy-in from providers and the community, are prerequisites for its success. The intervention's high acceptability among patients suggests potential scalability in similar

Table 2 Accuracy of the telemedicine-based SSI diagnosis

	Physical examination-based SSI diagnosis				
		Positive	Negative	Total	
Telemedicine-based SSI diagnosis	Positive	14	16	30	PPV 46.67%
	Negative	24	640	664	NPV 96.4%
	Total	38	656	694*	
		Sensitivity 36.8% (22.6–53.8)	Specificity 97.6% (96.1–98.5)		

*Only analysed those with both telemedicine and physical examination-based SSI diagnosis.
NPV, negative predictive value; PPV, positive predictive value; SSI, surgical site infection.

BMJ Glob Health: first published as 10.1136/bmjgh-2022-009365 on 28 July 2022. Downloaded from http://gh.bmj.com/ on January 24, 2024 by guest. Protected by copyright.

settings. However, the telemedicine-based SSI diagnosis had a low sensitivity that will need to be addressed by further studies.

Author affiliations
[1]Research Department, Partners In Health/Inshuti Mu Buzima, Kigali, Rwanda
[2]Epidemiology, Department of Sport and Health Sciences, Technical University of Munich, München, Germany
[3]Center for Surgery and Public Health, Brigham and Women's Hospital, Boston, Massachusetts, USA
[4]Center for Surgery and Public Health, Harvard Medical School and Harvard TH Chan School of Public Health, Boston, Massachusetts, USA
[5]Division of Trauma, Burns, and Surgical Critical Care, Brigham and Women's Hospital, Boston, Massachusetts, USA
[6]Program in Global Surgery and Social Change, Harvard Medical School, Boston, Massachusetts, USA
[7]Vascular Surgery, University of Southern California, Los Angeles, California, USA
[8]Biomedical and Clinical Sciences, Linköping University, Linkoping, Sweden
[9]Department of Global Health and Social Medicine, Harvard Medical School, Boston, Massachusetts, USA
[10]Northwest Heart and Lung Surgical Associates, Providence Sacred Heart Medical Center, Spokane, Washington, USA
[11]eHealth Unit, Republic of Rwanda Ministry of Health, Kigali, Rwanda

Twitter Theoneste Nkurunziza @Theonkurunziza, Elizabeth Miranda @lisatonimiranda, Lotta Velin @VelinLotta, Bethany L Hedt-Gauthier @BHedtGauthier, Partners In Health/Inshuti Mu Buzima-Rwanda @PIH_Rwanda and Technical University of Munich-Germany @TU_Muenchen

Acknowledgements We thank the study participants for their cooperation throughout the study, the CHWs and GPs who supported the study and the staff and leadership of KDH.

Contributors TN and WW wrote the original draft. BLH-G, FK and RR were the overall research project coprincipal investigators.TN, EM and AN led the study implementation. BLH-G and SJK provided academic supervision for TN. TN is responsible for the overall content as the guarantor. All authors contributed substantially to the development, revision and finalisation of the manuscript and approved its final version.

Funding This work was supported by the National Institutes of Health (NIH R21TW011229) and also received support from Partners In Health-Rwanda.

Disclaimer The funder had no role in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript.

Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval Study participants and CHWs were financially compensated for their study participation time in accordance with Rwanda national standards. This study had ethics approval from the Rwandan National Ethics Committee (326/RNEC/2019) and the Harvard Institutional Review Board (IRB18-1033). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. Data may be obtained from a third party and are not publicly available. The data that support the findings of this study are available from PIH/IMB but restrictions apply and so are not publicly available. With permission of PIH/IMB, we will make the data available on reasonable request.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

Author note The reflexivity statement for this paper is linked as an online supplemental file 1.

ORCID iDs
Theoneste Nkurunziza http://orcid.org/0000-0002-5475-3396
Elizabeth Miranda http://orcid.org/0000-0002-9574-1949
Lotta Velin http://orcid.org/0000-0002-1929-6011

REFERENCES

1 Galukande M, von Schreeb J, Wladis A, *et al*. Essential surgery at the district Hospital: a retrospective descriptive analysis in three African countries. *PLoS Med* 2010;7:e1000243.
2 Petroze RT, Nzayisenga A, Rusanganwa V, *et al*. Comprehensive national analysis of emergency and essential surgical capacity in Rwanda. *Br J Surg* 2012;99:436–43.
3 Sway A, Nthumba P, Solomkin J, *et al*. Burden of surgical site infection following cesarean section in sub-Saharan Africa: a narrative review]]&gt. *Int J Womens Health* 2019;11:309–18.
4 Betrán AP, Ye J, Moller A-B, *et al*. The increasing trend in caesarean section rates: global, regional and national estimates: 1990-2014. *PLoS One* 2016;11:e0148343.
5 Saeed KBM, Greene RA, Corcoran P, *et al*. Incidence of surgical site infection following caesarean section: a systematic review and meta-analysis protocol. *BMJ Open* 2017;7:e013037.
6 Rwabizi D, Rulisa S, Findlater A, *et al*. Maternal near miss and mortality due to postpartum infection: a cross-sectional analysis from Rwanda. *BMC Pregnancy Childbirth* 2016;16:177.
7 Alkema L, Chou D, Hogan D, *et al*. Global, regional, and national levels and trends in maternal mortality between 1990 and 2015, with scenario-based projections to 2030: a systematic analysis by the un maternal mortality estimation Inter-Agency group. *Lancet* 2016;387:462–74.
8 Badia JM, Casey AL, Petrosillo N, *et al*. Impact of surgical site infection on healthcare costs and patient outcomes: a systematic review in six European countries. *J Hosp Infect* 2017;96:1–15.
9 Woelber E, Schrick EJ, Gessner BD, *et al*. Proportion of surgical site infections occurring after hospital discharge: a systematic review. *Surg Infect* 2016;17:510–9.
10 de Oliveira AC, Carvalho DV. Evaluation of underreported surgical site infection evidenced by post-discharge surveillance. *Rev Lat Am Enfermagem* 2007;15:992–7.
11 Løwer HL, Eriksen H-M, Aavitsland P, *et al*. Methodology of the Norwegian surveillance system for healthcare-associated infections: the value of a mandatory system, automated data collection, and active postdischarge surveillance. *Am J Infect Control* 2013;41:591–6.
12 Grimes CE, Bowman KG, Dodgion CM, *et al*. Systematic review of barriers to surgical care in low-income and middle-income countries. *World J Surg* 2011;35:941–50.
13 Hsia RY, Mbembati NA, Macfarlane S, *et al*. Access to emergency and surgical care in sub-Saharan Africa: the infrastructure gap. *Health Policy Plan* 2012;27:234–44.
14 National Institute of Statistics of Rwanda (NISR)[Rwanda], Ministry of Health (MoH)[Rwanda] and ICF International. *Rwanda demographic and health survey 2014-15*. Rockville, Maryland, USA: NISR, MOH, and ICF International, 2015.
15 Adams YJ, Smith BA. Integrative review of factors that affect the use of postpartum care services in developing countries. *J Obstet Gynecol Neonatal Nurs* 2018;47:371–84.
16 Abelson JS, Symer M, Peters A, *et al*. Mobile health apps and recovery after surgery: what are patients willing to do? *Am J Surg* 2017;214:616–22.
17 Gunter R, Fernandes-Taylor S, Mahnke A, *et al*. Evaluating patient usability of an image-based mobile health platform for postoperative wound monitoring. *JMIR Mhealth Uhealth* 2016;4:e113.
18 Gunter RL, Chouinard S, Fernandes-Taylor S, *et al*. Current use of telemedicine for post-discharge surgical care: a systematic review. *J Am Coll Surg* 2016;222:915–27.
19 Semple JL, Sharpe S, Murnaghan ML, *et al*. Using a mobile APP for monitoring post-operative quality of recovery of patients at home: a feasibility study. *JMIR Mhealth Uhealth* 2015;3:e18.

BMJ Glob Health: first published as 10.1136/bmjgh-2022-009365 on 28 July 2022. Downloaded from http://gh.bmj.com/ on January 24, 2024 by guest. Protected by copyright.

