ISBN 978-82-326-2518-5 (printed ver.)
ISBN 978-82-326-2519-2 (electronic ver.)
ISSN 1503-8181

Doctoral theses at NTNU, 2017:223

Håkon Angell Bolkan

Addressing Surgical Needs Where There is No Surgeon

Status of Surgery in Sierra Leone, Safety and Future Contributions of a Task Sharing Training Programme, and Surgery as an Indicator of Hospital Function During the West African Ebola Outbreak

NTNU
Norwegian University of Science and Technology

Thesis for the Degree of Philosophiae Doctor
Faculty of Medicine and Health Sciences
Department of Cancer Research and Molecular Medicine

Håkon Angell Bolkan

Doctoral thesis

Doctoral theses at NTNU, 2017:223

NTNU

NTNU
Norwegian University of Science and Technology

NTNU
Norwegian University of Science and Technology

Håkon Angell Bolkan

Addressing Surgical Needs Where There is No Surgeon

Status of Surgery in Sierra Leone, Safety and Future Contributions of a Task Sharing Training Programme, and Surgery as an Indicator of Hospital Function During the West African Ebola Outbreak

Thesis for the Degree of Philosophiae Doctor

Trondheim, September 2017

Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Cancer Research and Molecular Medicine

NTNU
Norwegian University of
Science and Technology

NTNU
Norwegian University of Science and Technology

Thesis for the Degree of Philosophiae Doctor

Faculty of Medicine and Health Sciences
Department of Cancer Research and Molecular Medicine

ISBN 978-82-326-2518-5 (printed ver.)
ISBN 978-82-326-2519-2 (electronic ver.)
ISSN 1503-8181

Doctoral theses at NTNU, 2017:223

Printed by NTNU Grafisk senter

Summary in Norwegian

Vest-Afrika er den regionen i verden med høyest kirurgisk sykdomsbyrde og hvor det blir gjort færrest operasjoner pr innbygger. Få spesialister og stor legemangel er en av hovedgrunnene til den dårlige tilgangen til kirurgiske tjenester. Jobbglidning, hvor medisinske oppgaver flyttes til helsearbeidere med kortere utdanning er en ny og innovativ strategi for å øke tilgangen til kirurgi i områder med få spesialister. Strategien, som fortsatt er kontroversiell innen kirurgiske fag er forsøkt i noen øst- og sentral-Afrikanske land, men mindre brukt i Vest-Afrika.

Dette forskningsprosjektet ble utviklet samtidig med oppstarten av et kirurgisk opptreningsprogram for legeassistenter i Sierra Leone hvor jobbglidning var den sentrale strategien. Legeassistenter er helsearbeidere med kortere utdanning enn leger og finnes i mange afrikanske land. I Sierra Leone håndterer denne gruppen tilstander og en pasientpopulasjon tilsvarende det allmennleger gjør i Norge. Målet med arbeidene i denne avhandlingen har vært å evaluere behovet for innføring av jobbglidning i kirurgiske fag i Sierra Leone (publikasjon 1 og 2), undersøke om kirurgisk volum er anvendelig som indikator for funksjonsnivået av sykehus under en humanitær katastrofe (ebolaepidemi, publikasjon 3), samt evaluere det framtidige potensialet for jobbglidning i kirurgi og om dette er en trygg strategi (publikasjon 4).

Første publikasjon er en nasjonal kartlegging av alle kirurgiske operasjoner utført på operasjonsstuer i Sierra Leone i 2012. Andre publikasjon beskriver helsearbeidere som utførte disse kirurgiske operasjonene og deres produktivitet (operasjoner per årsverk). Tredje publikasjon evaluerer kirurgiske operasjoner og innleggelser av pasienter uten ebola på 40 sykehus, 20 uker før utbruddet ble bekreftet i Sierra Leone og 52 uker inn i ebolaepidemien. Ukentlige endringer før og under epidemiens utbrudd ble kalkulert. Fjerde publikasjon beskriver og evaluerer utkomme av de 27 216 kirurgiske operasjonene studenter og uteksaminerte kirurgiske legeassistenter har deltatt i eller selv utført fra begynnelsen av 2011 til juli 2016.

I 2012 ble det foretatt 24 152 kirurgiske operasjoner fordelt på 58 sykehus og klinikker i Sierra Leone. Med en befolkning på 6 millioner mennesker tilsvarte dette 400 kirurgiske operasjoner per 100 000 innbyggere, noe som utgjorde mindre enn 8 % av det antatte behovet. Det ble utført 30 ganger flere operasjoner per innbygger i hovedstaden Freetown sammenlignet med distriktene som gjorde færrest prosedyrer. Det ble tilsammen identifisert 164 årsverk av helsearbeidere som utførte kirurgiske operasjoner. Spesialister fra alle kirurgiske fagområder utgjorde 35,6 %, leger uten spesialisering 52,3 %, sykepleiere 3,8 % og legeassistenter 8,4 %. Pr. innbygger var det 8 ganger færre kirurgiske tilbydere i rurale strøk hvor størsteparten av befolkningen bor, enn i urbane områder. Det var en negativ sammenheng mellom lengde på kirurgisk utdannelse og sannsynlighet for at en kirurgisk tilbyder virket i rurale strøk. Kirurgisk produktivitet varierte betydelig mellom de forskjellig yrkesgruppene samt hvor de arbeidet (offentlig/privat sektor eller distrikts-/sentral-sykehus).

Det ble registrert 55 020 innleggelser (eksklusive pasienter med mistenkt, mulig eller bekreftet ebola) i løpet av det første året av ebola epidemien, noe som tilsvarte en reduksjon på 51 % sammenlignet med før epidemien. I løpet av epidemien ble det registrert 12 126 kirurgiske operasjoner, noe som tilsvarer en reduksjon på 41 % sammenlignet med tilsvarende uker fra 2012. Private sykehus reduserte antall keisersnitt med 43 % under epidemiens første år, mens offentlige sykehus økte antall keisersnitt med 45 %.

Av i alt 48 legeassistenter og unge leger som startet i det kirurgiske jobbglidningsprogrammet fram til juli 2016 hadde 13 gjennomført alle 3 år av utdanningen og blitt kirurgassistenter, mens 24 fortsatt var i programmet. De uteksaminerte utførte i gjennomsnitt 173 selvstendige operasjoner årlig etter opptreningen. Programmet vil trene 60 kirurgiske legeassistenter innen 2021, og om disse er like produktive, vil denne gruppen da kunne utføre 10 380 årlige operasjoner på offentlige distriktssykehus i Sierra Leone, en økning på 110 % fra 2012. Keisersnitt, operasjon for lyskebrokk og bukoperasjon (laparotomi) var de hyppigste utførte inngrepene både under og etter endt opptrening.

Dødelighet etter keisersnitt og bukoperasjon ble brukt til å evaluere om jobbglidning var en trygg strategi. Utkomme for kirurgiske legeassistenter under og etter opplæringen ble sammenlignet med tidligere resultater fra Sierra Leone og andre lav-inntektsland. Dødeligheten etter keisersnitt utført av legeassistenter var 0,7 % under opptreningen og 0,4 % etter, betydelig lavere enn tidligere kjente resultater fra Sierra Leone (1,2 %) og fra Vest-Afrika (1,4 % - gjennomsnitt av 19 publikasjoner). Dødeligheten etter bukoperasjon var 4,3 % i løpet av opptreningen og 8,0 % etterpå. Også dette var lavere en tidligere resultater fra Sierra Leone (10,4 %), men likt med en multinasjonal studie fra lav-ressursland (8,6 %).

I tillegg ble dødelighet for alle operasjoner gjort uten aktiv rådgivning fra kirurg både under og etter utdanningen, sammenlignet med utkomme for operasjoner gjort av programmets kirurgiske trenere. Statistisk analyse korrigert for pasientens kjønn, kirurgisk prosedyre, sykehus og hastegrad avdekket signifikant lavere risiko for fatalt utkomme for operasjoner utført av jobbglidningskandidater sammenlignet med programmets trenere, både under og etter opptreningen.

Avhandlingen konkluderer med at det gjøres svært få kirurgiske operasjoner i Sierra Leone og at det er et stort behov for å utvide det kirurgiske behandlingstilbudet, spesielt på distrikts sykehus. Mangelen på kirurgiske tilbydere er stort og det er et uttalt behov for nye og innovative løsninger for å avhjelpe den pågående helsepersonellkrisen landet erfarer. Jobbglidning synes å være en trygg strategi i Sierra Leone og kan potensielt doble antall operasjoner i offentlig sektor i løpet av få år. Kirurgisk volum var en anvendbar indikator for sykehusfunksjoner under ebolaepidemien, men ytterlige studier er nødvendig for å vurdere nytte og bruk.

Kandidat:

Håkon Angell Bolkan,
Kirurgisk klinikk, St. Olavs Hospital. Fakultet for medisin og helsevitenskap, Institutt for kreftforskning og molekylær medisin, NTNU.

Veiledere:

Arne Wibe,
Professor, Kirurgisk klinikk, St. Olavs Hospital. Fakultet for medisin og helsevitenskap, Institutt for kreftforskning og molekylær medisin, NTNU.

Johan von Schreeb,
Docent, Institutionen för folkhälsovetenskap, Karolinska Institutet.

Øyvind Salvesen,
1. amanuensis, Fakultet for medisin og helsevitenskap, Institutt for kreftforskning og molekylær medisin, NTNU.

"Education is the most powerful weapon which you can use to change the world."

Nelson Mandela

"I urge you to challenge this injustice and to build a shared vision

and strategy for global equity in essential surgical care."

Dr. Jim Kim

President of the World Bank addressing the inaugural meeting of the
Lancet Commission on Global Surgery, Boston, 2014

To our late trainees in the Surgical Training Programme, **Samuel Batty** and **Joseph Heindilo Ngegba** who kept on serving their people during the Ebola outbreak until themselves got infected, and **Allen Bockarie Mansaray** who was killed in a traffic accident on his way to a training hospital.

To the dedicated and brave **trainees and graduates of the Surgical Training Programme** that left safe jobs, friends and families to pursue the dream of learning surgery.

To **Sierra Leonean colleagues** and friends that also believed this was possible and firmly supported.

To **CapaCare's trainers**, all the surgeons, gynaecologists, anaesthesiologists, radiologists, doctors, midwifes, nurses and technicians that voluntary have passed on their skills and knowledge so desperately lacking in Sierra Leone.

Acknowledgements

I would like to express my sincere gratitude to

Arne Wibe, my main supervisor for the open door, friendly support and courage to take on this journey into the unknown.

Johan von Schreeb, co-supervisor for your wisdom, for always aspire for the best, for your fearless and humble enthusiasm to address the grand challenges for underserved population, and for being such an inspiration.

Brynjulf Ystgaard, co-founder of CapaCare for always seeing the bigger picture, for your strategic discussions and for your support.

Alex van Duinen, brother in arms for your dedication to improve surgery in West Africa, for taking our ideas and desires to the next level.

Lars Hagander, co-author and global surgical champion for sharing your rich scientific knowledge, for your gentle push, and for opening your networks.

Birger H. Endreseth and **Ola Sæther,** current and former clinical leads at the department of surgery at St. Olavs Hospital, for the support and flexibility which has allowed us to engage outside the catchment area of St. Olav.

Peter Bo Jørgensen, CapaCare board member and founder of Masanga Hospital for your energy, your large heart and tireless drive to improve healthcare in rural Sierra Leone.

Bart Waalewijn, Daniel van Leerdam and **Martelien Grootjans**, CapaCare International coordinators, for your dedications and invaluable contributions to develop CapaCare in Sierra Leone.

Bjørn Gustafsson and Stig Slørdahl, present and former deans at the Medical Faculty, for prioritising global health and for believing in us and me during our early days.

Øyvind Salvesen, co-supervisor for bearing over with my statistical shortcomings.

Colleagues at St. Olav's Hospital, for covering on-calls when I have not been in Trondheim.

Trainees and graduates of the STP for gathering much of the data and for providing high quality surgical care in rural Sierra Leone.

My family, for your flexibility and the willingness to help at home whenever needed.

My children, **Ragna and Trygve,** for always reminding me of what is most important in life.

The great love of my life **Ellen**, for sharing the beliefs, for your engagement at all levels of this project, and for allowing spending our time. Without your support, involvement and encouragements, this journey would not have started.

Table of Contents

List of Papers

This thesis is based upon the following papers, referred to as *Paper I* to *IV*:

Paper I

Met and Unmet Needs for Surgery in Sierra Leone: A Comprehensive, Retrospective, Countrywide Survey from all Health Care Facilities Performing Operations in 2012.

Bolkan HA, von Schreeb J, Samai MM, Bash-Taqi DA, Kamara TB, Salvesen Ø, B. Ystgaard, A. Wibe.

Surgery, 2015;157(6):992-1001.

Presented at:

1. Lancet Commission on Global Surgery, Second Regional Meeting, Freetown, Sierra Leone, June 2014 – *Oral Presentation*
2. UK-Sierra Leone Health Partners Conference, London, UK, April 2014 - *Oral Presentation*
3. 54th Annual Conference of the West African College of Surgeons, Kumasi, Ghana, February 2014 - *Oral Presentation*
4. Annual Conference of the Sierra Leonean Medical and Dental Association, Freetown, Sierra Leone, November 2013 - *Oral Presentation*
5. World Congress of Surgery, Obstetrics, Trauma and Anaesthesia, Port of Spain, Trinidad & Tobago, October 2013 – *Oral Presentation*

Paper II

The Surgical Workforce and Surgical Provider Productivity in Sierra Leone: A Countrywide Inventory.

Bolkan HA, Hagander L**,** von Schreeb J, Samai MM, Bash-Taqi DA, Kamara TB, Salvesen Ø, Wibe A.

World Journal of Surgery, 2016;40:1344-51.

Presented at:

1. 56th Annual Conference of the West African College of Surgeons, Yaoundé, Cameroon, February 2016 - *Oral Presentation*
2. Lancet Commission on Global Surgery, London, UK, April 2015 – *Poster*
3. Surgery in Low-Resource Settings Conference, Netherlands Society for International Surgery, Amsterdam, The Netherlands, November 2014 - *Oral Presentation*

Paper III

Admissions and Surgery as Indicators of Hospital Functioning in Sierra Leone During the West African Ebola Outbreak.

Bolkan HA, Van Duinen A, Samai M, Bash-Taqi D-A, Gassama I, Waalewijn B, Wibe A, von Schreeb J.

Submitted: *BMC Health Services Research, 11 August 2016*

Presented at:

1. 56th Annual Conference of the West African College of Surgeons, Yaoundé, Cameroon, February 2016 - *Oral Presentation*
2. Conference on Global Health and Vaccination Research, Oslo, Norway, March 2015 – *Oral Presentation*

Paper IV

Safety, Productivity and Predicted Contribution of a Surgical Task-Sharing Programme in Sierra Leone. Operational Research from the First Five Years of an Innovative New Model of Training.

Bolkan HA, Van Duinen A, Waalewijn B, Elhassein M, Kamara TB, Fadlu-Deen G, Bundu I, Ystgaard B., von Schreeb J, Wibe A.

British Journal of Surgery. doi: 10.1002/bjs.10552

Presented at:

1. Conference on Global Health and Vaccination Research, Trondheim, Norway, March 2017 – *Oral Presentation*
2. Even Better Nordic Trauma Care & Global Surgery Seminar, Annual Conference of the Norwegian Surgical Society, Oslo, Norway, October 2016 - *Oral Presentation*
3. 56th Annual Conference of the West African College of Surgeons, Yaoundé, Cameroon, February 2016 – *Oral Presentation*[*]
4. XXI FIGO World Congress of Gynaecology & Obstetrics, Vancouver, Canada, October 2015 – *Oral Presentation*[*]
5. Surgery in Low-Resource Settings Conference, Netherlands Society for International Surgery, Amsterdam, The Netherlands, November 2014 - *Oral Presentation*[*]
6. UK-Sierra Leone Health Partners Conference, London, April 2014 - *Oral Presentation*
7. 54th Annual Conference of the West African College of Surgeons, Kumasi - Ghana, February 2014 – *Oral Presentation*[*]
8. Annual Conference of the Sierra Leonean Medical and Dental Association, Freetown, November 2013 - *Oral Presentation*[*]

[*] Preliminary results

Abbreviations and Acronyms

AC	Associate Clinicians
CS	Caesarean Section
DALY	Disability Adjusted Life Year
EQUATOR	Enhancing the Quality and Transparency of Health Research
EVD	Ebola Viral Disease
FHCI	Free Health Care Initiative
FTP	Full-Time Position
HIV	Human Immunodeficiency Virus
LCoGS	Lancet Commission on Global Surgery
LIC	Low-Income Country
MD	Medical Doctor
MOHS	Ministry of Health and Sanitation
NCD	Non-Communicable Disease
NTNU	Norwegian University of Science and Technology
OECD	Organisation for Economic Co-operation and Development
OR	Odds Ratio
SACHO	Surgical Assistant Community Health Officer
SAO	Surgeon, Anaesthesiologist, Obstetrician
SSA	Sub-Saharan Africa
STP	Surgical Training Program
WHO	World Health Organization

Glossary and Definitions

Glossary	Definition
Annual unmet surgical need	The annual need subtracted from the met need in a given year
Assisted surgical procedure	Assisted procedure is a one where a more senior surgical provider is assisted
Associate Clinicians	Any other health care professional besides the medical doctor and nurse
Directly supervised surgical procedure	A procedure where the major part of the operation is performed, but there is assistance from a more senior surgical provider also scrubbed in
District hospital	Hospitals not offering highly differentiated clinical services
Full-Time Equivalent Position	Full-time equivalent position of surgical provider
Governmental health care facility	Health care facility owned and operated by the MOHS or armed forces.
Health system	All organisations, people and actions whose primary intent is to promote, restore or maintain health
Hospital	Facilities providing 24-hour emergency in-patient care
Human resource density	Number of health care providers per 100,000 population
Humanitarian crisis	A situation with high levels of human suffering in which basic human welfare is in danger on a large scale
Indirectly supervised surgical procedure	A procedure performed and supervised by a senior colleague not scrubbed in.
In-hospital postoperative mortality	Inpatient deaths following surgery divided by the number of surgeries performed
Non-Ebola admission	Any patient recorded by the hospital administration as being hospitalized, but excluding admissions of suspect, probable or confirmed EVD cases
Nurse	A medical practitioner licensed by the Nurses & Midwives Board
Observed surgical procedure	A procedure watched without the observers being scrubbed in
Physician	Non-specialist holder of a medical degree included house officers
Private for-profit health facility	Health care facility where profit generation is one of the aims
Private non-profit health facility	Any health care facility which is not governmental or private for-profit
Referral hospital	Hospitals offering highly differentiated clinical services
Rural village	Villages with less than 50,000 inhabitants
Specialist surgical provider	Senior physician who has completed specialist training in surgery, orthopaedics, gynaecology/obstetrics, ophthalmology or otolaryngology
Surgery	The discipline/branch of medicine concerned with surgical care and conditions. Encompasses surgery, anaesthesia, peri-operative care, critical care, specialty surgery incl. obstetric surgery and ophthalmology
Surgical care	Any measure that reduces the rates of physical disability or premature death associated with a surgical condition
Surgical conditions	Any disease state requiring the expertise of a surgically trained provider
Surgical procedure (operation)	Any procedure requiring anaesthesia, performed within an operation theatre, and listed in any of the records for the operation theatre
Surgical productivity	Annual/weekly number of surgical procedures performed per year/week
Surgical provider	Any health professional trained to provide surgical care, including generalist MDs, advanced practice clinicians and clinical officers

List of Tables

List of Figures

Synopsis

As a young surgical trainee in Norway, much of the author's perspective was from that of the operation room. After some years working in low-income countries (LICs), it became clear that a crucial aspect of health improvement initiatives depended on how well they were integrated within the larger health system. Until recently, surgeons and surgical advocates have largely been absent in global public health and health system-strengthening initiatives. Characteristic, none of the authors behind *Surgery and Global Health: A View from Beyond the Operation Room* in the World Journal of Surgery a decade ago were surgeons (Farmer 2008). Farmer and Kim urged surgeons to engage in the development of surgical health care systems in resource-constrained areas. Much has changed since; an increasing number of surgeons have been engaged and with this research project, I have had the privilege of crossing path with and been inspired by many of those early pioneers. The work presented in this thesis is a surgeon's attempt to look both inside and beyond the operation room and engage both with clinical surgery and public health in Sierra Leone.

This research project was developed alongside the establishment of a new and innovative nationwide surgical training programme (STP) in Sierra Leone. The STP came about based on to the extreme shortage of medical doctors (MDs) in rural areas. The lack of surgical human resources necessitated new and innovative strategies. The programme enrolled the first trainees in January 2011 and has since been jointly operated by the Ministry of Health and Sanitation (MOHS) and the non-governmental organisation, CapaCare (Ystgaard 2013). The overall aim of the STP was to increase the surgical workforce at district hospitals in Sierra Leone. Our assumption was that a substantial expansion of qualified surgical human resources at district hospitals was more likely if surgical tasks could be shared with healthcare workers with shorter training times required than MDs.

Task shifting is a strategy seeking to address health workforce shortages and skill mix imbalances (Fulton 2011). It is a rational redistribution of tasks among health care workers in order to maximize efforts of the existing workforce (World Health Organisation 2008). The approach is recommended by the World Health Organization (WHO) for certain surgical procedures (World Health Organisation 2012) and has, over the last decades, been implemented in surgical care in several East and Central African countries (Wilson 2011).

Surgical task shifting has not been adopted to the same extent in West Africa (Mullan 2007), and was not officially applied in Sierra Leone before the launch of this STP in 2011. Development of a new group of surgical health care workers, skilled to manage and treat highly vulnerable patients in need of emergency care in a context of poor infrastructure, limited resources (Kingham 2009), and hardly any policy support for developing surgical services (Dare 2016), is challenging and not without risk. There is limited literature on surgical task shifting between specialist MDs, non-specialist MDs and non-physician clinicians from the weak health care systems in Sub-Saharan West Africa. Therefore, it was necessary to rigorously and objectively evaluate key aspects of the rationale of introducing the strategy, its safety features and its potential for enhancing surgical service delivery in the future.

The first objective was to assess **the need** for an expansion of the surgical workforce in Sierra Leone (*Papers I and II*) and establish a baseline for current activity and availability of human resources before the new group of surgical health care workers engaged in surgical service delivery. Our approach to this objective was to examine the met and unmet need for surgery in Sierra Leone by establishing a national database of operations performed in 2012 (*Paper I*), compile an inventory of the existing surgical workforce and determine its productivity (*Paper II*). **Figure 1** provides an overview of the papers included in the thesis and how they relate.

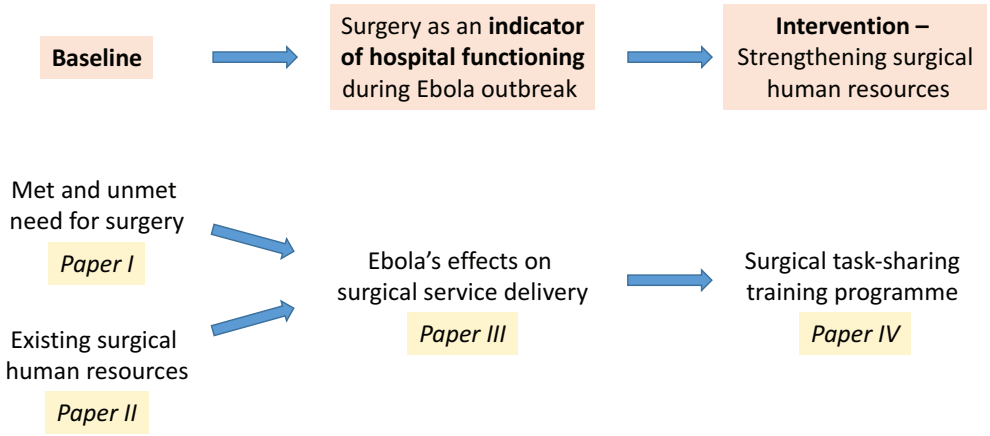

Figure 1 Overview of this thesis

Research in LICs is at its best challenging and often unpredictable. This became apparent with the outbreak of the Ebola viral disease (EVD) in West Africa in 2014. The international and local response to the epidemic focused most resources to containing the outbreak. Over the course of a few months in 2014, the countries most affected by the epidemic, namely Guinea, Liberia and Sierra Leone, experienced collapses of their entire health care systems (Loubet 2015). Disruption of basic health services became known as the collateral damage from Ebola, which by many was believed to cause even more mortality and morbidity than the Ebola virus itself (Walker 2015, Elston 2015).

Since a nationwide baseline of surgical services was established prior to the Ebola outbreak (*Paper I*), it became evident that we were in a unique position to quantify and monitor the collateral damage of the Ebola outbreak. Ongoing research was temporarily put on hold in order to explore how the Ebola epidemic affected provision of other essential services, such as surgery (Brolin Ribacke 2016, Bolkan 2014). In an attempt to assess the EVD's influence on service provision in hospitals in Sierra Leone, the second objective of this thesis became to evaluate changes in non-Ebola admissions and provision of surgery during the first year of the EVD outbreak.

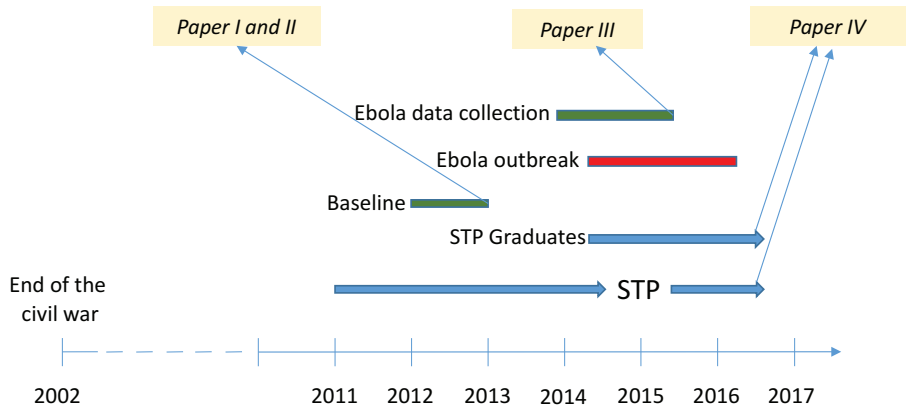

Figure 2 Timeline for papers featured in this thesis

Figure 2 sets out a timeline of events of importance for this thesis and when data for the included papers were collected. *Paper III* evaluates changes in provision of surgery and non-Ebola admissions during the first year of the EVD outbreak.

Although task sharing in surgery has been widely debated in key publications during the last number of years (World Health Organisation 2015, Meara 2015), little remains known on the role of such programmes within weak health systems. The third objective of this dissertation was to assess productivity and safety of the STP herein and estimate its future role in contributing to surgical volumes in Sierra Leone (*Paper IV*). Results from *Papers I and II* were used for baseline comparison purposes with *Papers III and IV*. In particular, *Paper III* was utilised to compare volumes of surgery during the Ebola outbreak against baseline data from 2012, and in *Paper IV*, there was the prediction of the percentage increase in volumes of surgery the graduates of the STP may add in the future.

Introduction

Global Surgery

Global surgery was just recently defined and suggested to be *an area for study, research, practice and advocacy that places priority on achieving health outcomes and health equity for all people worldwide who are affected by surgical conditions or have a need for surgical care* (Dare 2014). Surgery is the discipline/branch of medicine concerned with surgical care and conditions. It includes all surgical specialties, including ophthalmic, ear, nose and throat, orthopaedic, neurological, obstetric and gynaecological surgery. It also incorporates anaesthesia, perioperative care, emergency medicine, rehabilitation and palliative care as well as the nursing and the allied health professions involved in the care of the surgical patient (deVries CR 2012). A surgical condition is *any disease state requiring the expertise of a surgically trained provider* (Bickler 2010). Surgical care is defined as *any measure that reduces the rates of physical disability or premature death associated with a surgical condition* (Bickler 2010).

The need to define global surgery came from the recognition that surgical care had never been integrated in global public health (Farmer 2008) despite the fact that the last decades have witnessed an epidemiological transition of the burden of disease from communicable to non-communicable disease (NCD) (Lozano 2012). The proportion of deaths because of NCDs is projected to rise from 59 % in 2002 to 69 % by 2030 (Mathers 2006). Surgical care is an essential treatment modality in many of the NCD categories (Rose 2014). In 2013, close to a billion people sustained injuries that warranted some type of health care (Haagsma 2016). Five million people die because of injuries every year, which represents almost 10 % of all global deaths and makes it among the leading causes of mortality worldwide (Lozano 2012). The epidemiological transition and trauma care for the injured are just two examples of surgery's importance as a treatment modality.

Surgical care is pertinent to all ages and a necessary treatment modality not only for NCDs and injuries, but in nearly all major disease categories, spanning from infections to neoplastic, from congenital malformations to maternal conditions (Rose 2014). Nearly a third of the global burden of disease is estimated to require some sort of surgical care (Shrime 2015). In keeping with this perspective, in 2010, human immunodeficiency virus (HIV), tuberculosis

and malaria combined contributed to less than one-tenth of the global burden of disease (Lozano 2012). Despite the considerable load of surgical conditions, treatment options are often not available in low- and middle-income countries (Weiser 2015).

Roughly five billion people are estimated to lack access to timely, affordable, safe surgery and anaesthesia care should they need it (Alkire 2015). This has devastating consequences for patients and families along with societies at large. Barriers to access surgical care in low- and middle-income countries varies and are found to be dependent on the unique sociocultural context of each country (Forrester 2016). Barriers to surgical care from patient, physician, institution and structural perspectives include (Ologunde 2014):

i. Patient-related barriers to seeking care for surgical diseases were stigma and traditional beliefs about disease processes, absence of social support, high direct and indirect patient costs that includes loss of earnings during the peri-operative period and transportation costs.
ii. Physician-related barriers were shortages of health workers, lack of investment in education and poor access to skills training and inadequate continued professional development.
iii. Institution-related barriers were insufficient and poorly managed infrastructure, lack of finances, shortages in basic equipment and consumables, poor anaesthesia capacity with no access to oxygen and absence of anaesthetic machines or blood banks.
iv. Barriers related to structural factors included lack of collaboration and coordination between providers of similar surgical services.

Failure to scale up provision of surgical care in LICs is estimated to have a profound negative effect on national income and can reduce annual growth of the gross domestic product by as much as 1.7 % by 2030 (Alkire 2015). Surgical care has long been perceived as an expensive luxury unsuitable for resource-constrained health systems. However, a number of studies from the last decade have sharply contradicted this myth. Surgery has been demonstrated to be both highly efficient and cost-effective in resource-constrained areas. Surgical care is, in terms of economic benefits through reducing Disability Adjusted Life Years (DALY)s, on par with oral rehydration therapy, vitamin A supplementation, breast feeding promotion and several other interventions (Grimes 2014, Chao 2014).