20 Evans HL, Lober WB. A pilot use of Patient-Generated wound data to improve Postdischarge surgical site infection monitoring. *JAMA Surg* 2017;152:595–6.
21 Kummerow Broman K, Vella MA, Tarpley JL, *et al*. Identification of postoperative care amenable to telehealth. *Surgery* 2016;160:264–71.
22 Bianco A, Roccia S, Nobile CGA, *et al*. Postdischarge surveillance following delivery: the incidence of infections and associated factors. *Am J Infect Control* 2013;41:549–53.
23 Kachieng'a MO. Challenges in managing diffusion of telemedicine technology in South Africa. *Technol manage Conf (ITMC)*. *IEEE* 2011:121–5.
24 Nkurunziza T, Kateera F, Sonderman K. Prevalence and predictors of surgical site infections: a prospective cohort study of women undergoing caesarean section at a rural district hospital in Rwanda. *Br J Surg* 2019;106.
25 Powell BL, Nkurunziza T, Kateera F, *et al*. Synthesizing postpartum care pathways, facilitators, and barriers for women after cesarean section: a qualitative analysis from rural Rwanda. *J Glob Health Rep* 2021;5.
26 Niyitegeka J, Nshimirimana G, Silverstein A, *et al*. Longer travel time to district hospital worsens neonatal outcomes: a retrospective cross-sectional study of the effect of delays in receiving emergency cesarean section in Rwanda. *BMC Pregnancy Childbirth* 2017;17:1–10.
27 Nyirahabimana N, Ufashingabire CM, Lin Y, *et al*. Maternal predictors of neonatal outcomes after emergency cesarean section: a retrospective study in three rural district hospitals in Rwanda. *Matern Health Neonatol Perinatol* 2017;3:11.
28 National Institute of Statistics of Rwanda. Rwanda poverty profile report, 2016/17 (EICV 5). Kigali: National Institute of statistics, 2018. Available: https://www.statistics.gov.rw/publication/eicv-5-rwanda-poverty-profile-report-201617 [Accessed 15 Feb 2022].
29 Mugeni C, Levine AC, Munyaneza RM, *et al*. Nationwide implementation of integrated community case management of childhood illness in Rwanda. *Glob Health Sci Pract* 2014;2:328–41.
30 United Nations High Commissioner for Refugees (UNHCR). Mahama: now a safe Haven for over 50,000 Burundian refugees, 2016. Available: https://www.unhcr.org/rw/559-559.html [Accessed 15 Feb 2022].
31 Ezeanya-Esiobu C. The rise of homegrown ideas and grassroots voices: new directions in social policy in Rwanda, UNRISD working paper, No.2017-6. Geneva: United nations research Institute for social development (UNRISD). Available: https://www.unrisd.org/unrisd/website/document.nsf/(httpPublications)/3AC45BEF8587AD6AC1258122003E9475?OpenDocument [Accessed 15 Feb 2022].
32 Mukangendo M, Nzayirambaho M, Hitimana R, *et al*. Factors contributing to low adherence to community-based health insurance in rural Nyanza district, southern Rwanda. *J Environ Public Health* 2018;2018:1–9.
33 National Collaborating Centre for Women's and Children's Health (UK). Surgical site infection: prevention and treatment of surgical site infection. London: RCOG press; 2008 Oct. (NICE clinical guidelines, no. 74.) 3, definitions, surveillance, and risk factors. Available: https://www.ncbi.nlm.nih.gov/books/NBK53724/ [Accessed 15 Feb 2022].
34 Fletcher RR, Schneider G, Hedt-Gauthier B, *et al*. Use of Convolutional neural nets and transfer learning for prediction of surgical site infection from color images. *Annu Int Conf IEEE Eng Med Biol Soc* 2021;2021:5047–50.
35 Harris PA, Taylor R, Thielke R, *et al*. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42:377–81.
36 Centers for disease control and prevention (CDC). surgical site infection event (SSI). CDC 2022. Available: https://www.cdc.gov/nhsn/pdfs/pscmanual/9pscssicurrent.pdf [Accessed 6 Jun 2022].
37 Wirthlin DJ, Buradagunta S, Edwards RA, *et al*. Telemedicine in vascular surgery: feasibility of digital imaging for remote management of wounds. *J Vasc Surg* 1998;27:1089–100.
38 Segura-Sampedro JJ, Rivero-Belenchón I, Pino-Díaz V, *et al*. Feasibility and safety of surgical wound remote follow-up by smart phone in appendectomy: a pilot study. *Ann Med Surg* 2017;21:58–62.
39 Asiri A, AlBishi S, AlMadani W, *et al*. The use of telemedicine in surgical care: a systematic review. *Acta Inform Med* 2018;26:201–6.
40 Condo J, Mugeni C, Naughton B, *et al*. Rwanda's evolving community health worker system: a qualitative assessment of client and provider perspectives. *Hum Resour Health* 2014;12:71.
41 Tuyisenge G, Crooks VA, Berry NS. Facilitating equitable community-level access to maternal health services: exploring the experiences of Rwanda's community health workers. *Int J Equity Health* 2019;18:181.
42 Kummerow Broman K, Gaskill CE, Faqih A, *et al*. Evaluation of wound photography for remote postoperative assessment of surgical site infections. *JAMA Surg* 2019;154:117–24.
43 Hedt-Gauthier B, Miranda E, Nkurunziza T, *et al*. Telemedicine for surgical site infection diagnosis in rural Rwanda: concordance and accuracy of image reviews. *World J Surg* 2022;40.
44 Sanger PC, Simianu VV, Gaskill CE, *et al*. Diagnosing surgical site infection using wound photography: a Scenario-Based study. *J Am Coll Surg* 2017;224:8–15.
45 Crocker JB, Crocker JT, Greenwald JL. Telephone follow-up as a primary care intervention for Postdischarge outcomes improvement: a systematic review. *Am J Med* 2012;125:915–21.
46 Webster P. Virtual health care in the era of COVID-19. *Lancet* 2020;395:1180–1.
47 Fletcher RR, Olubeko O, Sonthalia H, *et al*. Application of machine learning to prediction of surgical site infection. *Annu Int Conf IEEE Eng Med Biol Soc* 2019;2019:2234–7.
48 Umutesi G, Velin L, Muwanguzi M, *et al*. Strengthening antimicrobial resistance diagnostic capacity in rural Rwanda: a feasibility assessment. *Ann Glob Health* 2021;87:78.
49 Velin L, Umutesi G, Riviello R, *et al*. Surgical site infections and antimicrobial resistance after cesarean section delivery in rural Rwanda. *Ann Glob Health* 2021;87:77.

BMJ Glob Health: first published as 10.1136/bmjgh-2022-009365 on 28 July 2022. Downloaded from http://gh.bmj.com/ on January 24, 2024 by guest. Protected by copyright.

CHAPTER IV: DISCUSSION

4.1 Findings overview and discussion

This thesis project determined enablers and barriers to return to the follow-up clinic after discharge among women who have undergone a CS at a rural district hospital in Rwanda and assessed the feasibility and accuracy of the telemedicine-based SSI diagnosis among these women. The project demonstrated two crucial facts: first, post-discharge follow-up compliance was higher among women who received a reminder call on the eve of the follow-up appointment. This finding implies the role of mHealth in increasing access to and uptake of follow-up care and reducing the eventual consequences of lost-to-follow-up. This finding supports the established effectiveness of reminder calls as an adaptation to increase client return rates in healthcare services. Following up post-discharge with phone calls has been shown to be feasible and effective in Tanzania (Nguhuni et al, 2017) and to maximize follow-up in other settings besides obstetric (Karageorgos et al, 2018; von Allmen et al, 2019).