Until the last decade, surgery has been absent in global public health, and is referred to by the President of the World Bank, Dr. Jim Kim, as "*the neglected stepchild in global health*" (Farmer 2008). Recent landmark publications, like the Lancet Commission on Global Surgery (LCoGS) (Meara 2015) and the 3rd edition of the World Bank's Disease Control Priorities (Mock 2015), have offered convincing evidence for the need and possibilities to change the current status of surgery and recommend wide-scale dissemination throughout the world. The WHO member states unanimously adopted a resolution in 2015 to strengthen emergency and essential surgical care worldwide. This resolution stipulated the importance of emergency and essential surgical care and anaesthesia in realizing universal health coverage and attaining the WHO's Sustainable Development Goal number three: *Ensure healthy lives and promote well-being for all at all ages* (World Health Organisation 2015).

The Unmet Need for Surgery

Universal health coverage is a central element of the wider 2030 Agenda for Sustainable Development (United Nations 2016). Health coverage relates to how much of the estimated need for a health care service is actually met. Coverage indicators are usually calculated by dividing the number of people receiving a defined intervention (met need) by the population eligible for or in need of the intervention (total need) (World Health Organisation 2009). The unmet need can be summarized as:

Unmet need = Total need - Met need

This formula is appropriate for calculating the unmet need for disease-specific interventions, such as provision of antiretroviral treatment for HIV. The prevalence and incidence of HIV will define present and future total need, while the number of patients already receiving antiretroviral treatment equate to the met need. For surgical diseases, this exercise is more complicated because surgical care is necessary in all major disease categories (Rose 2014), rendering the situation difficult in which how one defines need. Approximately 15 % of all pregnancies require some sort of emergency surgical care (United Nation Population Fund 2009), while 80 % of the more than 15 million new cases of cancer in 2015 necessitated one or several rounds of surgical involvement (Sullivan 2015). Many traumas may be managed without a surgical operation, but they do almost always require assessment from a surgical

provider. Furthermore, the need for surgery varies between geographical areas and populations. Early detection and treatment of an infection can be managed without surgery in certain parts of the world, while it might develop into an abscess or osteomyelitis needing a lifesaving surgical procedure in more resource-constrained areas. The need for surgical care might also be different where the proportion of a population is greater with respect to younger individuals compared to countries with older populations.

On a global scale, the LCoGS developed a model for estimation of unmet surgical need. Prevalence data from the Global Burden of Disease Study (Murray 2012) and national hospital data from New Zealand (Hider 2015) were employed to calculate frequency of operation per disease subcategory (based on admission diagnosis codes). This allowed a calculation of minimum global need for surgery based on the prevalence of the conditions in each region (Rose 2015). The global met need for surgery was obtained from published studies from 66 countries (Weiser 2015). Rates of surgery from countries without data were estimated based on health expenditures which had previously correlated well with surgical volumes (Weiser 2008). Applying this method, unmet need could be determined by subtracting met need from the total need across regions of the world. Per capita, Sub-Saharan West Africa had the largest surgical need (6,495 surgical procedures per 100,000 population/year) and the highest unmet need (5,625 surgical procedures per 100,000 population/year) for surgery globally (Rose 2015).

The above methodology estimated a minimum need of 143 million additional surgical operations to be performed worldwide every year (Meara 2015). Of the 21 Global Burden of Disease regions, 12 did not perform enough operations to address the basic surgical needs of their populations.

Sierra Leone

In *Paper I,* we made use of the conceptual framework of total, met and unmet need the LCoGS applied on a global scale at the national level in Sierra Leone. We attempted to establish the volume of met need and further estimated the unmet need for surgery. Sierra Leone is a West African country bordering Guinea to the north and east and Liberia to the south. Freetown, the capital, is located on the Atlantic coast. The country is 71,740 km^2 and is

divided into 14 administrative districts (CIA World Factbook 2016). The population of Sierra Leone increased from five to seven million between 2004 and 2015, an average annual growth rate of 3.2 % (United Nations in Sierra Leone 2016). Approximately 60 % of Sierra Leoneans live in rural areas (Statistics Sierra Leone 2006). The country was still recovering from the civil war that ended in 2002 when the health system was overwhelmed by the unprecedented Ebola outbreak between 2014 and 2016.

Life expectancy at birth is 45 years, and maternal mortality and child mortality are quite high at 1,165 per 100,000 live births and 156 per 1,000 live births, respectively (Statistics Sierra Leone 2013). Prior to the EVD outbreak, the total spending on health was $ 95 per capita, of which 62 % was private out-of-pocket contributions, 31 % derived from donor support and 7 % originating from the government (Ministry of Health and Sanitation 2015). The health care system in Sierra Leone is made up of public, private for-profit and private non-profit actors and is organized into three tiers of care: peripheral health units, district hospitals and referral hospitals. Governmental is the largest sector where the MOHS formulates policies, mobilizes resources and monitors and coordinates health care at the central level. Health care is provided through a web of health facilities comprising 1,054 peripheral health units and 51 hospitals. 20 hospitals are government-owned and the rest are operated by private entities, either for-profit or non-profit (Ministry of Health and Sanitation 2012). Comprehensive surgical care is primarily conducted within hospital facilities, but there are also governmental peripheral health units and private clinics performing surgical procedures in operation rooms (Bolkan 2015).

Sierra Leone has among the highest measured maternal mortality ratios in the world (World Health Organisation 2015). Only 7 % of obstetric complications were estimated to be treated in Sierra Leone in 2008 (Oyerinde 2011). This was one of the reasons for the Free Health Care Initiative (FHCI) for pregnant, lactating women and children less than five years of age was introduced in 2010 (Alex Jones 2016). The purpose of the FHCI was to increase access to health services for vulnerable groups. It has not been possible to directly measure if maternal mortality has changed as a result of the FHCI (Alex Jones 2016), though national caesarean section (CS) rates rose from 1.5 % in 2008 (Statistics Sierra Leone 2009) to 2.1 % in 2012 (Bolkan 2015) and 2.9 % in 2013 (Statistics Sierra Leone 2013). Inequality between urban and rural areas, however, remains significant at 3.2 % versus 0.9 % in 2008 and 4.9 % versus 2.2 %, respectively, in 2013. A CS rate below 10 % is associated with increased maternal

mortality (World Health Organisation 2015) given the operations are performed on medical indications (Miller 2016). The FHCI had greater effects on child mortality - a sharp drop from 187 to 126 deaths per 1,000 live births was documented between 2009 and 2012 (Alex Jones 2016).

Preceding the Ebola outbreak in 2014, the country made substantial progress towards the Millennium Development Goal targets for health. Between 2008 and 2013, attendance of skilled personnel at births increased from 42 % to 62 %, malaria bed net utilization from 26 % to 49 % and basic immunization (percentage of the population that received the third diphtheria, pertussis, and tetanus (DPT) vaccine) increased from 54 % to 78 % (Statistics Sierra Leone 2009, Statistics Sierra Leone 2013). Simultaneously, several important strategic steps to reinforce health care delivery were taken. The National Health Sector Strategic Plan 2010 – 2015 (Ministry of Health and Sanitation 2009) implemented national strategies according to defined standards in the Basic Package of Essential Health Services (Ministry of Health and Sanitation 2015, Ministry of Health and Sanitation 2009). Although a few specific emergency surgical interventions were included in the 2015 - 2020 version of the basic package (Ministry of Health and Sanitation 2015), the development of surgical services has not yet been prioritized in key policy documents in Sierra Leone (Dare 2015).

When the STP was planned, the country had 167 MDs in clinical practice (Ministry of Health and Sanitation 2009), poor output from the medical school (Samai 2014) and no formal postgraduate training in surgery or obstetrics (Vaughan 2015).

Surgery, the Healthcare System and the Ebola Outbreak

A health system is defined as *all organisations, people and actions whose primary intent is to promote, restore or maintain health* (World Health Organisation 2007). Health systems can be conceptualised by six building blocks; i) service delivery, ii) human resources, iii) governance and leadership, iv) access to essential medicines, v) financing, and vi) health information systems. The surgical system incorporates elements of all these. It also rests upon a wide range of support functions, such as radiology, blood banking, microbiology, and a broad set of infrastructure requirements, like running water, electricity, supplies of medical products and surgical equipment sometimes including advanced technologies. The surgical

system is composed of human resources that includes a broad mix of health care professionals. Besides curative care, surgical service delivery features preventive medicine (e.g., circumcision against HIV), diagnostics (e.g., biopsy, endoscopy) as well as palliative care. In most settings, surgical care is delivered by a combination of public, private for-profit and private non-profit organisations in need of adequate information systems, robust leadership and governance. The surgical system spans from the community to the most advanced tertiary health care facilities (Mills 2014).

When the WHO declared an end to Ebola transmission in West Africa in mid-2016, the outbreak had claimed more than 11,000 lives and infected almost 29,000 (World Health Organisation 2016). Over a short period of 2014, the frail health systems in Guinea, Liberia and Sierra Leone were overwhelmed with urgent and profound new challenges (Gostin 2015). Fears of contracting EVD, deaths of health care staff members (Evans 2015), closures of health facilities and disruption of essential health programmes (Walker 2015, Loubet 2015) contributed to reduced health service consumption (Bolkan 2014, Barden-O'Fallon 2015, Leuenberger 2015, Plucinski 2015) and increased all causes of mortality (Elston 2015).

How the health system adapted and functioned during the EVD outbreak, and the epidemics' consequences for essential health services were, with a few exceptions (Barden-O'Fallon 2015, Plucinski 2015, Elston 2015, Delamou 2014, Brolin Ribacke 2016), largely based on primary health care services (Loubet 2015, Elston 2015) or estimated by modelling analyses (Evans 2015, Walker 2015, Parpia 2016, Takahashi 2015).

Hospitals, an essential service delivery component of the health care system, are of particular concern during an EVD outbreak because many potential EVD patients are admitted (Hall 2008), and it is where most EVD-infected health care workers believe they contracted the disease (Olu 2015). With a few exceptions, hospital function has proven difficult to measure in LICs (McNatt 2015). In a humanitarian crisis, *defined as a situation with high levels of human suffering in which basic human welfare is in danger on a large scale* (Internews 2014), this is even more difficult. Far simpler, yet pertinent approaches are necessary. *Paper III* explored the feasibility of surgery as an indicator of hospital functioning during the EVD outbreak in Sierra Leone and discussed its significance.

Human Resources for Surgery

Among the chief barriers to the safe provision of surgical services in LICs is the shortage of surgical providers (Bergstrom 2015, Ologunde 2014). A surgical provider is *any health professional trained to provide surgical care, including generalist MDs, advanced practice clinicians and clinical officers* (Debas 2006). Data from the WHO Global Surgical Workforce estimated the global surgical workforce to include 1.1 million specialist surgeons, 550,000 specialist anaesthetic providers and 480,000 specialist obstetricians (Holmer 2015). Of those, only 12 % are found in Africa and South East Asia, home to a third of the world's population. The LCoGS made an attempt to justify a minimum target of needed specialist surgeons, anaesthesiologists and obstetricians (SAO) by correlating the density of those providers against specific health outcomes. There was a steep improvement in maternal mortality if the density of specialist SAOs per 100,000 inhabitants was elevated from 0 to 20 (Holmer 2015). Beyond densities of 40 per 100,000, the improvements were less pronounced and the LCoGS suggested those thresholds might serve as trace indicators for specialist surgical providers (Meara 2015). Based on the threshold of 40 per 100,000, another million specialist SAOs in 143 low- and middle-income countries were needed in 2015, and more than two million by 2030 if population growth is to be taken into account (Meara 2015).

The surgeon density in the African region ranges from 0.2 to 1.0 per 100,000 people (Holmer 2015), or 15- to 450-fold lower than Organisation for Economic Co-operation and Development (OECD) countries (OECD 2016). Shortage of surgical human resources is further aggravated by an uneven geographical distribution, and a particular disparity between the shortage of surgical providers and the large unmet need for surgery in rural areas in LICs (Knowlton 2013, Henry 2015, Bolkan 2015).

Task Sharing

Task shifting is defined as: "…*the rational redistribution of tasks among health workforce teams. Specific tasks are moved, where appropriate, from highly qualified health workers to health workers with shorter training and fewer qualifications in order to make more efficient use of the available human resources for health*" (World Health Organisation 2008). The term, task shifting, has been used interchangeably with task sharing (World Health Organisation 2012). The LCoGS made a distinction between the terms, and in contrast to task

shifting that transfer tasks and responsibility from one professional to another, task sharing emphasises a shared responsibility (Meara 2015). Task sharing better describes the reality in Sierra Leone and will be applied when describing distribution of surgical tasks there.

Until the early nineteenth century, surgery was a non-medical profession (barbers) (Lyon 1914). In addition, after surgeons were enrolled in the medical profession, allocation of medical tasks among MDs and between cadres of health care workers constantly changed (Loudon 1995). In modern times, there are several examples where large-scale programmes have shifted tasks from MDs to non-physician clinicians. Among the best known projects was the so-called "barefoot doctors" project that strengthened health care for rural populations in 1950s China (Sidel 1972). In the 1990s, the international community adopted large-scale task shifting programmes to address human resource shortages during the HIV epidemic (World Health Organisation 2008). Pursuant to this, in 2008, the WHO developed global recommendations and guidelines for task shifting (World Health Organisation 2008).

Task shifting in surgery is not a new phenomenon in Sub-Saharan Africa (SSA), and dates back to colonial times (Bergstrom 2015). More recent examples are described in academic publications and there has been increased attention during the last decade paid to task shifting as a promising solution for addressing human resource shortages. Mozambique has trained *Técnicos de Cirurgia* to perform advanced surgery since 1984 (Vaz 1999). This group of middle-level health care staff has generically been called "non-physician clinicians" and later "associate clinicians" (ACs), of which the latter terminology will be applied hereafter. Already in the 1990s, ACs performed as much as 90 % of all operations in Mozambique's district hospitals (Vaz 1999). Equal figures have been documented in Malawi (van Amelsfoort 2010).

Training ACs has been found to be four times as cost-effective as training MDs in Mozambique (Kruk 2007). Further, retention of ACs at district hospitals is superior to that of the MDs. Almost 90 % of ACs remained at a district hospital seven years after graduation, while all MDs had left (Pereira 2007). A qualitative study from Mozambique suggested that surgically trained ACs reduced unnecessary referrals, leading to lower costs and diminished workload for the referral hospitals (Cumbi 2007). In 2012, the WHO suggested that particular surgical tasks, like CSs, could safely be shifted to ACs if supervision and adequate monitoring were accessible (World Health Organisation 2012). A model developed by the LCoGS

estimated that expansion of the global surgical workforce to reach a minimum of 20 surgical providers per 100,000 inhabitants would decrease the overall cost and time to implement by 40 % if task sharing were applied (Meara 2015).

Surgical procedures in LICs are conducted by a wide variety of health workers, including specialist surgical providers, non-specialist MDs, midwifes, nurses and ACs (Meara 2015), and it is thought that task sharing is far more widespread than the literature suggests (Hoyler). A systematic review found 30 countries using task sharing in surgery (Federspiel 2015).

Quality of Care Offered by Task Sharing Surgical Providers

Each year, at least seven million people experience complications following surgery, with no less than one million deaths (Weiser 2015). It is estimated that as many as 50 % of these deaths and complications are preventable (Weiser 2008). There is an urgent need to both improve the monitoring and quality of surgical care in low-resource countries (Weiser 2015). A review of in-hospital deaths from a university teaching hospital in Zambia found that avoidability based on surgical factors was unchanged between 1987 and 2012 (Lillie 2015). Maintaining quality of care has been one of the main issues related to introducing task sharing in surgery in resource-poor countries (Galukande 2013, Bergstrom 2015, Meara 2015).