Second, in rural Rwanda, implementing the telemedicine-guided SSI diagnosis by the CHW is feasible and successful in following up women with CS. This finding is similar to the fact demonstrated by systematic reviews exploring the potential for providing access to follow-up care through remote monitoring. They found that mHealth-facilitated follow-up improved the quality of healthcare for populations, even those living in low-resource settings of LMICs (Griffiths et al., 2020; Gjellebæk et al., 2020; Daves et al., 2021). However, telemedicine interventions for postoperative follow-up are not commonly used in SSA despite promising results in high-income countries (Abelson et al., 2017; Gunter et al., 2016a; Gunter et al., 2016b). The successful implementation of our intervention can be attributed to the available decentralized and well-established healthcare delivery using CHW to provide primary care in their communities. In addition, the CHWs are respected and trusted in their communities because local community members elect them. Volunteering to provide community-based care and linking the community to the health system incite confidence and uptake of their services (Condo et al., 2018). Additionally, implementing culturally competent adaptations of mHealth technologies also increases patient engagement and adherence to follow-up care (Handtke, Schilgen, & Mösko, 2019). In our study, we employed female CHWs to implement telemedicine intervention for follow-up on women at their homes. It culturally resonated that women would feel comfortable being examined at home by a female provider.

Similarly, our first study demonstrated the association between matching the gender of the provider to that of the patient and higher follow-up uptake. The female data collector who provided discharge counseling to women obtained a higher return to care than her male counterparts. We attribute this concept to other factors such as patient preferences, cultural norms, or communication styles. This finding suggests that gender-matching between data collectors and patients may be an essential factor to consider when designing interventions to improve return to care among female patients. This finding is supported by previous studies in psychology that demonstrated gender-matching within the therapeutic initiatives to improve growth in the therapeutic alliance and adhesion to treatment (Behn, Davanzo, & Errázuriz, 2018; Bhati, 2014). Further research should be conducted to explore the underlying reasons for this gender-based difference in return to care.

Our study found that the likelihood of returning for follow-up reduces as transport costs rise because women's residences are farther away or in hard-to-reach areas. This disparity was also highlighted by Zafar and colleagues (2013) in their study on disparity in access to care. In LMICs, people with low incomes, those living in rural areas, and those marginalized are the most disadvantaged in accessing care. As such, these people face a greater risk of being lost-to-follow-up. Lost-to-follow-up in surgical care increases morbidity and mortality burdens. For example, post-operative complications such as SSI go unchecked and results in complex and deep SSI with poor outcome and, to some extent, death (Casper et al., 2018; Jenks et al.,2014). Strategies to increase follow-up rates comprise decentralized follow-up, including community-based telemedicine-guided SSI diagnosis. Existing studies suggest that decentralizing this follow-up at the nearest health facility is also viable. However, these decentralized services are still financially and physically demanding for the health system and the patient (Cobos et al., 2017; Powell et al, 2021). The study by Western and colleagues (2016) suggests that the population from these hard-to-reach areas suffers from social and economic vulnerability, mainly due to unemployment, poor infrastructure, and disadvantaged settings.

Further, in our findings, uninsured women have significantly fallen into the lost-to-follow-up category. We attribute this failure of patients without health insurance to this economic vulnerability and unaffordable out-of-pocket expenses incurred at the hospital, discouraging them from returning to follow-up clinics. Previous studies demonstrated that lack of health insurance has a negative effect on utilization of health services (Atake, 2020; Spaan et al., 2012). The patients in Ubudehe category 2 face greater risk of lacking health insurance because they are not subsidized by the government and yet belong to low wealth quintile (Mukangendo et al., 2019). Subsequently, uninsured people are vulnerable to impoverishing expenditures. This scenario appears to be a vicious cycle of lack of health insurance and impoverishment by medical as determined by other studies (Atake, 2018).

This thesis identified areas for improvement for effective environment of telemedicine implementation. We found a few cases in which the cellular network connection hindered the transmission or reception of communication between the study CHW and GP. This challenge resulted in delays in receiving feedback on SSI diagnosis. The same challenge hampered a non-negligible proportion of the study participants from receiving our reminder call and subsequently missing their appointments. Other studies in SSA (Kachieng'a, 2011; Nsor-Anabiah, Udunwa, & Malathi, 2019) faced these challenges and recommended that in rural communities, universal network coverage is necessary to deliver mHealth benefits (Nsor-Anabiah, Udunwa, & Malathi, 2019). Better coverage of mobile phones is expected to increase the number of patients reached by reminders. In Rwanda, we note a promising improvement. For example, there has been an increase in phone ownership in rural areas from 54% in 2014 to 67% in 2019 and nationally from 60 to 71% (NISR 2015; NISR, 2021). In addition to sufficient mobile penetration, an established CHW network with reliable communication infrastructures is required for mHealth interventions' scalability. In our study in rural Rwanda, this mHealth intervention was successfully implemented by CHW. How integrated CHW home visits with primary care are in Rwanda's health system contributed to how well patients accepted the mHealth-CHW intervention and to the overall success of this intervention.

4.2 Policy implications and recommendations

Our findings lead us to recommend essential policy actions to be implemented to optimize caesarean patients’ post-discharge follow-up and outcome. These include appointment reminder notifications, implementing CHW-led telemedicine intervention, and targeted supports for women at risk of lost-to-follow-up.

4.2.1 Reminder notifications on the eve of the scheduled follow-up clinic

We found was higher post-discharge follow-up compliance among women who received a reminder call on the eve of the follow-up appointment. Several interventions have been tested to improve adherence to follow-up care. One intervention identified is reminder SMS notifications, which have been shown to be effective at increasing client return visits (Bauer et al., 2021; McLea et al., 2014). It may be more effective when the reminder includes more details such as date, time, and location and include information on the benefits of screening and the recommended screening intervals (McLea et al. 2014). Implementing reminder call initiative can be burdensome and challenging in settings with unreliable networks. We recommend alternatives with similar effects, such as sending SMS reminder notifications on the eve of the scheduled clinic. As a result, those who would otherwise not be accessible during the time of the call would be reached. Additionally, if healthcare providers are overburdened, setting up an automated SMS notifications can be less stressful (Robotham et al, 2016).

4.2.2 Telemedicine implementation by CHW with GP assistance

Our study found that CHW can successfully implement the telemedicine with remoted GP-guided SSI diagnosis. There is a conducive environment to implement such innovative approach to follow-up on women who undergo CS. We highlighted the integrated, respected, and trusted CHWs who usually conduct home visits to provide primary health and maternal and children health services. We find this CHWs network as an opportunity for scaling up the mHealth-CHW intervention. However, before scaling up this mHealth-CHW intervention, the cellular network penetration should be improved to provide reliable communication infrastructures in rural areas and the telemedicine diagnosis accuracy should be enhanced.

4.2.3 Targeted supports for women at risk of lost-to-follow-up

We found that uninsured women and those spending more than 10 Euro for transport to and from hospital have significantly fallen into the lost-to-follow-up category. These vulnerable women should also be prioritized for existing social protection programs or other empowerment initiatives, such as the maternal health voucher program (Nguyen et al., 2012). Furthermore, we make a case that a home-based mHealth-CHW intervention for post-discharge follow-up should target these women.

Our findings of high negative predictive value for telemedicine-based SSI diagnosis are beneficial and could help rule out post-discharge SSIs for these women without travel hardships. Two facts show the benefit of this finding according to previous studies. First, in the rural context, the costs related to follow-up care are prohibitive (Nkurunziza et al., 2019). Second, health facilities are understaffed, and subsequently, healthcare providers are overwhelmed (Bazirete et al., 2020). Telemedicine can benefit patients who would otherwise lack access to post-discharge follow-up care while relieving clinicians' burden (Haleem et al., 2021). This intervention could reduce the number of unnecessary post-operative clinic visits (De La Cruz Monroy & Mosahebi, 2019). As a result, it could relieve financial and travel hardships for vulnerable patients as well as clinicians' workload.

4.3 Thesis strengths and limitations

This thesis had several strengths. First, the study was population-based, involving the local community, and prospectively conducted. The population is important but rarely included in studies. The first-hand data collection ensured maximum data quality while minimizing missingness. Second, we requested additional data from third parties to ensure that all the potential factors of return to follow-up care were accounted for. For example, transport costs obtained from PIH/IMB served as proxy of distance from home to the hospital and transport requirements. We also obtained from Rwanda Meteorology Agency the rainfall data of the study area to analyse the effect of rain on return to follow-up clinic. Third, the large sample size increases our power to analyse difference in outcomes. Finally, the study generated new hypothesis potentially useful for improving follow-up care among this patient population. The hypothesis of association between discharge counselling of female patients by the female data collector and greater return to care is important and worth to explore further.

The second study had four strengths; the first strength was its innovative approach. This was the first of its kind implementing the telemedicine interventions for post-discharge follow-up of surgical patients in rural Africa. Secondarily, this study introduced Wound Screener, a new tool to obtain standardized and high-quality images. Additional measures, such as a locally affordable smartphone with high image quality in a context of low light housing, were applied to maximize data quality. Thirdly, this community-based and prospective study strived to minimized follow-up biases through collaboration with local CHW networks. This collaboration helped localise participants at home and achieve high follow-up rate. Finally, it generated new knowledge. The study demonstrated that detecting SSI using telemedicine applications is feasible in rural Africa and would improve access to follow-up care without the burden of travel while ruling out unnecessary health facility visits.

This thesis project encountered several limitations. For the first publication, generalizing the results is limited because the population of this study was part of a more extensive study whose participants received additional services to promote their return to the follow-up clinic. Nonetheless, the hypotheses generated in this study are pertinent to the general population. Further studies are needed to explore the situation further and determine the impact those add-on services have on the return to follow-up care. In addition, there are likely other possible enablers or barriers not considered in this study, such as geographic landscape and location, patient motivation, and influence from husbands, families, or peers. Notwithstanding, we believe that proxy for home-to-hospital distance and transportation requirements as designed by PIH/IMB was a reasonable alternative to transport hardship variables. Furthermore, the ratio of male to female data collectors was 4:1 leading to proportionately fewer women being counseled by the female data collector. Even so, the study generated hypothesis that discharge counseling by the same gender data collector is associated with a greater return to follow-up.

The main limitation of the telemedicine study was that an SSI diagnosis was based on a physical examination conducted by a GP instead of swabbing or cultured fluids to isolate pathological organisms. This approach is the standard practice in Rwanda due to the lack of required laboratory infrastructure at a district hospital. Although this diagnosis may be subject to bias, the GP diagnosis is a suitable gold standard in this context. Further, SSI prevalence declined from 10.9% to 5.4% at Kirehe District Hospital, making SSI cases lower than expected and negatively affecting the precision in our sensitivity estimates. Another limitation is that the telemedicine screening was conducted a day before the physical examination. Although the wound might have significantly changed during that time, even for an SSI to develop, we believe that, by having all follow-up visits by a GP within one day of the telemedicine diagnosis, the SSI status or wound appearance may have changed minimally. Further, the study findings are limited to the population from SSA with black skin, so the results may not be generalized to other types of skin colours.

4.4 Future studies

This dissertation generated new hypothesis and research questions worth exploring. First, we suggest that it may have been difficult for GPs to accurately diagnose SSI despite our best efforts to obtain high-quality and standardized wound images. To this end, we strongly suggest to future researchers to include clinical data and wound photos to increase telemedicine-based SSI sensitivity. This was demonstrated by other studies elsewhere (Sanger et al.,2017; Sawyer, Evans, & Hedrick, 2019). Another strategy to explore is tracking wound change over time by examining wound images taken at different times after surgery. Further, artificial intelligence, especially machine learning, can be used to develop algorithms that allow for automated SSI, provided they are fed with wound pictures. This technology has many benefits, including high sensitivity and reduced workload for healthcare providers (Fletcher et al., 2019).

Second, the discharge counseling by a female data collector had a higher return to follow-up care than her male counterparts. Therefore, this hypothesis of an association between discharge counseling by the same gender provider and a greater return to follow-up is worth further exploring. Reasons behind this finding are unclear and warrant further studies.

CHAPTER 5: CONCLUSIONS

This dissertation identified challenges to post-CS follow-up and provided evidence on feasibility of CHW-led telemedicine implementation to address these barriers. We found that an overall high return to follow-up was achieved in this study population. mHealth interventions such as participant reminders via phone calls may contribute to their return for post-discharge follow-up. Therefore, healthcare services should consider implementing reminder calls and other adaptations to improve patient engagement and outcomes. Furthermore, we make a case for decentralizing follow-up care to the community level to reach those at risk of lost-to-follow-up or facing hardship to return to follow-up care. To this effect, a CHW-implemented telemedicine intervention could benefit both patients and healthcare providers for post-discharge follow-up in rural Rwanda. Though the telemedicine-based SSI diagnosis had low sensitivity, its high negative predictive value is essential to rule out SSI and relieve the burden of unnecessary return to a health facility. Alternatively, this intervention would guide the selective return based on likelihood of SSI for early diagnosis and treatment. Travel costs and lack of insurance negatively impacted those lost-to-follow-up. These barriers reflect the need for decentralizing follow-up care and more financial support such as voucher program to those vulnerable.

REFERENCES

Abbott, P., Sapsford, R., & Binagwaho, A. (2017). Learning from success: how Rwanda achieved the millennium development goals for health. *World development*, 92, 103-116.

Adams, Y. J., & Smith, B. A. (2018). Integrative Review of Factors That Affect the Use of Postpartum Care Services in Developing Countries. *Journal of obstetric, gynecologic, and neonatal nursing : JOGNN*, 47(3), 371–384. https://doi.org/10.1016/j.jogn.2018.02.006

Ahmed, S., & Khan, M. M. (2011). A maternal health voucher scheme: what have we learned from the demand-side financing scheme in Bangladesh*? Health policy and planning*, 26(1), 25-32.

Aiken, A. M., Wanyoro, A. K., Mwangi, J., Mulingwa, P., Wanjohi, J., Njoroge, J., Juma, F., Mugoya, I. K., Scott, J. A., & Hall, A. J. (2013). Evaluation of surveillance for surgical site infections in Thika Hospital, Kenya. The Journal of hospital infection, 83(2), 140–145. https://doi.org/10.1016/j.jhin.2012.11.003

Akintayo, A. A., Ade-Ojo, I. P., Olagbuji, B. N., Akin-Akintayo, O. O., Ogundare, O. R., & Olofinbiyi, B. A. (2014). Cesarean section on maternal request: the viewpoint of expectant women. *Archives of gynecology and obstetrics*, 289, 781-785.

Alipour, A., Hantoushzadeh, S., Hessami, K., Saleh, M., Shariat, M., Yazdizadeh, B., ... & Emami, Z. (2022). A global study of the association of cesarean rate and the role of socioeconomic status in neonatal mortality rate in the current century. *BMC Pregnancy and Childbirth*, 22(1), 1-9.

Althabe, F., Sosa, C., Belizán, J. M., Gibbons, L., Jacquerioz, F., & Bergel, E. (2006). Cesarean section rates and maternal and neonatal mortality in low-, medium-, and high-income countries: an ecological study. *Birth* , 33(4), 270–277. https://doi.org/10.1111/j.1523-536X.2006.00118.x

Amoroso, C. L., Akimana, B., Wise, B., & Fraser, H. S. (2010). Using electronic medical records for HIV care in rural Rwanda. *In MEDINFO 2010* (pp. 337-341). IOS Press.

Antoine, C., & Young, B. K. (2021). Cesarean section one hundred years 1920–2020: the Good, the Bad and the Ugly. *Journal of Perinatal Medicine*, 49(1), 5-16.

Astagneau, P., Rioux, C., Golliot, F., & Brücker, G. (2001). Morbidity and mortality associated withsurgical site infections: results from the 1997–1999 INCISO surveillance. *Journal of Hospital Infection*, 48(4), 267-274

Atake E. H. (2020). Does the type of health insurance enrollment affect provider choice, utilization and health care expenditures?. *BMC health services research*, 20(1), 1003. https://doi.org/10.1186/s12913-020-05862-7

Atake E. H. (2018). Health shocks in sub-Saharan Africa: are the poor and uninsured households more vulnerable?. Health economics review, 8(1), 26. https://doi.org/10.1186/s13561-018-0210-x

Baid, J. M., Casey, A. L., Petrosillo, N., Hudson, P. M., Mitchell, S. A., & Crosby, C. (2017). Impact of surgical site infection on healthcare costs and patient outcomes: a systematic review in six European countries. *Journal of Hospital Infection*, 96(1), 1-15.