As safety of surgical care offered by task sharing surgical providers are an essential part of the thesis, a thorough review of the existing literature was carried out. 29 papers, including four systematic reviews, have to date documented outcomes of surgical procedures performed by ACs (**Table 1**). All 13 studies on emergency obstetric care and general surgery originated from LICs in SSA, while studies examining outcomes of abortion (4), circumcision (5) and tubal ligation (7) also included Asian and middle-income countries.

A systematic review indicated that trained mid-level providers may effectively and safely provide first-trimester surgical and medical termination of pregnancy services, however the data are limited, no randomized controlled trials have been carried out and potential bias from cohort studies made the conclusions uncertain (Renner 2013).

Table 1 Publications on outcomes of surgery performed by ACs

Subject	**(Author Year)**	**WB region**	**WB income group***
Abortion	(Jewkes 2002, Jejeebhoy 2011, Warriner 2006, Renner 2013)	SSA (2), S-Asia (2)	Upper-middle (2), Lower-middle (2)
Circumcision	(Ahmed 2007, Buwembo 2012, Frajzyngier 2014, Bailey 2007, Ford 2012)	SSA (4)	Low (2), Lower-middle (2)
Tubal ligation	(Chowdhury 1975, Dusitsin 1980, Gordon-Maclean 2014, Koetsawang 1981, Ghorbani 1979, Satyapan 1983, Rodriguez 2014)	S-Asia (1), E-Asia (3), SSA (1), M-East (1)	Lower-middle (1), Upper-middle (4), Low (1)
Emergency obstetrics	Malawi (Chilopora 2007, Fenton 2003), Ethiopia (Gessessew 2011), Burkina Faso (Hounton 2009), Tanzania (McCord 2009), Mozambique (Pereira 1996), (Wilson 2011) Zaire (White 1987)†	SSA (7)	Low (7)
General surgery	Tanzania (Beard 2014), Malawi (Tyson 2014, Wilhelm 2011) Mozambique (Vaz 1999), Zaire (White 1987)†	SSA (5)	Low (5)

WB: World Bank; SSA: Sub-Saharan Africa; S-Asia: South Asia; E-Asia: East Asia; M-East: Middle East

*(The World Bank 2016); **Bold: Systematic review and/or meta-analysis**: †Same publication;

Source: Ovid MEDLINE search using medical subject headings terms including "*Developing Countries*", "*General Surgery*", "*Surgical Procedures*" and "*Physician Assistants*" and "*Allied Health Personnel*" and "*Outcome Assessment (Health Care)*", plus keywords including "*essential surgery*", "*task shifting*", "*task sharing*", "*clinical officer*", "*mid-level health provider*", "*tecnico de cirurgia*" "*assistant medical officer*" and "*non-physician clinician*", with no language restrictions or publication dates was performed 15 December 2016.

A systematic review and meta-analysis, including 10 studies with a total of 25,119 circumcisions, concluded that task shifting of male medical circumcisions to ACs can be carried out safely, with reported rates of adverse events similar to MDs and specialists (Ford 2012). Nine studies of fair to poor quality reported on safety and acceptability outcomes of tubal ligations performed by ACs, but limited generalizability of findings, inadequate sample sizes, lack of statistical comparisons and no long-term efficacy determinants made the authors abstain from definitive conclusions (Rodriguez 2014). A meta-analysis of six controlled non-randomised studies with 16,018 patients evaluated the safety of ACs performing CSs - no significant differences in maternal or perinatal outcomes when comparing ACs and MDs were observed (Wilson 2011).

A retrospective review of 1,700 major non-obstetrical surgical procedures in Tanzania did not expose any significant variations neither in postoperative morbidity nor mortality following procedures performed by ACs compared with MDs (Beard 2014). A case-control study from Malawi that featured 1,186 operations performed on 1,004 paediatric patients where MDs performed 60 % and ACs 40 % found similar complication rates (4.5 % versus 4.0 %) and mortality rates (2.5 % versus 2.1 %), respectively (Tyson 2014). Another Malawian study that retrospectively reviewed 2,931 major general surgical procedures determined similar perioperative outcomes when ACs operated alone or together with a surgeon (Wilhelm 2011). The limited literature highlights the need and importance of further studies investigating the safety of surgical task sharing.

Aims

I. To estimate the met and unmet need for surgery in Sierra Leone by describing the amount of surgery performed during 2012 and comparing that against the need estimated by a survey in Rwanda in 2011 and another in Sierra Leone in 2012.

II. To identify all surgical providers in an entire LIC and to map the distribution and productivity of this surgical workforce.

III. To evaluate changes in non-Ebola admissions and provision of surgery during the first year of the EVD outbreak.

IV. To describe the setup of a surgical task-sharing programme in Sierra Leone, to assess the productivity and safety of the programme and to estimate its future role in contributing to surgical volumes in Sierra Leone.

Methodology

Materials

Papers I and *II* are based on data collected during a country-wide assessment of all health care facilities performing surgery under anaesthesia within an operation room in Sierra Leone in 2012. Facilities were identified by triangulation at three levels. First, all health care facilities registered by the Sierra Leone Medical and Dental Council, were included. Secondly, interviews with four key directors of the MOHS, including the Chief Surgeon at the main tertiary surgical teaching and referral hospital and the Liaison Officer for Non-Governmental Organisations, supplemented the records from the Medical and Dental Council. Thirdly, a selection of District Medical Officers was consulted to ensure that all district-based facilities were included. A surgical procedure was equivalent to *any procedure requiring anaesthesia, performed within an operation room and listed in its recording system* (Weiser 2008). Healthcare facilities performing surgical procedures were included if they performed one or more of the 21 surgical procedures (**Table 2**) listed as comprehensive in the WHO-developed health facility assessment tool, the Service Availability and Readiness Assessment (World Health Organisation 2012).

Table 2 Surgical procedures included in the Service Availability and Readiness Assessment tool

Hernia repair	Appendectomy
Urethral stricture dilatation	Vasectomy
Laparotomy	Cystostomy
Caesarean section	Episiotomy
Obstetric fistula repair	Repair of cervical and vaginal laceration
Tubal ligation	Tracheostomy
Skin grafting	Open treatment of fracture
Neonatal surgery	Congenital hernia repair
Cataract surgery	Clift lip repair
Amputation	Contracture release
Dilatation & curettage	

A total of 12 fourth- and fifth-year medical students from the University of Sierra Leone and the Norwegian University of Science and Technology (NTNU) visited 75 locations between January 14th and February 15th and May 10th and May 20th, 2013. All possible sources where operation room data were recorded were included and comprised of anaesthesia logbooks, maternity logbooks and surgical logbooks. Hospital characteristics and surgical provider information together with key data related to the surgical provider were also captured.

In *Paper III*, 21 Community Health Officers employed in CapaCare's STP (Ystgaard 2013) re-visited the same health care facilities surveyed in 2013 (*Papers I* and *II*) during the peak of the Ebola outbreak. Data pertaining to weekly accumulated non-Ebola admissions, inguinal hernia repairs, CSs and all combined operations were gathered from the same sources. The data were obtained from the first 38 weeks of 2014 during an initial visit to all hospitals in September the same year and later during bi-weekly visits until the end of May 2015, altogether totalling 72 weeks. The two most commonly performed surgical operations in Sierra Leone before the EVD outbreak (Bolkan 2015), inguinal hernia repair and CS, were selected for the study. Inguinal hernia repair is a predominantly non-acute surgical intervention conducted even in humanitarian crisis (Stewart 2015) while CSs are almost exclusively an acute operation in Sierra Leone (Chu 2012). Weekly numbers of new confirmed EVD cases were retrieved from the WHO (World Health Organisation 2016). Sierra Leone announced its first confirmed EVD case in week 21 of 2014. Week 1 to 20 of 2014 were considered before the outbreak, while week 21 of 2014 to week 20 of 2015 resembled the first year of the outbreak.

The material used in *Paper IV* is compiled from surgical logbooks every trainee and graduate of the STP use to track the operations they have performed or attended. It is mandatory to keep an updated personal surgical logbook for trainees, but voluntary for graduates. The logbook includes 20 variables with characteristics of the patient, the surgical procedure, the surgical provider and the hospital, as well as outcomes, such as in-hospital death, referral, postoperative infection and length of stay. Trainees and graduates can select four possible roles during a surgical procedure - observer, assistant, directly supervised or indirectly supervised. Observer is when seeing the surgical procedure without being washed sterile. Assistant is when helping within the operation field, but not primarily perform the procedure.

Directly supervised is when performing major parts of the operation, but there is assistance or guidance from a more senior surgical provider that also takes part in the procedure. Finally, the indirectly supervised category refers to a procedure performed independently with only limited guidance from a senior colleague that has **not** scrubbed or actively taken part in the operation. The trainees and graduates upload a digital version of their personal logbook on a monthly basis for compilation and quality control. Between January 2011 and July 2016, a total of 27,216 operations were recorded in the combined registry of operations.

Methods

Papers I, II and *III* are retrospective observational studies while *Paper IV* is a prospective observational study. *Papers III* and *IV* were prepared according to reporting guidelines suggested by the Enhancing the Quality and Transparency of Health Research (EQUATOR) Network. The Equator Network is an international initiative that seeks to improve the reliability and value of published health research literature by promoting transparent and accurate reporting and wider use of robust reporting guidelines (The EQUATOR Network). The *Strengthening the Reporting of Observational Studies in Epidemiology* (STROBE) checklist was employed for manuscript III (von Elm 2007).

Paper IV was prepared according to a newly suggested guideline for implementation and operational research (Hales 2016). *Reporting guidelines for implementation research and operational research* is currently under development by the Equator Network, of which, according to it, implementation research "*is rooted in the identification of practical problems facing disease control programmes and in finding solutions which improve access to health interventions and lead to better health outcomes*". Further, "*operational research uses an existing resource – the data routinely collected by programmes – to provide ways of improving programme operations and thereby delivering more effective, efficient and equitable care. Implementation and operational research are usually carried out in close collaboration between researchers and the disease control programme staff*" (The EQUATOR Network 2016).

The Need for Surgery

The need for surgery is a central element applied in *Paper I* and is required to estimate unmet need for surgery. Estimations were based on two population surveys from Rwanda (Petroze 2013) and Sierra Leone (Groen 2012) that had the objective of quantifying medical conditions that may require a surgical consultation or an intervention. In those similarly performed surveys, random population cohorts were asked about their perceived need for surgery the year preceding the interview. 13 % of the Sierra Leonean cohort and 14.8 % (95 % CI 13.3 - 16.5) of the Rwandan cohort reported to have developed a surgical condition. The Rwandan data equals an annual incidence of 14,800 (13,300 – 16,500)/100,000. Only the Rwandan survey included a severity rating of the perceived need of surgery, where 34.3 % of the surgical conditions were reported as disabling, e.g., to cause "significant shame" or "inability to work" and implied that the respondents "needed help" with daily activities or transportation. All self-reported surgical conditions likely did not require a surgical procedure within an operation room. The fraction of those with a disabling surgical condition might better reflect those in need of a surgical procedure and was applied to calculate the need in Sierra Leone. The annual need for surgery in Sierra Leone was therefore estimated from the annual incidence of surgical conditions with disabilities from the Rwandan study - 34.3 % of 14,800 (13,300 – 16,500)/100,000, which equals an annual need of 5,100 (4,562 – 5,660) per 100,000 inhabitants. The estimated need for surgery in Sierra Leone was 307,000 (275,000 – 342,000).

There are significant limitations to the previous calculations. First, a patient self-reported need for surgery is different from conditions in need of an operation as judged by a surgical provider. Even as the need for a surgical procedure was restricted to just include disabling surgical conditions, it might not reflect the true need for an operation. Our estimated need of an annual 5,100 operations per 100,000 inhabitants of Sierra Leone is, however, fairly consistent with the 6,495 surgical procedures per 100,000 population/year the LCoGS estimated for Sub-Saharan West Africa (Rose 2015). Knowing that Sierra Leone is among the least developed countries in the region, our estimated need for surgery was probably rather conservative.

Others have also utilised the need for surgery from incidence rates of surgical diseases and subtracted the met need as the volume of surgery performed in a given year to be able to estimate unmet need (Grimes et al. 2012), but still with substantial limitations as many

incidence rates applied in low-income settings are based on rates from high-income countries (Beard 2013). Yet, Bickler and colleagues introduced unmeetable need of surgery and defined it as *the disability and premature death in a population that is unpreventable or un-correctable with even the best surgical care available* (Bickler 2010). The latter assigned a DALY value to each surgical condition and a DALY-averted value to each surgical intervention and also included a measure of quality of surgical care. They argued that with this approach, it is possible to quantify the burden of surgical conditions along with the impact of surgical care. The underlying premise for their calculations was "*that surgically related DALYs within a population are determined by the incidence of surgical conditions and the quantity and quality of surgical care*" (Bickler 2010).

The methodology proposed by Bickler and colleagues is useful for obtaining a value for the impact of surgical care and would be more suitable if the aim was to compare different health care services. This methodology was not feasible for application within the resources available for this study as we would have needed to either measure or estimate the quality of operations performed in Sierra Leone. In addition, quality of operations is likely context-dependant and the concept of quality of surgical care is not well-defined or developed.

The Met Need for Surgery

As *Paper I* claimed to establish national rates for surgery in Sierra Leone, a further discussion on the methodology is relevant to justify this prerogative. The most obvious strengths of the study are the large inclusion of facilities known to perform surgery in Sierra Leone and the clearly delineated catchment population, which is the population of the country. A challenge for facility-based studies is often to establish reliable catchment populations as patients undergoing operations are willing to travel greater distances than nonsurgical patients to receive care at a rural hospital (Faierman 2015). The triangulation at three levels to identify facilities possibly performing operations may also be considered a strength. The three levels were the most relevant local experts at the central and district level as well as the national regulatory body. Whenever any of those were in doubt if surgery was performed, the facility was contacted either by phone or through a physical visit.

The limitation is that the method applied will not capture operations performed outside legal health care facilities. The most likely procedure conducted outside regulated health care facilities would be unsafe abortion, which is reported to occur at rates of 18 to 39 per 1,000

women in SSA (Rasch 2011). Another surgical procedure probably underestimated in our material is ritual circumcision. Additionally, Sierra Leoneans having their operations performed outside the country were not captured with this methodology. Surgical providers from hospitals nearest to the borders of neighbouring countries were asked about cross-border travel for surgery. This was reported as rare, though its extent was not quantified. Among patients with a known residential address, less than 2 % were foreigners, which makes cross-border travel in to Sierra Leone for operative care also negligible. An alternative approach to a retrospective facility study would be either a prospective registration or a community household study examining surgical procedures. Those approaches were not available because of resources, and a community study would also feature recall bias.

The operation room log book, often equal to the surgeon's personal log, is by some considered the gold standard for records of surgical procedures (Holt 1998). Individual recording habits will evolve, nevertheless, and may serve as a source of bias. As our methodology included three different sources for obtaining data on operations performed, irregularities in recording routines might have been less likely in this study. Duplicates were removed but inconsistencies between the records could also lead to the same procedure being included more than once.

Human Resources

Human resources are, among most health workforce indicators and publications, quantified as a headcount and reported by population rates, typically by 1,000 or 100,000 inhabitants (Meara 2015, Hoyler 2014, World Health Organisation 2016). Comparable national inventories from LICs apply the same unit of measure (Iddriss 2011, Lebrun 2012, Choo 2010). In Sierra Leone, we found headcount inadequate as many surgical providers had multiple part-time positions at different work locations, while others, particularly the private non-profit organisations, had variable availability of surgical providers. With headcount, we faced the possible bias of counting the same individual several times. To obtain a more granular overview of the surgical workforce in Sierra Leone, surgical providers were quantified as full-time equivalent positions (FTP), meaning a time dimension was also added to the headcount. A full-time position available for one year was considered one FTP. A full-time position for six months and a half-time position for one year both counted as 0.5 FTP. With this unit of measure, productivity could be defined as the volume of surgical procedures performed within a time period per FTP available during the same time period. By applying

FTP to quantify human resources, it was also possible to calculate the distribution of surgical providers between different actors more accurately. A limitation to this approach was that individual surgical providers could overestimate the time spent in each location, where all positions combined for one surgical provider often were found to be greater than one FTP. On the other hand, given the extreme shortage of surgical providers in Sierra Leone, many will likely work more than one full-time position.

In *Paper II*, a surgical provider was defined as any health care worker who performed operations and had been listed as the primary operator in the operation room records. This definition could be perceived to be narrower than that suggested by Debas and colleagues, which was any "*health professional trained to provide surgical care…"* (Debas 2006). As surgical care is any "*measure that reduces the rates of physical disability or premature death associated with a surgical condition*" (Bickler 2010), non-operating health care providers could also be included if they primarily worked with surgical patients. The two different definitions applied will likely have limited implications as the understanding of Debas's definition seems to be health care workers actually carrying out surgical procedures.

Surgery and the Health System During the West African Ebola Outbreak

Any health system performance metric needs to be measurable, locally relevant, reliable and valid as well as feasible to implement (Kruk 2008). Because of its complexity, the provision of surgery signals the presence of the '*staff, stuff, space and systems*' of a hospital (Meara 2015). Provision of surgery might, for this reason, be a relevant indicator for the hospitals' capacity to deliver a broader range of services. Many of the elements required for surgery are part of a shared delivery infrastructure that is the basis of hospital functioning (Kim 2013), so surgery could be a relevant indicator of hospital functioning during humanitarian crises in resource-constrained areas when more comprehensive tools are not able to be applied. Volume of surgery is a reliable proxy-indicator because a surgical procedure is clearly defined, easy to identify and often uniformly recorded in operation room logbooks at a limited number of health care facilities (Bolkan 2015). The bellwether procedures - CSs, laparotomies and management of open fractures - were already suggested and applied as proxies for health systems' capacity to supply services for a broader range of surgical disease categories (Meara 2015, Stewart 2016). With this, in an attempt to assess the EVDs' effects on service provisions in hospitals in Sierra Leone, our hypothesis was that provision of surgery could be

a feasible and relevant indicator of the hospitals' capabilities to deliver a broader range of services.

Safety

A goal of *Paper IV* was to evaluate safety of the STP and operations performed by task-shared surgical providers. Safety was determined based on two comparisons:

i. Crude in-hospital mortality of CSs and laparotomies performed by trainees and graduates of the STP (Surgical Assistant Community Health Officers; SACHOs) under indirect supervision was compared against previously published mortality of the same procedures from Sierra Leone and comparable low-recourse settings.
ii. Adjusted for patient age, sex, urgency of the operation, type of procedure and hospital owner, crude in-hospital mortality of all operations performed by trainees and SACHOs under indirect supervision was compared against operations performed by the trainers and the supervisors of the programme.

The landmark report, *Safe Surgery Saves Lives*, by the World Alliance for Patient Safety, which also introduced the WHO Surgical Safety Checklist, suggested the number of in-hospital deaths following surgery as vital statistics for monitoring safety of surgical services (World Health Organisation 2008). In-hospital postoperative mortality is defined as *inpatient deaths following surgery divided by the number of operations performed,* which makes this the crude postoperative mortality. The surgical log books of trainees and SACHOs included several other outcomes variables, like postoperative surgical site infection, length of stay, reoperation and referral. When evaluating the safety of the STP in *Paper IV*, we chose to employ crude in-hospital mortality rates as the measure of safety because it is a more reliable endpoint than morbidity events. Surgical site infection was discarded because it could only be based on clinical judgement in an extreme low-resource environment, such as Sierra Leone. Length of hospital stay was another option for an indicator, but also with limitations, most notably non-medical reasons for prolonged inpatient stay after surgery. Lastly, mortality is the most applied indicator of surgical quality and permitted a comparison with reports from similar low-resource settings (Ng-Kamstra 2015).

The limitation of crude postoperative mortality is that it includes all causes of death, including those not related to the performance of the surgical provider, such as anaesthesia-related deaths and non-surgical complications like pneumonia, sepsis and thrombose-embolic events.

As opposed to crude mortality, a more detailed cause-specific mortality might have been an option, though it would have required a different methodology where all deaths would needed to have been evaluated by verbal autopsy. This was not possible given the large number of hospitals and the considerable volume of operations included over many years.

Morbidity events related to the surgical procedure may offer a better causal relationship to the performance of the surgical provider, however a comparison between different cadres of surgical providers was not the aim of this study and the applied methodology was therefore not suitable for such comparison. Restricting observation to in-hospital events underestimates mortality compared to 30-days postoperative mortality that was applied in one study comparing safety in *Paper IV* (GlobalSurg 2016). *Paper IV* is solely based on in-hospital events, which we contend makes sense considering the very minimal resources available in a low-resource environment with poorly maintained death registries. The vast majority of studies utilized for comparison of postoperative mortality following CSs are also based on in-hospital events alone (Chu 2015, McConkey 2002, Uribe-Leitz 2016, Hoestermann 1996, Landry 2014, Ozumba 2002, Okafor 2005, Okezie 2007, Oladapo 2007).

In order to allow comparisons with other studies and limit the effects of different case mixes, we used CSs and laparotomies for further investigation. CSs were relevant because it is among the most commonly performed surgical procedure in LICs, just as stated before (Weiser 2016). Laparotomy was pertinent because of the high-risk nature of the procedure. Postoperative mortality is frequently a rare event in surgery, rendering it less valuable for safety comparisons, however all laparotomies in the material applied in *Paper IV* recorded 9.7 % (229/2,368) postoperative deaths, which makes it a relatively common occurrence.

Another limitation in terms of comparisons to other studies was the shortage of previous studies from Sierra Leone – at present, only one study reported mortality following CS (Chu 2015) and there was just one for laparotomies, as well (McConkey 2002). Mortality after CSs were therefore also compared with 19 publications from SSA (Landry 2014, Ministry of Health 2012, Kaboro 2012, Fesseha 2011, Hoestermann 1996, Fenton 2003, Chilopora 2007, Ozumba 2002, Okafor 2005, Okezie 2007, Oladapo 2007, Rahlenbeck 2002, Imbert 2003, Sorbye 2011, Maaloe 2012, Litorp 2014, Sekirime 2008, Glenshaw 2005, Rutgers 2008). However, the range of reported mortality increased considerably, ranging from 0.4 % in Burkina Faso to 4 % in Chad. Mortality after laparotomies were compared with a multi-

country low-human development index setting (GlobalSurg 2016). Other limitations to the comparisons with other studies were the potential differences in patient cohorts and factors known to affect surgical outcomes, such as access to surgical services, quality of anaesthesia provided, pre- and postoperative management and several other matters related to safety in surgery (World Health Organisation 2008).

Comparing in-hospital mortality of operations performed by the trainees and SACHOs with similar procedures conducted by the trainers and supervisors needs to be interpreted with caution. The methodological strength is the large cohort of operations included, (7,027 indirectly supervised surgeries performed by trainees and SACHOs) which makes this, to our knowledge, the second largest study evaluating outcomes after surgery performed by ACs (**Table 8**) described in the literature. Another strength is the adjustment for the potential confounders: age, sex, surgical procedure, urgency and hospital owner. Only two other studies (Beard 2014, Fenton 2003) examining outcomes of operations performed by ACs adjusted for confounders (**Table 8**).

Procedures performed by trainers and supervisors as a reference for safe surgery is prone to selection bias because comorbidities and severity of the surgical condition were not adjusted for. As a result, we consider this analysis inappropriate for comparing surgical performance between trainees, SACHOs and trainers, but more suitable as an assessment of how operative risks were distributed between task-shared providers and their supervisors/trainers. We chose to include this in the analysis of safety for two reasons: i) there are just a few existing studies reporting postoperative mortality for CSs and laparotomies from Sierra Leone; and ii) the comparison may serve as an indication of how operative risks were distributed within the training programme and between the newly graduated SACHOs and their supervisors. Safety in surgery is much about an active selection of which patients to operate on, who will perform the surgery, when and where. An active selection where high-risk operations are directed to the most competent providers is a necessary and desired practise. Although this methodology is not suitable for comparison of mortality between the supervision groups, it might be a relevant indirect measure of safety of the programme itself and the introduction of a new group of surgical healthcare providers.

Lastly, an important methodological limitation in *Paper IV* was that the surgical providers themselves collected their own outcomes data. If selective underreporting of one's own

negative outcomes took place, it would certainly constitute a bias. Yet, supervisors and trainers reviewed and signed a paper version of the logbook subsequent to the procedures, which should have counteracted this to a certain extent.

Statistical Analysis

Data were analysed using Statistical Package for the Social Sciences (SPSS) release 21 to 23 for Macintosh (IBM Corp., Armonk, NY), R version 2.13.1 (R Foundation for Statistical Computing, Vienna, Austria), and Stata version 13.1 (StataCorp, College Station, Texas). *Paper I* relied primarily on descriptive statistics, where health care facilities were presented as absolute numbers and fractions, while surgical productions were presented as median rates per 100,000 population, including interquartile ranges. *Paper II* is also mainly descriptive with absolute numbers and fractions. Human resource density (surgical providers per 100,000 population) and productivity (surgical procedures performed per time unit) were introduced. The χ^2 test for trends was applied to evaluate if working in rural areas decreased with higher degrees of specialization. Spearman's rank correlation testing was used to explore the relationship between the rate of surgery, density and productivity of surgical providers.

The non-parametric Wilcoxon rank-sum test (Mann-Whitney U-test) was employed in *Paper III* to determine if there were differences in weekly admissions or the volume of operations conducted before and during the Ebola outbreak. Weekly admissions and volume of surgery varied considerably during the outbreak and were not normally distributed. The more efficient student's t-test to verify the null hypothesis of equal volumes of surgery before and during the outbreak could not be applied.

The Pearson χ^2 test was utilised to evaluate the differences in volumes of surgery between trainees and SACHOs and the risk of in-hospital mortality in *Paper IV*. The risk of in-hospital mortality was analysed both by univariate and multivariate logistic regressions models with adjustments for supervision status during the surgery, patient gender, emergency surgery, surgical procedure and hospital owner. Estimates of odds ratios were accompanied by 95 % confidence intervals (CI). The age of patients was reported as mean including standard deviation and compared between groups with a two-sample t-test. All tests were two-tailed and statistical significance was set at $p < 0.050$.

Ethical Considerations

This section explores ethical considerations from two perspectives - the introduction of task sharing in surgery from a programme perspective and relevant ethical dilemmas within operational research. How research ethics were dealt with in each paper included in this thesis is also addressed. Ethical considerations within operational research is discussed, partly because *Papers I, II* and *IV*, if combined, can be seen as a larger project implementing surgical task sharing in Sierra Leone, partly because *Paper IV* has strong elements of implementation research and lastly because ethics within operational and implementation research is a novel and emerging field (Gopichandran 2016).

Introduction of Surgical Task Sharing

The development and introduction of a new health profession, equipped with a high-risk tool to be applied on vulnerable, often illiterate patients, raises several ethical questions. As it is outside the scope of this thesis to discuss all aspects of the ethical challenges related to the introduction of task sharing, features related to safety will be focused on.

In a system with substantial shortages of surgical health care providers, is it ethical to accept poorer outcomes in order to increase coverage? This question might also be rephrased: In settings with low coverage of life-saving surgical interventions, is it ethical to discourage a solution that increases the coverage because outcomes might be poorer than those with the existing services? Several elements are present in those questions; given the existing outcomes of surgical services are poorly evaluated in Sierra Leone, what benchmarks for quality are sensible to be applied? As increased access to surgery is the goal of the task sharing initiative, and there hardly exists any surgical service in several of the areas this programme seeks to reach, what existing surgical services are relevant for comparison?

If the outcomes of SACHOs are equal or better than those with the existing service, there may be less ethical concerns surrounding introducing surgical task sharing in Sierra Leone. Assuming the outcomes of the operations performed by the SACHOs are less robust than for the MDs, is it still ethical to introduce the strategy? From a health system perspective, it is relevant to balance gains against costs. It is not arbitrary to assume that obstetric emergencies with a maternal indication for CS has far higher mortality untreated compared with post-CS mortality. At population level, gains from improved access of the operation may outweigh

potential higher mortality if performed by a SACHO. With this perspective, and the fact that several studies actually suggest similar mortality for MDs and ACs with regards to CSs (Wilson 2011), it seems like the rephrased question at the beginning of this chapter is more conducive to the reality. Provided the mortality gains, it is also pertinent to ask the same question for morbidity, albeit morbidity consequences from introducing surgical task sharing have been far less explored. A systematic review found elevated wound dehiscence for ACs performing CSs compared with MDs (Wilson 2011). Presumptuous gains in mortality, how many more instances of wound dehiscence and other morbidities is the system willing to accept?

For the sake of this exercise, we are still assuming poorer outcomes for ACs compared with MDs, but consider the patient perspective. Applying the same assumptions as before, a pregnant woman would have higher chances of surviving her pregnancy within a task sharing model because of the gains from increased access to life-saving services. Yet, she will have slightly poorer outcomes if she ends up being one of those needing the operations. Herd versus individual trade-offs are common for health interventions and this example resembles many of the same dilemmas experienced by administrators of vaccines or screening programmes. Public health benefits need to balance potential individual harm. Individual side effects from vaccines or unnecessary mastectomies because the screenings detect breast cancer, which turn out not to require surgery, include many of the same types of ethical considerations.

In *Paper IV*, in-hospital mortality following operations performed by trainees and SACHOs were compared with those carried out by their supervisor. Task-shared providers are not mandated to replace fully qualified specialists or additional trained non-specialist medical doctors. Rather, task-shared providers are developed within this programme as an addition to the very limited existing surgical workforce. In that sense, one may argue that quality of care provided by the SACHOs could be compared against the current practice, where at some of the most rural district hospitals, virtually no surgical treatment exists (Bolkan 2015). The latest update from the World Medical Association Declaration of Helsinki (World Medical Association 2013) states that "*the benefits, risks, burdens and effectiveness of a new intervention must be tested against those of the best proven intervention(s), except where no proven intervention exists, the use of no intervention, is acceptable*." One may interpret "*best proven intervention*" as not necessarily including world-class treatment options, but what is

regionally or locally available (Nuffield Council on Bioethics 2005). Truthfully, surgical services are available in Sierra Leone, but are not very accessible for many living in rural environments. Is it then reasonable to compare the best proven accessible interventions? This is also further complicated in particular from a financial point of view as many within a community may have financial access while others do not. The ethics of introducing sub-standards of care to enhance access is not answered. We found it however necessary to evaluate outcomes of operations performed by SACHOs and compare them with the best available local treatment options with the hope of informing those discussions at the policy level. Given that access to surgical services varies, such comparisons were considered relevant from an ethical point of view. It is also appropriate to question the pertinence of those ethical considerations in this particular case. As the methodology presented in study IV was that of an observational study and not a trial where interventions are tested, the strict guidelines of the Declaration of Helsinki may not apply.