Bauer, K. L., Sogade, O. O., Gage, B. F., Ruoff, B., & Lewis, L. (2021). Improving Follow-up Attendance for Discharged Emergency Care Patients Using Automated Phone System to Self-schedule: A Randomized Controlled Trial. *Academic emergency medicine: official journal of the Society for Academic Emergency Medicine*, 28(2), 197–205. https://doi.org/10.1111/acem.14080

Bazirete, O., Nzayirambaho, M., Umubyeyi, A., Uwimana, M. C., & Evans, M. (2020). Influencing factors for prevention of postpartum hemorrhage and early detection of childbearing women at risk in Northern Province of Rwanda: beneficiary and health worker perspectives. *BMC pregnancy and childbirth*, 20(1), 1-14.

Behn, A., Davanzo, A., & Errázuriz, P. (2018). Client and therapist match on gender, age, and income: Does match within the therapeutic dyad predict early growth in the therapeutic alliance?. *Journal of Clinical Psychology*, 74(9), 1403-1421.

Bellows, B. W., Conlon, C. M., Higgs, E. S., Townsend, J. W., Nahed, M. G., Cavanaugh, K., ... & Gorter, A. C. (2013). A taxonomy and results from a comprehensive review of 28 maternal health voucher programmes. *Journal of health, population, and nutrition*, 31(4 Suppl 2), S106.

Betrán, A. P., Ye, J., Moller, A. B., Zhang, J., Gülmezoglu, A. M., & Torloni, M. R. (2016a).

The increasing trend in caesarean section rates: global, regional and national estimates: 1990-2014. *PloS one*, 11(2), e0148343.

Betrán, A. P., Torloni, M. R., Zhang, J. J., Gülmezoglu, A. M., Aleem, H. A., Althabe, F., ... & Zongo, A. (2016b). WHO statement on caesarean section rates. *Bjog*, 123(5), 667.

Betran, A. P., Ye, J., Moller, A. B., Souza, J. P., & Zhang, J. (2021). Trends and projections of caesarean section rates: global and regional estimates. *BMJ Global Health*, 6(6), e005671.

Bhati, K. S. (2014). Effect of client-therapist gender match on the therapeutic relationship: An exploratory analysis. *Psychological reports*, 115(2), 565-583.

Biccard, B. M., Madiba, T. E., Kluyts, H. L., Munlemvo, D. M., Madzimbamuto, F. D., Basenero, A., Gordon, C. S., Youssouf, C., Rakotoarison, S. R., Gobin, V., Samateh, A. L., Sani, C. M., Omigbodun, A. O., Amanor-Boadu, S. D., Tumukunde, J. T., Esterhuizen, T. M., Manach, Y. L., Forget, P., Elkhogia, A. M., Mehyaoui, R. M., … African Surgical Outcomes Study (ASOS) investigators (2018). Perioperative patient outcomes in the African Surgical Outcomes Study: a 7-day prospective observational cohort study. *Lancet*, 391(10130), 1589–1598. https://doi.org/10.1016/S0140-6736(18)30001-1

Binagwaho, A., Farmer, P. E., Nsanzimana, S., Karema, C., Gasana, M., Ngirabega, J. D., Ngabo, F., Wagner, C. M., Nutt, C. T., Nyatanyi, T., Gatera, M., Kayiteshonga, Y., Mugeni, C., Mugwaneza, P., Shema, J., Uwaliraye, P., Gaju, E., Muhimpundu, M. A., Dushime, T., Senyana, F., … Drobac, P. C. (2014). Rwanda 20 years on: investing in life. *Lancet*, 384(9940), 371–375. https://doi.org/10.1016/S0140-6736(14)60574-2

Broex, E. C., van Asselt, A. D., Bruggeman, C. A., & van Tiel, F. H. (2009). Surgical site infections: how high are the costs?. *The Journal of hospital infection*, 72(3), 193–201. https://doi.org/10.1016/j.jhin.2009.03.020

Casper, D. S., Zmistowski, B., Hollern, D. A., Hilibrand, A. S., Vaccaro, A. R., Schroeder, G. D., & Kepler, C. K. (2018). The Effect of Postoperative Spinal Infections on Patient Mortality. *Spine*, 43(3), 223–227. https://doi.org/10.1097/BRS.0000000000002277

Centers for Disease Control and Prevention [CDC]. 2010, 24 November). Surgical Site Infection (SSI). https://www.cdc.gov/hai/ssi/ssi.html

Condo, J., Mugeni, C., Naughton, B., Hall, K., Tuazon, M. A., Omwega, A., ... & Binagwaho, A. (2014). Rwanda's evolving community health worker system: a qualitative assessment of client and provider perspectives. *Human resources for health*, 12(1), 1-7.

Cobos Muñoz, D., Merino Amador, P., Monzon Llamas, L., Martinez Hernandez, D., & Santos Sancho, J. M. (2017). Decentralization of health systems in low and middle income countries: a systematic review. International journal of public health, 62(2), 219–229. https://doi.org/10.1007/s00038-016-0872-2

Crocker, J. B., Crocker, J. T., & Greenwald, J. L. (2012). Telephone follow-up as a primary care intervention for post-discharge outcomes improvement: a systematic review. *The American journal of medicine*, 125(9), 915–921. https://doi.org/10.1016/j.amjmed.2012.01.035

Dawes, A. J., Lin, A. Y., Varghese, C., Russell, M. M., & Lin, A. Y. (2021). Mobile health technology for remote home monitoring after surgery: a meta-analysis. *The British journal of surgery*, 108(11), 1304–1314. https://doi.org/10.1093/bjs/znab323

De La Cruz Monroy, M. F. I., & Mosahebi, A. (2019). The Use of Smartphone Applications (Apps) for Enhancing Communication With Surgical Patients: A Systematic Review of the Literature. *Surgical innovation*, 26(2), 244–259. https://doi.org/10.1177/1553350618819517

Dennis, M. L., Abuya, T., Campbell, O. M. R., Benova, L., Baschieri, A., Quartagno, M., & Bellows, B. (2018). Evaluating the impact of a maternal health voucher programme on service use before and after the introduction of free maternity services in Kenya: a quasi-experimental study. *BMJ global health*, 3(2), e000726.

Farmer P. (2003). Pathologies of power: Health, human rights and the new war on the poor. Berkeley &Los Angeles, California: University of California Press. 144pp. Foreword by Amartya Sen.

Findeisen A, Arefian H, Doenst T, Hagel S, Pletz MW, Hartmann M, et al. Economic burden of surgical site infections in patients undergoing cardiac surgery. *Eur J cardio-thoracic Surg Off J Eur Assoc Cardio-thoracic Surg*. 2019;55(3):494–500.

Fitzwater, J. L., & Tita, A. T. (2014). Prevention and management of cesarean wound infection. *Obstetrics and gynecology clinics of North America*, 41(4), 671–689. https://doi.org/10.1016/j.ogc.2014.08.008

Fletcher, R. R., Olubeko, O., Sonthalia, H., Kateera, F., Nkurunziza, T., Ashby, J. L., ... & Hedt-Gauthier, B. (2019, July). Application of machine learning to prediction of surgical site infection. In 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (pp. 2234-2237). IEEE.

Forrester, J. A., Koritsanszky, L., Parsons, B. D., Hailu, M., Amenu, D., Alemu, S., ... & Weiser, T. G. (2018). Development of a surgical infection surveillance program at a tertiary hospital in Ethiopia: lessons learned from two surveillance strategies. Surgical Infections, 19(1), 25-32.

Galukande, M., von Schreeb, J., Wladis, A., Mbembati, N., de Miranda, H., Kruk, M. E., ... & Macfarlane, S. B. (2010). Essential surgery at the district hospital: a retrospective descriptive analysis in three African countries. *PLoS medicine*, 7(3), e1000243.