Ethics Within Implementation and Operational Research

Clinical research aims to answer a pre-determined clinical question within a controlled environment comparing well-defined cohorts with strict inclusion and exclusion criteria. As the goal of implementation research is to develop knowledge that could initiate further dissemination of similar interventions in novel environments, the priority focus is different (Special Programme for Research and Training in Tropical Diseases (TDR - WHO) 2014). Implementation research is often executed in real-world scenarios and seeks to evaluate feasibility and effectiveness of an intervention in real-life conditions, therefore the boundary between research and clinical care/public health practice can be quite blurred (Gopichandran 2016).

Implementation research must include a broad range of research subjects, explicitly comprising vulnerable peoples to enhance justice and equity in access to the intervention. The ambition of implementation research is often to develop knowledge that can be transformed into health policy and health action, and therefore studies must be conducted with the vision of sustainable scale-up and roll-out of effective interventions (Gopichandran 2016). Consequently, all surgical procedures performed by all participants enrolled in the programme were included in *Paper IV* along with all trainees that exited the programme prior to completion.

Within clinical research, the study participants are often able to balance benefits and risks before consent is granted and the hazards are most often conveyed to the study participants. The risks related to implementation research are far more complex up-front because interactions between various components of the health care system are hard to predict (Lange 2014). This was obviously the case within this project as the development of the programme, its acceptability, and how it would interact with the surgical health system was highly uncertain.

Informed consent and the opportunity to withdraw from a study is another central element of clinical research (World Medical Association 2013). Operationalizing informed consent is often difficult within implementation research (Gopichandran 2016). In *Paper IV*, consent was obtained at two levels - from hospitals and institutions where operations were conducted and from trainees and SACHOs. Consent was garnered at the hospital level partly because the introduction of surgical task sharing in Sierra Leone had the objective of increasing the provision of surgical services at the hospital level. Furthermore, all surgical procedures carried out by trainees and SACHOs were supervised by an MD, which also then resumed responsibility for the quality and outcomes. Trainees and graduates consented because they were directly tested. One may claim that the main risks were taken on by the individual patients who had their operation performed by a new surgical provider. However, the aim of this work was to assess the safety of the intervention, where the onus for quality of care was on the individual hospitals and its surgical practitioners, and as a result, it was thought to be unnecessary to obtain consent from individual patients.

It is considered ethically significant that implementation research strives for horizontal assimilation of public health interventions into the health system such that a project empowering any component of the health system may have positive outcomes for the entire system (Gopichandran 2016). The STP programme focused on many key elements of surgical care, from planning and organisation of surgical services to minimum standards of equipment and consumables, prevention of infections not only in the operating room, but within all facets of patient care. All these elements were not measured within the present study, though should contribute to an empowering of a hospital health system beyond the provision of surgical procedures.

Strategies and steps with the objective of transforming research findings into health policy are fundamental to implementation research (Pratt 2015), and it is also deemed a moral imperative to propagate the research outcomes broadly (Wyber 2015). To meet those obligations, most of the papers featured within this thesis were presented on several occasions to a broad range of stakeholders in Sierra Leone, regionally in West Africa, at the national level in Norway and globally.

Research Ethics Related to Papers I-IV

The main ethical considerations in relation to *Papers I and II* were related to the very scarce resources available for preventive and curative health care activities and if it would be ethical to use them for mapping and describing the health care system. A mapping of surgical activity and surgical provider resources in Sierra Leone was anticipated to supply the MOHS and international community with important knowledge that could serve as a basis for taking necessary measures to bolster surgical services. Risks for the research participants were determined to be non-existent. Patient identifiable information was not recorded and did not pose any disadvantages or possibilities of being recognized. There were risks such that certain information provided by surgical health care providers could be traced back to individuals' or individual hospitals as some districts had very few surgical providers and only one hospital. Written consent was, for this reason, obtained from all individual health care providers and from directors or in-charges of the health care facilities. The potential benefits from a nationwide mapping of surgical volumes and human resources were considerable and there were limited to no risks or inconveniences for patients, healthcare facilities or healthcare providers. The Sierra Leone Ethics and Scientific Review Committee and the Regional Committee for Medical and Health Research Ethics in Central Norway (No: 2012/2,187) ultimately granted ethical clearance for the study.

For *Paper III*, the data were collected retrospectively from routine health care registers and anonymized, and patient consent was not considered necessary. The Director of Hospitals and Laboratory Services and the Director of Research and Non-Communicable Diseases, the two most relevant and senior directors of the MOHS, approved the study. They facilitated the data collection with a formal letter from the MOHS in which they encouraged all hospitals to share what we requested. It was highlighted that the risks for data collectors had to be minimized; hence, data collection needed to be safe, rapid and cost-effective. As professional health care workers, the data collectors had, prior to the hospital visits, received training in infection

prevention control and were equipped with personal protective equipment. The registry books were kept in separate rooms from patients; hence, the data collectors were not exposed to symptomatic patients potentially infected with EVD. As public transportation posed the highest risk of accidental EVD exposure, the data collectors were provided with a travel allowance to ensure safe movement.

For *Paper IV*, all hospitals taking part in the STP as well as the trainees and graduates signed an informed consent form to share non-identifiable surgical log book data for research purposes. This consent was given when trainees and partner hospitals were introduced to the training. Ethical approval from the Sierra Leone Ethics and Scientific Review Committee to publish the data was granted in November 2016. The study is based on non-identifiable, routinely collected programme activity data and there were no potential risks characterized related to the acquisition of the data used in the study.

Results

Paper I

From a total of 164 locations where surgical operations possibly could occur, 89 were excluded because they did not perform surgical procedures (**Figure 3**). The 75 remaining locations were visited and among them, 15 turned out not to carry out surgery of any kind. The number of health care facilities in Sierra Leone offering surgical services in 2012 was 60, of which 58 (96.7 %) institutions had records of operations performed and were willing to share the data. Of the remaining two facilities, one was a private clinic that only conducted operations during the last month of 2012 and thus had not implemented a data collection tool, while the other was a private clinic not willing to share their data.

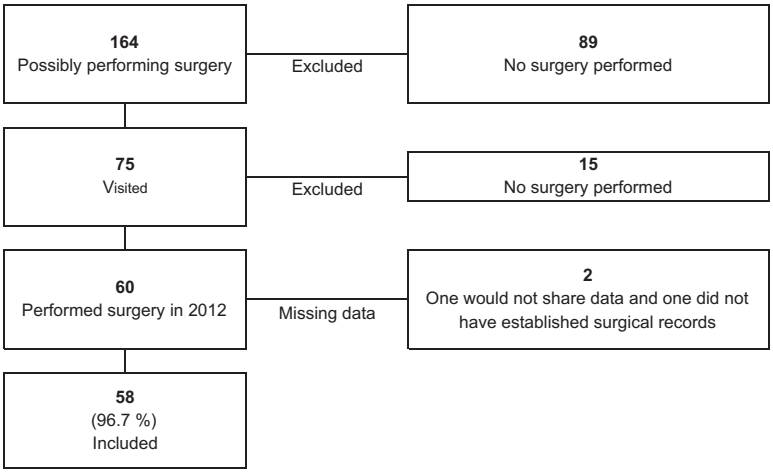

Figure 3 Process to identify health care facilities performing surgery in Sierra Leone in 2012

A total of 24,152 surgical procedures were recorded in 2012, equal to 400 operations per 100,000 population, of which 54 % were performed in private non-profit facilities, 40 % in governmental hospitals and the remaining 6 % in private for-profit institutions (**Table 3**). When comparing the estimated need of 5,100 surgical procedures per 100,000 population (Petroze 2013, Groen 2012) with surgical volume performed, a total of 92 % were unmet in Sierra Leone in 2012. To put it differently, only 8% of needed operations in Sierra Leone were actually conducted throughout that year. More than 65 % of all operations performed in governmental hospitals were either a hernia repair, appendectomy or a CS.

Table 3 Operations performed in 2012; estimated need and unmet need for surgery

	n	(%)	Rate*
Population (2012)	6,039,000		
Need for surgery†	307,000	(100)	5,100
Operations performed (Met need)	24,152	(7.9)	400
Private non-profit	13,050	(54.0)	
Private for-profit	1,537	(6.4)	
Governmental	9,565	(39.6)	
Operations not performed (Unmet need)	283,000	(92.1)	4,700

*Surgeries per 100,000 population; †Kwon et. al, 2013

The rates of surgery differed 30-fold between the most- and least-served districts (**Figure 4**). The district Western Area, including the capital Freetown, had the greatest coverage. Surgical operations within governmental hospitals were performed in all but one district, while the private non- and for-profit facilities performed the majority of the surgery in five and three districts, respectively.

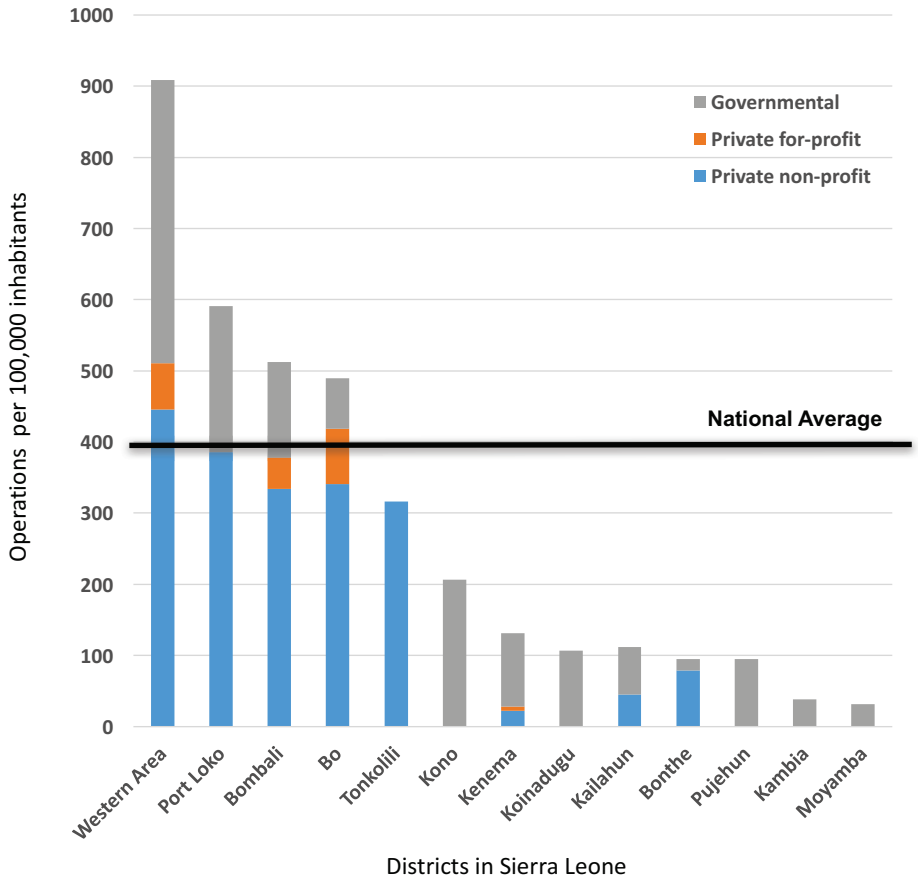

Figure 4 Rates of surgery by district in Sierra Leone

Most orthopaedic operations (86.3%, 2,224/2,576) were performed in the private non-profit sector. Monopolization of operative treatment of fractures was even more pronounced as 96 % (872/906) of those operations were conducted in the private non-profit sector. 65 % (6,098/9,383) of the operations in the governmental sector were either a hernia repair, CS or an appendectomy.

Paper II

The surgical workforce in Sierra Leone in 2012 comprised of 164.4 FTPs, of which 35.6 % were surgical specialists, 52.3 % were non-specialist MDs without specialist training, 3.8 % were nurses and 8.4 % were ACs (**Table 4**).

Table 4 Surgical provider FTP, density, volume of surgery, and productivity by hospital owner and urban/rural location

	All	Specialist MD	Non-Specialist MD	Nurse	Associate Clinician
	Surgical Provider FTP (%)				
Owner					
Governmental	76.3 (46.4)	21.3 (36.3)	50.1 (58.2)	2 (32.4)	3 (21.8)
Private non-profit	71.8 (43.7)	26.4 (45.2)	32.6 (37.9)	4.1 (66.2)	8.8 (63.6)
Private for-profit	16.2 (9.9)	10.8 (18.5)	3.3 (3.9)	0.1 (1.4)	2 (14.5)
Urban/Rural					
Urban	123.6 (75.2)	53.2 (90.9)	60.6 (70.4)	4.1 (66.2)	5.8 (41.8)
Rural	40.8 (24.8)	5.3 (9.1)	25.4 (29.6)	2.1 (33.8)	8 (58.2)
Total	164.4 (100)	58.5 (35.6)	86.0 (52.3)	6.2 (3.8)	13.8 (8.4)
			Density		
Urban/Rural					
Urban		3.21	3.65	0.25	0.35
Rural		0.12	0.58	0.05	0.18
Total		0.97	1.42	0.10	0.23
			Volume of Surgery (Productivity)		
Owner					
Governmental	9,408 (2.4)	3,091 (2.8)	5,700 (2.2)	406 (3.9)	211 (1.4)
Private non-profit	12,749 (3.4)	6,999 (5.1)	3,481 (2.1)	1,148 (5.4)	1,121 (2.5)
Private for-profit	1,536 (1.8)	1,082 (1.9)	147 (0.8)	20 (4.6)	287 (2.8)
Urban/Rural					
Urban	17,100 (2.7)	8,825 (3.2)	5,970 (1.9)	1,054 (4.9)	1,251 (4.1)
Rural	6,593 (3.1)	2,347 (8.5)	3,358 (2.5)	520 (4.8)	368 (0.9)
Total	23,693 (2.8)	11,172 (3.7)	9,328 (2.1)	1,574 (4.9)	1,619 (2.3)

FTP: Full Time Eqvivalent Position; Density: FTP per 100,000 inhabitants; Productivity: weekly operations per FTP

In 2012, Sierra Leone had five urban settlements, which are defined as those with more than 50,000 inhabitants (United Nations Centre for Human Settlement 2001), namely Kono, the three regional centres, Bo, Makeni and Kenema, and the capital, Freetown (**Figure 7**). 62 %

(36/58) of the healthcare facilities performing surgery were located in these centres. Less than one-quarter (24.8 %) of the total workforce worked in rural areas.

Although three-quarter of all surgical providers worked in urban areas, the maldistribution of human resources was more pronounced when reported as densities. **Figure 5** shows that the density of surgical providers in relation to population size was eight-fold higher in urban compared to rural areas.

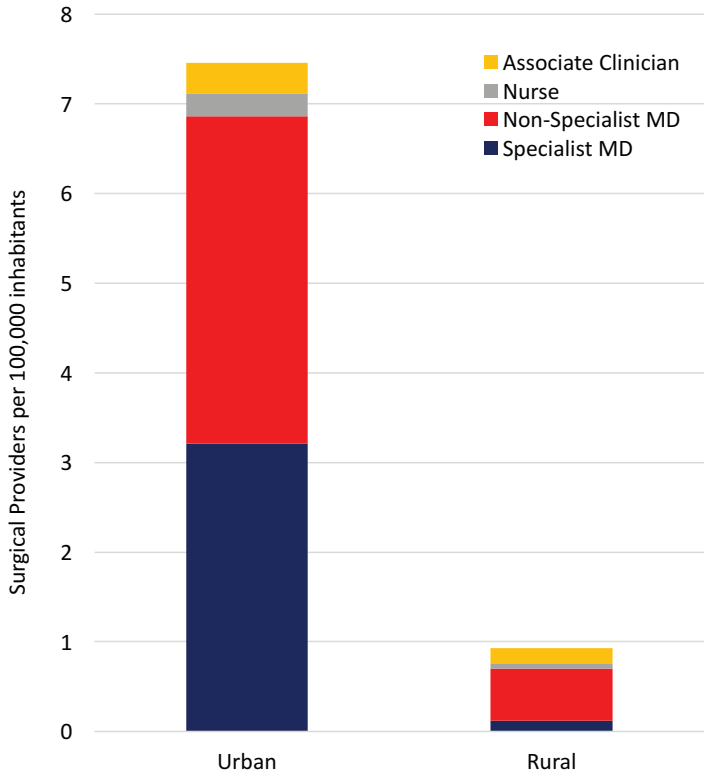

Figure 5 Surgical provider density in urban and rural areas

There was a significant ($p < 0.001$) preference for working in urban areas as one gained more advanced medical qualifications (**Figure 6**).

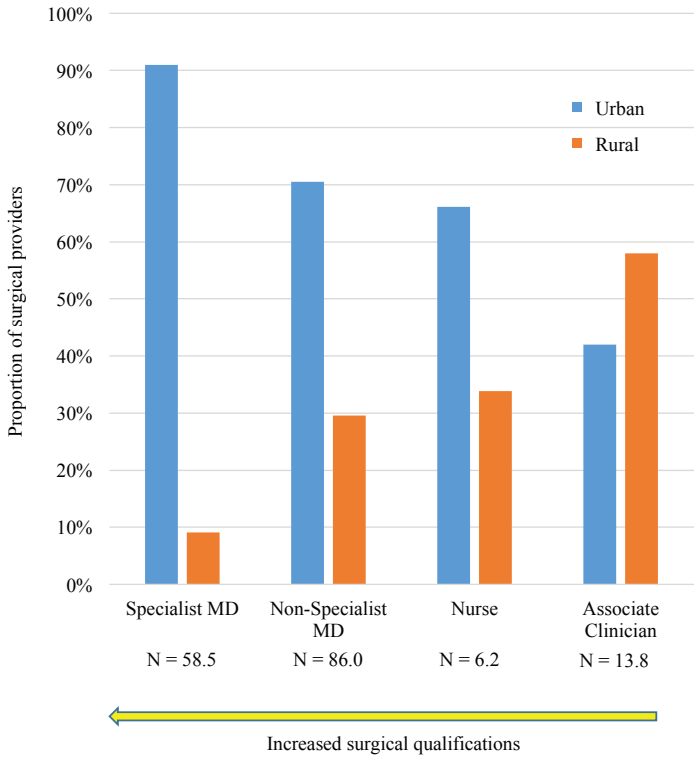

Figure 6 Proportion of surgical providers and level of qualifications by urban and rural areas

Productivity

The survey was able to classify the cadre category of surgical providers in 23,693 (98.1 %) of the operations documented. The mean productivity for all surgical providers was 2.8 weekly operations (**Table 4**). Nurses performed 4.9 weekly surgical procedures and were the most productive. In contrast, non-specialised MDs conducted 2.1 weekly procedures. Nurses carried out a high number of cataract operations, which to a large extent may explain their high productivity. Specialists working in rural areas performed 8.5 operations per week, more than double their peers in urban areas (3.2/week). The opposite was observed for ACs, who were more than four times as productive in urban areas (4.1/week) compared to their colleagues in rural areas (0.9/week). Urban-to-rural differences were not found for non-specialist MDs or nurses.

Paper III

Only healthcare facilities classified as hospitals in the 2012 data collection (*Papers I* and *II*) were eligible in *Paper III*. From 42 hospitals performing in-patient surgery in Sierra Leone in 2012 (Bolkan 2015), 40 (95 %) were included in this analysis. The hospitals that constituted this sample performed 98 % of the national volume of operations in hospitals in 2012 (Bolkan 2015). Patient records were available in 96 % (2,759/2,880) of the investigated 72 weeks (January 2014 to May 2015). All 14 districts in Sierra Leone were represented among the included 40 hospitals.

Admissions

91,399 non-Ebola admissions were recorded; 36,379 in 20 weeks before the EVD outbreak in 2014 and 55,020 during the first year (**Table 5**). There was an overall 51 % ($p < 0.001$) reduction in non-Ebola admissions during the EVD outbreak (week 21, 2014 to week 20, 2015) compared with before the onset (week 1 to 20, 2014), where, it was observed that males experienced a larger decrease (55 % versus 50 %, $p < 0.001$) versus females. The governmental hospitals had diminished admissions by 45 %, significantly less ($p < 0.001$) than the 60 % reduction observed at private non-profit hospitals. Governmental hospitals accounted for 57 % (20,676/36,379) of the admissions before and 63 % (34,418/55,020) during the outbreak. Meanwhile, private non-profit hospitals accounted for 41 % (14,856/36,379) of the admissions before and 36 % (19,912/55,020) during the outbreak.

Surgery

A total of 20,187 surgical operations were recorded in the 40 hospitals during the study period between week 1, 2014 to week 20, 2015. Out of those, 8,061 were performed during the first 20 weeks of 2014, e.g., before the onset of EVD, while 12,126 were conducted the consecutive 52 weeks, accounting for the first year of the outbreak. No differences in surgical volume was noted when comparing the 20 weeks before the EVD outbreak of 2014 with similar institutions and the weeks of 2012 (weekly median: 407 vs. 397, $p = 0.552$). During the EVD outbreak's first year, the hospitals, in total performed 41 % ($p < 0.001$) fewer operations compared to 2012. The drop in surgical volume over the first year of the EVD outbreak was larger at private non-profit hospitals when compared with governmental facilities (53 % versus 31 %, $p < 0.001$).

Table 5 Admissions and surgical procedures performed before and during the EVD outbreak

	Before EVD	EVD	Change*	Z
	n (Weekly Median)		*%*	
Admissions	*Week 1-20/2014*	*Week 21/2014 - 20/2015*		
All hospitals (40)				
Total	36,379 (1804)	55,020 (880)	-51	-4.7†
Female	20,227 (1013)	32,141 (511)	-50	-4.7†
Male	16,151 (812)	22,879 (366)	-55	-4.8†
Governmental (19)				
Total	20,676 (1019)	34,418 (565)	-45	-4.8†
Female	12,433 (610)	21,238 (353)	-42	-4.8†
Male	8,243 (403)	13,180 (226)	-44	-5.0†
Private non-profit (17)				
Total	14,856 (732)	19,912 (291)	-60	-4.7†
Female	7,401 (368)	10,514 (155)	-58	-4.6†
Male	7,454 (372)	9,398 (127)	-66	-4.7†
Private for-profit (4)				
Total	846 (44)	690 (0)	-100	-4.6†
Female	392 (18)	389 (0)	-100	-4.6†
Male	453 (22)	301 (0)	-100	-5.1†
Surgical Procedures	*52 weeks in 2012*	*Week 21/2014 - 20/2015*		
All hospitals (40)				
All surgeries	19,670 (383)	12,126 (227)	-41	-7.1†
CS	4,598 (87)	4,718 (91)	5	-0.2, $P = 0.820$
Inguinal hernia repair	4,502 (90)	1,846 (30)	-67	-8.0†
Governmental (19)				
All surgeries	9,441 (182)	6,628 (125)	-31	-6.3†
CS	2,602 (49)	3,523 (71)	45	-5.8†
Inguinal hernia repair	2,593 (50)	1,101 (19)	-62	-7.7†
Private non-profit (17)				
All surgeries	9,689 (188)	5,331 (88)	-53	-6.7†
CS	1,854 (35)	1,163 (20)	-43	-6.6†
Inguinal hernia repair	1,775 (36)	723 (12)	-67	-7.3†
Private for-profit (4)				
All surgeries	640 (10)	167 (0)	-100	-6.6†
CS	142 (3)	32 (0)	-100	-7.0†
Inguinal hernia repair	134 (3)	22 (0)	-100	-5.0†

EVD: Ebola Viral Disease; CS: Cesarean Section; *Change in weekly medians by comparing identical institutions and weeks; †$P < 0.005$

For all hospitals, there was a non-significant 5 % ($p = 0.820$) increase in CSs performed during the first year of the EVD outbreak compared to 2012. While private non-profit hospitals performed 43 % ($p < 0.001$) fewer CSs, the governmental hospitals increased provision of CSs by 45 % ($p < 0.001$) during the EVD outbreak. The decline in surgical volume observed during the first year of the EVD outbreak coincided with a change in the

types of operations performed. The non-acute inguinal hernia repair operation decreased from approximately 20 % of the total volume of surgical procedures before the EVD outbreak to less than 10 % during the peak of the outbreak in November 2014. An opposite trend was observed for CSs, which represented fewer than 30 % of all surgical operations before the EVD outbreak, yet increased to more than 50 % during the peak of the epidemic. The governmental sector increased the proportion of CSs both more quickly and to a larger extent compared with the private non-profit sector.

Paper IV - Outcomes of the STP, January 2011 to July 2016

Trainees and Graduates

A total of 48 trainees were included in the STP between January 2011 and July 2016. 11 dropped out, of those because three had died, three left for personal reasons (chronic sickness (1), emigration (1) and lack of motivation (1)) while five were dismissed by CapaCare because of insufficient training progress. By July 2016, a total of 13 trainees had completed three years of training and graduated (12 community health officers and one non-specialist MD). Nine of the 13 were employed by the MOHS as SACHOs, while the remaining four had not yet been involved in any operations post-graduation because they were still waiting for governmental positions when the data collection for this paper ended in July 2016 (**Figure 7**).

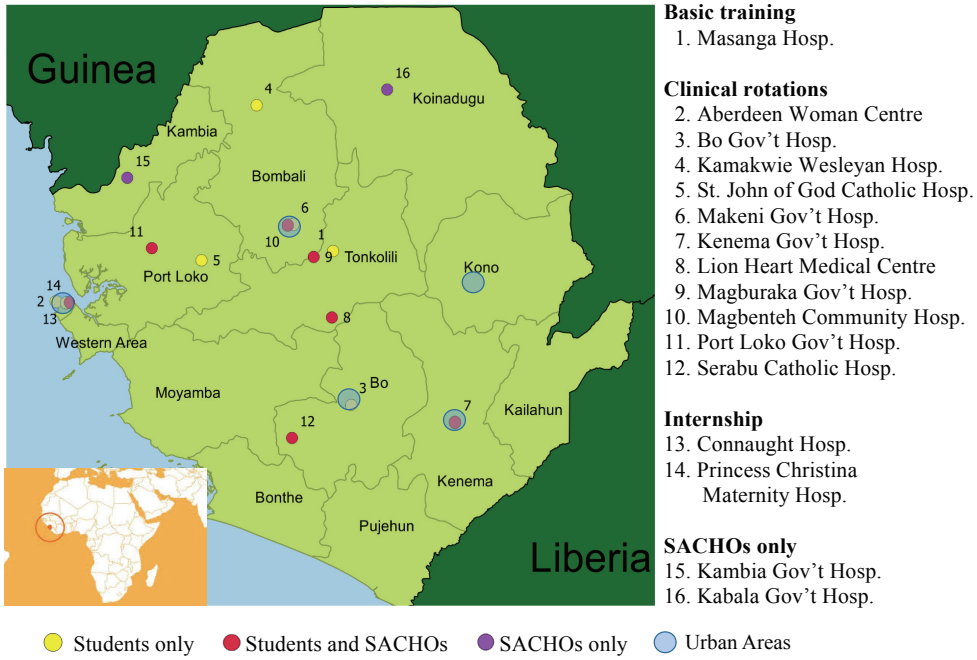

Figure 7 Map of Sierra Leone featuring urban areas and hospitals where trainees and/or SACHOs were located as of July 2016

Productivity

The 48 trainees and the nine graduates logged 27,216 operative training and service delivery episodes during the study period; 24,272 as trainees and 2,944 as graduates. The SACHOs took part in a median 204 operations annually, where 173 (Quartile (Q) 1 - 3: 109 - 226) were indirectly supervised. CS, hernia repair and laparotomy were the three most common surgical procedures both for trainees and SACHOs. 81 % (2,396/2,944) of the operations recorded by the SACHOs were indirectly supervised.

Compared to the trainees, SACHOs participated in more operations in governmental hospitals (27.1 versus 58.1 %, $p < 0.001$), a greater number of emergency operations (46.2 versus 69.2 %, $p < 0.001$), the patients were younger ($p < 0.001$) and they were more likely to be females (57.7 versus 71.0 %, $p < 0.001$). CSs accounted for 44 % (1,290/2,944) of the SACHOs' operations.

Postoperative Mortality

During training, crude in-hospital mortality for all operations combined was 1.9 % (466/24,256); 2.6 % (116/4,513) for surgical procedures observed and 0.8 % (36/4,714) for operations indirectly supervised (**Table 6**). Adjusted for patient sex, surgical procedure, urgency and hospital, the risk of fatal outcomes was significantly lower (OR: 0.47, 95 % CI 0.32, 0.71, $p < 0.001$) for operations the trainees performed under indirect supervision (n = 4,714) versus operations observed (n = 4,513). For the observed CSs, crude in-hospital mortality was 1.2 % (8/688) and it was 0.7 % (13/1,915) when indirectly supervised. For laparotomies, mortality following observed operations was 7.5 % (53/703) and 4.3 % (7/164) when indirectly supervised.

The nine SACHOs that carried out surgeries subsequent to completion of the training recorded an overall mortality of 1.7 % (51/2,944); 9.7 % (11/114) for operations observed and 0.9 % (20/2,369) when they were indirectly supervised. The adjusted analysis of the surgical procedures performed by the SACHOs under indirect supervision (n = 2,369) demonstrated significantly lower risk of fatal outcomes (OR: 0.16, 95 % CI 0.07, 0.41, $p < 0.001$) compared with operations the SACHOs observed (n = 114). Postoperative mortality for indirectly supervised CSs was 0.4 % (5/1,169) while being 8.0 % (11/137) for laparotomies.

Table 6 Factors associated with in-hospital mortality during training and after graduation

	Trainees (n=24,272)					SACHOs (n=2,944)			
	Alive	Death (%)*	Mis-sing	Multivariable OR†	*P*	Alive	Death (%)*	Multivariable OR†	*P*
Level of supervision									
Observer	4,397	116 (2.57)	2	1.00 (reference)		103	11 (9.65)	1.00 (reference)	
Assistant	9,075	225 (2.42)	11	0.99 (0.78, 1.25)	*0.915*	273	17 (5.86)	0.65 (0.26, 1.65)	*0.364*
Directly supervised	5,633	89 (1.55)	2	0.74 (0.55, 0.99)	*0.045*	167	3 (1.76)	0.12 (0.02, 0.50)	*0.004*
Indirectly supervised	4,678	36 (0.76)	1	0.47 (0.32, 0.71)	*< 0.001*	2,349	20 (0.84)	0.16 (0.07, 0.41)	*< 0.001*
Missing	7	0	0			1	0		
Sex									
M	9,974	262 (2.56)	8	1.00 (reference)		819	34 (3.99)	1.00 (reference)	
F	13,804	204 (1.46)	8	0.43 (0.35, 0.54)	*< 0.001*	2,073	17 (0.81)	0.19 (0.09, 0.39)	*< 0.001*
Missing	12	0	0			1	0		
Urgency									
Planned	12,907	120 (0.92)	4	1.00 (reference)		899	6 (0.66)	1.00 (reference)	
Emergency	10,865	345 (3.07)	12	4.05 (3.18, 5.15)	*< 0.001*	1,992	45 (2.21)	3.95 (1.48, 10.59)	*0.006*
Missing	18	1	0			2	0		
Surgical procedures									
CS	6,383	54 (0.84)	1	1.00 (reference)		1,284	6 (0.47)	1.00 (reference)	
Hernia repairs	6,435	33 (0.51)	3	0.68 (0.41, 1.13)	*0.135*	607	3 (0.49)	0.50 (0.10, 2.62)	*0.412*
Laparotomy	1,937	199 (9.29)	6	7.14 (5.06, 10.08)	*< 0.001*	202	30 (12.93)	10.51 (3.77, 29.26)	*< 0.001*
Appendectomy	826	8 (0.96)	0	0.93 (0.44, 2.00)	*0.861*	134	0 (-)	-	-
D&C	860	6 (0.69)	0	0.97 (0.41, 2.23)	*0.917*	100	0 (-)	-	-
Hysterectomy	654	13 (1.95)	0	3.62 (1.93, 6.79)	*< 0.001*	67	0 (-)	-	-
Other	6,695	153 (2.23)	6	2.78 (1.96, 3.95)	*< 0.001*	499	12 (2.35)	1.49 (0.44, 4.94)	*0.513*
Hospital									
Governmental	6,510	67 (1.02)	0	1.00 (reference)		1,694	15 (0.88)	1.00 (reference)	
Non-Governmental	17,228	399 (2.26)	16	1.54 (1.16, 2.03)	*0.003*	1,199	36 (2.91)	1.50 (0.72, 3.11)	*0.277*
Missing	52	0	0			0	0		

OR: Odds Ratio; M: Male; F: Female; CS: Cesarean section; D&C: Dilletation and currettage; *Values in parentheses are rate of fatal outcome; †values in parentheses are 95 % confidence intervals.