Gibson, A., Tevis, S., & Kennedy, G. (2014). Readmission after delayed diagnosis of surgical site infection: a focus on prevention using the American College of Surgeons National Surgical Quality Improvement Program. *American journal of surgery*, 207(6), 832–839. https://doi.org/10.1016/j.amjsurg.2013.05.017

Gjellebæk, C., Svensson, A., Bjørkquist, C., Fladeby, N., & Grundén, K. (2020). Management challenges for future digitalization of healthcare services. *Futures*, 124, 102636.

Griffiths, F., Watkins, J. A., Huxley, C., Harris, B., Cave, J., Pemba, S., ... & Sturt, J. (2020). Mobile consulting (mConsulting) and its potential for providing access to quality healthcare for populations living in low-resource settings of low-and middle-income countries. *Digital health*, 6, 2055207620919594.

Grimes, C. E., Bowman, K. G., Dodgion, C. M., & Lavy, C. B. (2011). Systematic review of barriers to surgical care in low-income and middle-income countries. *World journal of surgery*, 35, 941-950.

Gunter, R. L., Chouinard, S., Fernandes-Taylor, S., Wiseman, J. T., Clarkson, S., Bennett, K., Greenberg, C. C., & Kent, K. C. (2016a). Current Use of Telemedicine for Post-discharge Surgical Care: A Systematic Review. *Journal of the American College of Surgeons*, 222(5), 915–927. https://doi.org/10.1016/j.jamcollsurg.2016.01.062

Gunter, R., Fernandes-Taylor, S., Mahnke, A., Awoyinka, L., Schroeder, C., Wiseman, J., ... & Kent, K. C. (2016b). Evaluating patient usability of an image-based mobile health platform for postoperative wound monitoring. *JMIR mHealth and uHealth*, 4(3), e6023

Haleem, A., Javaid, M., Singh, R. P., & Suman, R. (2021). Telemedicine for healthcare: Capabilities, features, barriers, and applications. *Sensors international*, 2, 100117. https://doi.org/10.1016/j.sintl.2021.100117

Handtke, O., Schilgen, B., & Mösko, M. (2019). Culturally competent healthcare - A scoping review of strategies implemented in healthcare organizations and a model of culturally competent healthcare provision. *PloS one*, 14(7), e0219971. https://doi.org/10.1371/journal.pone.0219971

Harrison, M. S., Pasha, O., Saleem, S., Ali, S., Chomba, E., Carlo, W. A., ... & Goldenberg, R. L. (2017). A prospective study of maternal, fetal and neonatal outcomes in the setting of cesarean section in low-and middle-income countries. *Acta obstetricia et gynecologica Scandinavica*, 96(4), 410-420.

Hategeka, C., Ruton, H., & Law, M. R. (2019). Effect of a community health worker mHealth monitoring system on uptake of maternal and newborn health services in Rwanda. *Global health research and policy*, 4, 8. https://doi.org/10.1186/s41256-019-0098-y

Haver, J., Brieger, W., Zoungrana, J., Ansari, N., & Kagoma, J. (2015). Experiences engaging community health workers to provide maternal and newborn health services: implementation of four programs. *International Journal of Gynecology & Obstetrics*, 130, S32-S39.

Iyawa, G. E., Herselman, M., & Botha, A. (2016). Digital health innovation ecosystems: From systematic literature review to conceptual framework. *Procedia Computer Science*, *100*, 244-252.

Jang, S. R., Chen, B. P., Guilfoyle, J., Tewari, P., Elangovanraaj, N., & Johnston, S. S. (2022). Surgical site infection following cesarean delivery incidence, risk factors, and association with incremental healthcare use. *AJOG global reports*, 3(1), 100144. https://doi.org/10.1016/j.xagr.2022.100144

Jenks, P. J., Laurent, M., McQuarry, S., & Watkins, R. (2014). Clinical and economic burden of surgical site infection (SSI) and predicted financial consequences of elimination of SSI from an English hospital. *Journal of Hospital infection*, 86(1), 24-33.

Kachieng'a, M. O. (2011, June). *Challenges in managing diffusion of telemedicine technology in South Africa.* First International Technology Management Conference, San Jose, CA, USA, 2011, pp. 121-125, doi: 10.1109/ITMC.2011.5995936

Kang, E., Gillespie, B. M., Tobiano, G., & Chaboyer, W. (2020). General surgical patients' experience of hospital discharge education: A qualitative study. *Journal of clinical nursing*, 29(1-2), e1–e10. https://doi.org/10.1111/jocn.15057

Karageorgos, G., Andreadis, I., Psychas, K., Mourkousis, G., Kiourti, A., Lazzi, G., & Nikita, K. S. (2018). The promise of mobile technologies for the health care system in the developing world: a systematic review. IEEE reviews in biomedical engineering, 12, 100-122.

Kateera, F., Hedt-Gauthier, B., Luo, A., Niyigena, A., Galvin, G., Hakizimana, S., Molina, R. L., Boatin, A. A., Kasonde, P., Musabeyezu, J., Ngonzi, J., Riviello, R., Semrau, K., & Sayinzoga, F. (2023). Safe recovery after cesarean in rural Africa: Technical consensus guidelines for post-discharge care. *International journal of gynaecology and obstetrics: the official organ of the International Federation of Gynaecology and Obstetrics*, 160(1), 12–21. https://doi.org/10.1002/ijgo.14284

Kibe, P. M., Mbuthia, G. W., Shikuku, D. N., Akoth, C., Oguta, J. O., Ng'ang'a, L., & Gatimu, S. M. (2022). Prevalence and factors associated with caesarean section in Rwanda: a trend analysis of Rwanda demographic and health survey 2000 to 2019–20. *BMC pregnancy and childbirth*, 22(1), 1-13.

Kreitmair, K. V., Cho, M. K., & Magnus, D. C. (2017). Consent and engagement, security, and authentic living using wearable and mobile health technology. *Nature biotechnology*, 35(7), 617-620.

Litorp, H., Mgaya, A., Kidanto, H. L., Johnsdotter, S., & Essén, B. (2015). 'What about the mother?'Women′ s and caregivers′ perspectives on caesarean birth in a low-resource setting with rising caesarean section rates. *Midwifery*, 31(7), 713-720.

Lucas, D. N., Yentis, S. M., Kinsella, S. M., Holdcroft, A., May, A. E., Wee, M., & Robinson, P. N. (2000). Urgency of caesarean section: a new classification. *Journal of the Royal Society of Medicine*, 93(7), 346-350.

Maeder, A. J. (2021). Development of a conceptual framework for e-health readiness assessment in the context of developing countries. Telehealth Innovations in Remote Healthcare Services Delivery: *Global Telehealth* 2020, 277, 68.

Mascarello, K. C., Horta, B. L., & Silveira, M. F. (2017). Maternal complications and cesarean section without indication: systematic review and meta-analysis. *Revista de saude publica*, 51, 105. https://doi.org/10.11606/S1518-8787.2017051000389

Mazimpaka, C., Uwitonze, E., Cherian, T., Hedt-Gauthier, B., Kateera, F., Riviello, R., El-Khatib, Z., Sonderman, K., Gruendl, M., Habiyakare, C., Hakizimana, S., Kayitesi, D., & Nkurunziza, T. (2020). Perioperative Management and Outcomes After Cesarean Section-A Cross-Sectional Study From Rural Rwanda. *The Journal of surgical research*, 245, 390–395. https://doi.org/10.1016/j.jss.2019.07.070

Mehtar, S., Wanyoro, A., Ogunsola, F., Ameh, E. A., Nthumba, P., Kilpatrick, C., Revathi, G., Antoniadou, A., Giamarelou, H., Apisarnthanarak, A., Ramatowski, J. W., Rosenthal, V. D., Storr, J., Osman, T. S., & Solomkin, J. S. (2020). Implementation of surgical site infection surveillance in low- and middle-income countries: A position statement for the International Society for Infectious Diseases. *International journal of infectious diseases : IJID : official publication of the International Society for Infectious Diseases*, 100, 123–131. https://doi.org/10.1016/j.ijid.2020.07.021

Mengistu, D. A., Alemu, A., Abdukadir, A. A., Mohammed Husen, A., Ahmed, F., Mohammed, B., & Musa, I. (2023). Global Incidence of Surgical Site Infection Among Patients: Systematic Review and Meta-Analysis. INQUIRY: *The Journal of Health Care Organization, Provision, and Financing,* 60, 00469580231162549.

Ministry of Health [Rwanda]. (2018). National Surgical, Obstetrics, and Anesthesia Plan 2018-2024. https://www.moh.gov.rw/fileadmin/user_upload/Moh/Publications/Strategic_Plan/NSOAP_Rwanda-_Approved1.pdf

Ministry of Health [Rwanda]. 2016. Maternal and Child Health Division National Postnatal Care Guideline for Mother and Newborn.

Molina, G., Esquivel, M. M., Uribe-Leitz, T., Lipsitz, S. R., Azad, T., Shah, N., ... & Haynes, A. B. (2015). Avoidable maternal and neonatal deaths associated with improving access to caesarean delivery in countries with low caesarean delivery rates: an ecological modelling analysis. *The Lancet*, 385, S33.

Monahan, M., Jowett, S., Pinkney, T., Brocklehurst, P., Morton, D. G., Abdali, Z., & Roberts, T. E. (2020). Surgical site infection and costs in low- and middle-income countries: A systematic review of the economic burden. *PloS one*, 15(6), e0232960. https://doi.org/10.1371/journal.pone.0232960

Moore, M. (2003). Cesarean Section: Understanding and Celebrating Your Baby's Birth. *Johns Hopkins University Press*, p 31.

Mori AT, Binyaruka P, Hangoma P, Robberstad B, Sandoy I. Patient and health system costs of managing pregnancy and birth-related complications in sub-Saharan Africa: a systematic review. *Health Econ Rev*. 2020 Aug 15;10(1):26. doi: 10.1186/s13561-020-00283-y

Morton, R., Burton, A. E., Kumar, P., Hyett, J. A., Phipps, H., McGeechan, K., & de Vries, B. S. (2020). Cesarean delivery: Trend in indications over three decades within a major city hospital network. *Acta obstetricia et gynecologica Scandinavica*, 99(7), 909-916.

Mukangendo, M., Nzayirambaho, M., Hitimana, R., & Yamuragiye, A. (2018). Factors Contributing to Low Adherence to Community-Based Health Insurance in Rural Nyanza District, Southern Rwanda. *Journal of environmental and public health*, 2018, 2624591. https://doi.org/10.1155/2018/2624591

National Collaborating Centre for Women's and Children's Health (UK). (2008). *Surgical Site Infection: Prevention and Treatment of Surgical Site Infection*. RCOG Press.

National Institute of Statistics of Rwanda (NISR) [Rwanda], Ministry of Health (MOH) [Rwanda], and ICF. 2021. Rwanda Demographic and Health Survey 2019–20 Final Report. Kigali, Rwanda, and Rockville, Maryland, USA: NISR and ICF.

Nguhuni, B., De Nardo, P., Gentilotti, E., Chaula, Z., Damian, C., Mencarini, P., ... & Ippolito, G. (2017). Reliability and validity of using telephone calls for post-discharge surveillance of surgical site infection following caesarean section at a tertiary hospital in Tanzania. *Antimicrobial Resistance & Infection Control*, 6(1), 1-6.

Nguyen, H. T., Hatt, L., Islam, M., Sloan, N. L., Chowdhury, J., Schmidt, J. O., ... & Wang, H. (2012). Encouraging maternal health service utilization: an evaluation of the Bangladesh voucher program. *Social science & medicine*, 74(7), 989-996.

NISR (2018, December). Rwanda poverty profile report, 2016/17 (EICV 5). Kigali: National Institute of statistics, 2018. https://www.statistics.gov.rw/publication/eicv-5-rwanda-poverty-profile-report-201617

NISR. (2023). The Fifth Rwanda Population and Housing Census, Main Indicators Report, February 2023 https://www.statistics.gov.rw/publication/size-resident-population

Niyigena, A., Alayande, B., Bikorimana, L., Miranda, E., Rudolfson, N., Ndagijimana, D., Kateera, F., Riviello, R., & Hedt-Gauthier, B. (2022). The true costs of cesarean delivery for patients in rural Rwanda: Accounting for post-discharge expenses in estimated health expenditures. *International journal for equity in health*, 21(1), 62. https://doi.org/10.1186/s12939-022-01664-x

Njoroge, M., Zurovac, D., Ogara, E. A., Chuma, J., & Kirigia, D. (2017). Assessing the feasibility of eHealth and mHealth: a systematic review and analysis of initiatives implemented in Kenya. *BMC research notes*, 10(1), 90. https://doi.org/10.1186/s13104-017-2416-0

Nkurunziza, T., Kateera, F., Sonderman, K., Gruendl, M., Nihiwacu, E., Ramadhan, B., Cherian, T., Nahimana, E., Ntakiyiruta, G., Habiyakare, C., Ngamije, P., Matousek, A., Gaju, E., Riviello, R., & Hedt-Gauthier, B. (2019). Prevalence and predictors of surgical-site infection after caesarean section at a rural district hospital in Rwanda. *The British journal of surgery*, 106(2), e121–e128. https://doi.org/10.1002/bjs.11060

Nkurunziza, T., Riviello, R., Kateera, F., Nihiwacu, E., Nkurunziza, J., Gruendl, M., Klug, S. J., & Hedt-Gauthier, B. (2022a). Enablers and barriers to post-discharge follow-up among women who have undergone a caesarean section: experiences from a prospective cohort in rural Rwanda. *BMC health services research*, 22(1), 733. https://doi.org/10.1186/s12913-022-08137-5

Nkurunziza, T., Toma, G., Odhiambo, J., Maine, R., Riviello, R., Gupta, N., ... & Hedt-Gauthier, B. (2016). Referral patterns and predictors of referral delays for patients with traumatic injuries in rural Rwanda. *Surgery*, 160(6), 1636-1644.

Nkurunziza, T., Williams, W., Kateera, F., Riviello, R., Niyigena, A., Miranda, E., Bikorimana, L., Nkurunziza, J., Velin, L., Goodman, A. S., Matousek, A., Klug, S. J., Gaju, E., & Hedt-Gauthier, B. L. (2022b). mHealth-community health worker telemedicine intervention for surgical site infection diagnosis: a prospective study among women delivering via caesarean section in rural Rwanda. *BMJ global health*, 7(7), e009365. https://doi.org/10.1136/bmjgh-2022-009365

Nsor-Anabiah, S., Udunwa, M. U., & Malathi, S. (2019). Review of the prospects and challenges of mHealth implementation in developing countries. *Int J Appl Eng Res*, 14, 12.

Ntakirutimana, T., Tuyizere, M., Ndizeye, O., & Sunday, F. X. (2020). Status of water, hygiene and sanitation practices in Southern Rwanda. Rwanda Journal of Medicine and Health Sciences, 3(1), 40-48. DOI:10.4314/rjmhs.v3i1.6

Petherick, E. S., Dalton, J. E., Moore, P. J., & Cullum, N. (2006). Methods for identifying surgical wound infection after discharge from hospital: a systematic review. *BMC infectious diseases*, 6(1), 1-10.

Petroze, R. T., Nzayisenga, A., Rusanganwa, V., Ntakiyiruta, G., & Calland, J. F. (2012). Comprehensive national analysis of emergency and essential surgical capacity in Rwanda. *The British journal of surgery*, 99(3), 436–443. https://doi.org/10.1002/bjs.7816

Pillay, Y., & Motsoaledi, P. A. (2018). Digital health in South Africa: innovating to improve health. *BMJ global health*, 3(Suppl 2), e000722. https://doi.org/10.1136/bmjgh-2018-000722

Powell, B. L., Nkurunziza, T., Kateera, F., Dusabe, L., Kubwimana, M., Koch, R., Hedt-Gauthier, B.L., Riviello, R. (2021). Synthesizing postpartum care pathways, facilitators, and barriers for women after cesarean section: a qualitative analysis from rural Rwanda. Journal of Global Health Reports, 5, e2021043. doi:10.29392/001c.23615

Richard, F., Zongo, S., & Ouattara, F. (2014). Fear, guilt, and debt: an exploration of women's experience and perception of cesarean birth in Burkina Faso, West Africa. *International journal of women's health*, 469-478.

Robb KA, Habiyakare C, Kateera F, Nkurunziza T, Dusabe L, Kubwimana M, Powell B, Koch R, Gruendl M, Ngamije P, Riviello R. Variability of water, sanitation, and hygiene conditions and the potential infection risk following cesarean delivery in rural Rwanda. *J Water Health.* 2020;18(5):741–52.

Robotham, D., Satkunanathan, S., Reynolds, J., Stahl, D., & Wykes, T. (2016). Using digital notifications to improve attendance in clinic: systematic review and meta-analysis. *BMJ open*, 6(10), e012116.

Rosenberg, K. R., & Trevathan, W. R. (2018). Evolutionary perspectives on cesarean section.

Evolution, Medicine, and Public Health, 2018(1), 67-81. https://doi.org/10.1093/emph/eoy006

Rubin R. H. (2006). Surgical wound infection: epidemiology, pathogenesis, diagnosis and management. *BMC infectious diseases*, 6, 171. https://doi.org/10.1186/1471-2334-6-171

Sanger, P. C., Hartzler, A., Han, S. M., Armstrong, C. A., Stewart, M. R., Lordon, R. J., ... & Evans, H. L. (2014). Patient perspectives on post-discharge surgical site infections: towards a patient-centered mobile health solution. *PloS one*, 9(12), e114016.

Sanger, P. C., Simianu, V. V., Gaskill, C. E., Armstrong, C. A., Hartzler, A. L., Lordon, R. J., ... & Evans, H. L. (2017). Diagnosing surgical site infection using wound photography: a scenario-based study. *Journal of the American College of Surgeons,* 224(1), 8-15.

Sapkota, V. P., Bhusal, U. P., & Acharya, K. (2021). Trends in national and subnational wealth related inequalities in use of maternal health care services in Nepal: an analysis using demographic and health surveys (2001–2016). *BMC Public Health*, 21(1). https://doi.org/10.1186/s12889-020-10066-z

Sawyer, R. G., Evans, H. L., & Hedrick, T. L. (2019). Technological Advances in Clinical Definition and Surveillance Methodology for Surgical Site Infection Incorporating Surgical Site Imaging and Patient-Generated Health Data. *Surgical infections*, 20(7), 541–545. https://doi.org/10.1089/sur.2019.153

Shears P. (2007). Poverty and infection in the developing world: healthcare-related infections and infection control in the tropics. *The Journal of hospital infection*, 67(3), 217–224. https://doi.org/10.1016/j.jhin.2007.08.016

Sochet, A. A., Cartron, A. M., Nyhan, A., Spaeder, M. C., Song, X., Brown, A. T., & Klugman, D. (2017). Surgical site infection after pediatric cardiothoracic surgery: impact on hospital cost and length of stay. *World Journal for Pediatric and Congenital Heart Surgery*, 8(1), 7-12.

Spaan, E., Mathijssen, J., Tromp, N., McBain, F., ten Have, A., & Baltussen, R. (2012). The impact of health insurance in Africa and Asia: a systematic review. *Bulletin of the World Health Organization*, 90(9), 685–692. https://doi.org/10.2471/BLT.12.102301

Sullivan, E., Gupta, A., & Cook, C. H. (2017). Cost and Consequences of Surgical Site Infections: A Call to Arms. *Surgical infections*, 18(4), 451–454. https://doi.org/10.1089/sur.2017.072

Sway, A., Nthumba, P., Solomkin, J., Tarchini, G., Gibbs, R., Ren, Y., & Wanyoro, A. (2019). Burden of surgical site infection following cesarean section in sub-Saharan Africa: a narrative review. *International journal of women's health*, 11, 309–318. https://doi.org/10.2147/IJWH.S182362

Tanner, J., Padley, W., Davey, S., Murphy, K., & Brown, B. (2013). Patient narratives of surgical site infection: implications for practice. *The Journal of hospital infection*, 83(1), 41–45. https://doi.org/10.1016/j.jhin.2012.07.025

Triantafyllidis, A. K., & Tsanas, A. (2019). Applications of Machine Learning in Real-Life Digital Health Interventions: Review of the Literature. *Journal of medical Internet research*, 21(4), e12286. https://doi.org/10.2196/12286

Tusting, L. S., Gething, P. W., Gibson, H. S., Greenwood, B., Knudsen, J., Lindsay, S. W., & Bhatt, S. (2020). Housing and child health in sub-Saharan Africa: A cross-sectional analysis. PLoS medicine, 17(3), e1003055. https://doi.org/10.1371/journal.pmed.1003055

Velin, L., Umutesi, G., Riviello, R., Muwanguzi, M., Bebell, L. M., Yankurije, M., Faktor, K., Nkurunziza, T., Rukundo, G., de Dieu Gatete, J., Emil, I., Hedt-Gauthier, B. L., & Kateera, F. (2021). Surgical Site Infections and Antimicrobial Resistance After Cesarean Section Delivery in Rural Rwanda. Annals of global health, 87(1), 77. https://doi.org/10.5334/aogh.3413

von Allmen, R. S., Tinner, C., Schmidli, J., Tevaearai, H. T., & Dick, F. (2019). Randomized controlled comparison of cross-sectional survey approaches to optimize follow-up completeness in clinical studies. *PloS one*, 14(3), e0213822. https://doi.org/10.1371/journal.pone.0213822

Weiser, T. G., Haynes, A. B., Molina, G., Lipsitz, S. R., Esquivel, M. M., Uribe-Leitz, T., Fu, R., Azad, T., Chao, T. E., Berry, W. R., & Gawande, A. A. (2016). Size and distribution of the global volume of surgery in 2012. *Bulletin of the World Health Organization*, 94(3), 201–209F. https://doi.org/10.2471/BLT.15.159293

Western, B., Braga, A., Hureau, D., & Sirois, C. (2016). Study retention as bias reduction in a hard-to-reach population. *Proceedings of the National Academy of Sciences of the United States of America,* 113(20), 5477–5485. https://doi.org/10.1073/pnas.1604138113

Williams, P., Murindahabi, N. K., Butrick, E., Nzeyimana, D., Sayinzoga, F., Ngabo, B., Musabyimana, A., & Musange, S. F. (2019). Postnatal care in Rwanda: facilitators and barriers to postnatal care attendance and recommendations to improve participation. *Journal of global health reports*, 3(1), 10.29392/joghr.3.e2019032. https://doi.org/10.29392/joghr.3.e2019032

World Health Organization [WHO]. (Jun 2, 2021). Caesarean section rates continue to rise, amid growing inequalities in access. https://www.who.int/news/item/16-06-2021-caesarean-section-rates-continue-to-rise-amid-growing-inequalities-in-access

WHO. (2018). *Global Reference List of 100 Core Health Indicators (plus health-related SDGs)*. Geneva:World Health Organization; 2018. Licence: CC BY-NC-SA 3.0 IGO.

WHO. (2014). *WHO Recommendations on Postnatal Care of The Mother and Newborn*. World Health Organization.

World Bank. (March 23, 2023). The World Bank In Rwanda: overview. http://www.worldbank.org/en/country/rwanda/overview

Zafar, S. N., Fatmi, Z., Iqbal, A., Channa, R., & Haider, A. H. (2013). Disparities in access to surgical care within a lower income country: an alarming inequity. *World journal of surgery*, 37(7), 1470–1477. https://doi.org/10.1007/s00268-012-1732-8

Reprint Permissions

Publications one and two are published open access under the terms and conditions of the Creative Commons Attribution License (CC BY). Therefore, these articles are accessible online without any restrictions and can be re-used in any way, subject only to proper citation.