Future Contributions to Surgical Volumes

If graduates' productivity remains at 173 (Q 1-3; 109 - 226) operations per year, 60 graduates will perform 10,404 (6,528 – 13,566) operations annually in Sierra Leone in 2021. If 44 % continue to be CSs, the graduates of the STP will carry out 4,578 (2,872 – 5,969) CSs each year.

Discussion

Main Findings

The main findings from this thesis are the high unmet need for surgery in Sierra Leone and the considerable domestic inequity with 30-fold more operations performed per capita in the best performing districts compared to the least. More than half of all operations were performed in the private non-profit sector, and nearly 65 % of all operations performed in governmental hospitals constituted only three procedures - CS, hernia repair or appendectomy. Sierra Leone experiences extreme shortage of skilled surgical providers, far more pronounced in rural than urban areas. There was also an increased preference for working in urban areas when one had longer surgical training. In addition, productivity varied considerably between health cadres and work locations.

During the first year of the EVD outbreak in 2014/2015, there was an overall 50 % reduction in non-Ebola in-hospital admissions and 41 % fewer operations performed in Sierra Leone. This was equivalent to 40,000 fewer hospitalizations during the first year of the EVD epidemic and almost 7,500 less operations conducted. During the EVD outbreak, there was significantly less of a decrement in the volumes of surgery at governmental hospitals compared to private hospitals. With this, the number of CSs was not reduced at the time of the outbreak, contradicting reports suggesting there was an almost complete breakdown in maternal health care (Delamou 2014). These findings may be consistent with a retrospective household survey investigating health-seeking behaviour and non-Ebola mortality in the Western Area of Sierra Leone during the first nine months of the EVD outbreak (Vygen 2016). Although there was underutilization of health services, the survey did not show a demonstrable effect on non-Ebola-related mortality.

In a crisis context like the EVD epidemic, where more comprehensive health care system information tools are not feasible for implementation, readily available routine data on volumes of surgery seems to be a promising indicator of hospital functioning that merits further examination.

During the STP, the volume of surgical training episodes was high and the exposure corresponded to procedures performed after graduation. Crude in-hospital mortality, both

during and after completion of the STP, was not greater than the previously recorded mortality from identical operations in Sierra Leone or from comparable low-resource settings in SSA. Keeping this in mind, the STP was indeed able to facilitate teaching and training within private non-profit hospitals and transfer graduates to governmental district hospitals. The current productivity of SACHOs indicates that task-shared surgical providers can safely perform a considerable volume of emergency surgery at district government hospitals in the near future.

Unmet Need of Surgery

The very high unmet need for surgery demonstrates an urgent call for scaling up surgical services in Sierra Leone. Dare and colleagues suggested that limited knowledge of the unmet need for surgery in Sierra Leone prevented surgical services from attracting attention from policy makers and larger donors (Dare 2016). Failure to disseminate research findings or poor absorption of those results among policy makers and politicians, particular studies originating from international organizations, were also identified as one of several causes of why advocacy for surgical services was found to be weak in Sierra Leone. This supports the importance of research being endeavoured together with relevant local stakeholders, and further underscores the importance of disseminating the findings. However, despite wide conveyance of such results at the local and regional levels, Dare and colleagues identified competing national public health agendas as barriers for translation of research findings into policy changes (Dare 2016). Another obstacle to influencing policy priorities identified in Sierra Leone was the small surgical community, which often possesses limited knowledge of public health priorities. This allows external donors to decide priorities, frequently outside the scope of national surgical actors to affect. Others has also highlighted that advocacy for robust surgical services in the most resource-poor countries seems to be dependent on international forces (McQueen 2017).

Recently, six core surgical indicators have been included in the 2016 edition of World Development Indicators (Ng-Kamstra 2016). Although unmet need for surgery was not featured, met need or annual volume of surgery per 100,000 population were chosen to track delivery of surgical care. It makes sense to use met need instead of unmet need because of the major uncertainty that is involved in calculating unmet need for surgery as covered earlier. Yet, we would still argue for the relevance of unmet need as an important indicator. An

indicator without a context-adapted target (unmet need) may resonate less with local policy makers compared to a description of activity levels exclusively (met need). Despite earlier highlighted uncertainties when estimating total surgical need, there are currently few alternative approaches at national level besides modelling methodologies.

Human Resources

The Sierra Leonean specialist surgical workforce accounts for less than 5 % of the minimum targeted 20 SAO providers the LCoGS has recommended per 100,000 population (Meara 2015). As less than half of the operations were performed by specialists, it needs to be taken into account that this surgical human resource metric undervalues the surgical providers in Sierra Leone, and likely in many other low-income countries. Subnational distribution of all health care workers conducting operations is a prerequisite for a complete description of the surgical workforce. The findings in *Paper II* fostered discussion of reasonable strategies for expansion of surgical human resources in Sierra Leone. This included an increase in the workforce by training new surgical providers, sharing surgical tasks with other health care workers and, finally, utilising the existing workforce more efficiently.

Expansion of the Workforce – New Regular Surgical Providers

More non-specialist MDs must be trained to perform surgery in Sierra Leone. This may be through domestic individual on-the-job training initiatives as, to date, this has been how most surgical providers in Sierra Leone have acquired their surgical competencies. Post-graduate surgical specialist training within regulated institutions, such as the West African College of Surgeons or other internationally recognized training schemes, are equally significant. Accredited post-graduate surgical training inside Sierra Leone by the West African College of Surgeons became available for the two first years of training in as late as 2016 (West African College of Surgeons 2017). Although presently there are only three candidates (personal communication, Ibrahim Bundu, Chief Surgeon, Connaught Hospital, Sierra Leone), allowing domestic MDs this opportunity is crucial for the development of surgery in the nation. Both the low number of trainees and highly specialized provider's tendencies to work in urban settlements suggests that this strategy will have less of an effect on bolstering the surgical workforce in rural areas in the foreseeable future.

As non-specialist MDs perform the majority of surgical procedures at district hospitals (Bolkan 2015), it is vital that the training offered to this group is adequate. Domestic surgical specialists are the most suitable trainers, and it is worrying that specialists performed most operations in the private for-profit sector, which does not seem to have fully taken on its responsibility as a capacity building entity (Shrime 2015). The fact that non-specialized MDs conducted only 1.5 operations weekly in the referral hospitals indicates that they may not receive sufficient surgical training. House officers were included in the non-specialist MD category, many of whom may have little interest in surgery as they already know they will later pursue a medical career without needing to engage in surgical procedures. This may partially explain the low productivity of non-specialist MDs at training hospitals, which continues to be a concern as junior MDs at times are required to perform complex high-risk surgical procedures when they are posted to district hospitals subsequent to their house tenures. As such, it is necessary to look into the efficiency and quality of individual on-the-job training of non-specialist MDs at referral hospitals.

There are several reasons for strengthening surgical training of non-specialist MDs in Sierra Leone and in other similarly resourced countries, as well. Firstly, this group is an important and large portion of the surgical providers in Sierra Leone. Structured and organised training to reach the highest achievable local standards should be aimed for. Secondly, dilution of the surgical profession has been raised as a concern if the MDs are excluded from the operation rooms (Baine 2014). A surgical workforce trained to the highest reasonable standards should have universal goals, ideally with full coverage of specialist providers, however this is outside a realistic scope for most LICs in the not-too-distant future (Mock 2015). The available numbers of medical doctors in Sierra Leone further implies that it is not feasible to develop a significant surgical workforce relying solely on MDs (Samai 2014). A balanced skill-mix of specialists, non-specialist MDs and task-shared surgical providers are critical for the interest, development and status of surgery, an issue also raised in other countries where task sharing in surgery has been introduced (Baine 2014). Thirdly, in regions with extreme shortages of specialist surgical providers, it is fundamental that dedicated specialists or non-specialist MDs are in place to supervise and mentor ACs trained to perform surgery. This comes back to the earlier point distinguishing task sharing and task shifting, where the former requires more highly trained providers to share both tasks and responsibilities.

Expansion of the Workforce – the Role of Task Sharing

A substantial elevation in the volumes of surgery cannot be met by increasing the productivity of the very few working in rural areas in Sierra Leone. Additional human resources are urgently required. Several findings presented in this thesis support an introduction of regulated delegation of surgical tasks to non-MD providers.

Operations are already commonly performed by non-specialist MDs, nurses and ACs. Additionally, all ACs and nurses conducting surgical procedures were Sierra Leonean national health workers, and a vast majority of the operations performed by the ACs were carried out at district hospitals and thereby attending to the most underserved population. Retention of ACs at district hospitals is found to be superior to that of MDs (Pereira 2007). Furthermore, the three surgical procedures - hernia repair, CS and appendectomy - comprised nearly 65 % of the surgical volumes in governmental hospitals in Sierra Leone, which also is consistent with other SSA countries (Watters 1987). As only three procedures make up such a considerable proportion of all operations performed in the country, sharing a few common and less complicated procedures with mid-level providers may be more feasible in a context like Sierra Leone compared to more mature surgical systems where a broader range of operations is performed. This is not unique to Sierra Leone - the diversity of operations offered is far less in countries with lower volumes of surgery. A relationship between total volumes of surgery and fraction of CSs has already been described in the literature (Kushner 2010, Bjerring 2015, Weiser 2016). In countries/areas with lower rates of surgery, CSs constitutes a larger fraction of the total volume. Rates of surgical procedures conducted in Sierra Leone is low and an expansion of surgical services demands not only an increased volume of services and operations already available, but also incorporation of new surgical treatment alternatives. If the high-volume procedures identified in Sierra Leone were shared with ACs, it may allow the few highly skilled surgical professionals to engage in developing new surgical services and thereby applying their expertise more rationally. Similar recommendations were suggested 30 years ago following a one-year audit of surgical activity at eight hospitals in Zambia. 86 % of all operations were classified as not complex and suggested as suitable for doctors or paramedics specifically trained for such procedures (Watters 1987).

Task sharing is still a controversial subject within the surgical community. Advocates against it cite concerns for safety, efficacy and the breakdown of professional roles that could result in a surgical practice that neither is regulated nor widely accepted (Atiyeh 2010, Chu 2009, Meo 2006, White 1987, Meara 2015). In Malawi, ACs had adequate manual skills, but lacked diagnostic accuracy (Chilopora 2007). The authors of that study concluded that more research was necessary to compare these skills with those of medical officers. Along the same lines, a study of 300 low-risk CSs from Burkina Faso indicated that ACs performed more unnecessary CSs than obstetrician-gynaecologists (Kouanda 2014). A systematic review found that operations performed by ACs were more likely to result in a wound infection or a wound dehiscence (Wilson 2011). Another study from Burkina Faso demonstrated there were significantly higher new-born case fatality rates for CSs performed by ACs versus obstetricians (Hounton 2009), but this was not reproduced in a meta-analysis (Wilson 2011).

Surgical task sharing programmes have not been introduced without having to overcome barriers. In Senegal, the main resistance came from senior academic clinicians, and barriers were poor career progression and inadequate programme coordination (De Brouwere 2009). A government-initiated surgical training initiative of non-specialised MDs in India became stranded because a number of the trainees were not allowed to perform surgery by specialist colleagues and anaesthetists refused to work with them. Infrastructure, such as operation room and surgical equipment, was absent and there was inadequate access to blood transfusions in areas the task-shifted providers were allocated. The authors concluded that *"training medical officers in comprehensive emergency obstetric care is only one piece of the puzzle"* and that *"training cannot occur in a vacuum"* (Evans 2009). Those in favour of task shifting in a Ugandan study claimed that ACs already were performing tasks of specialist providers (Baine 2014). Others contended that ACs were more expensive compared with trained health workers, along with being incompetent and overworked. From the same study, antagonists felt that, "*consumers of health services were either uninformed or ignorant about the competencies of the health providers and/or had no other options*". An investigation from Mozambique highlighted that collaboration between ACs and MDs, in particular, was challenging. A possible explanation was that ACs saw themselves as champions because they performed life-saving surgery as opposed to physicians who "only" prescribed medicines. This attitude may have stimulated confrontations with MDs and hampered the implementation of a task-sharing strategy at large (Cumbi 2007).

On the contrary, in a different study from Uganda set out to explore the views of clinicians and managers surrounding the use of surgical task shifting determined that most managers of health facilities and health workers supported surgical task shifting (Galukande 2013). Regulatory mechanisms and influential policies were established as important factors for positive attitudes towards the strategy. Moreover, those supporting the strategy considered task shifting to be a solution to skilled workforce shortages, while those opposed were worried it could lower the quality of care and "*weaken the health system by opening it up to unregulated practice and abuse of privilege*" (Galukande 2013).

In most of the developed world, surgery is divided into different sub-specialities.
A similar partition exists in LICs, and many surgeons have obtained sub-specialist training, with some even having the luxury of attending to patients predominantly related to it. However, most surgical providers in LICs and in particular those working in rural areas need to manage a broad range of surgical pathologies, including orthopaedics, gynaecology, obstetrics and general surgery. In Sierra Leone, out-of-pocket payment is the main restriction for obtaining surgical care (Forrester 2016). Indirect expenses, like travel, are featured in total surgical expenses (Meara 2015), which leave many patients without any choice but to have their surgical conditions treated at the closest district hospital. Financial incentives for surgical providers to perform the operation and poor regulation of surgical activity may also contribute to high-risk operations being conducted at facilities that are not truly appropriate and by providers not adequately trained. A regulation of surgical services, where certain operations are allocated to hospitals with minimum requirements of staffing and infrastructure and to providers with a certain level of training, may be worth considering in Sierra Leone. The negative consequences of a regulation like this must be considered, however. Indirect expenses could rise because of longer travel, and monopolization of some surgical services within a smaller subset of surgical providers may also elevate direct costs and exclude an even larger proportion of the population from access to surgical care.

Regulation of surgical services are poorly attended to in Sierra Leone and the development of such regulations have to take into account a broad range of health care needs and priorities which not only involve the field of surgery, but also other facets of core health care activities. Such directions should be addressed at national level. The LCoGS emphasized the importance of national surgical plans that "*rest within a broader strategy of the national health systems"* (Meara 2015). In Sierra Leone discussions concerning adoption of task sharing strategies in

surgery have so far been owned by the surgical community. The focus has mostly been directed to what is transpiring in the operation room and narrowed to the outcomes of the surgeries themselves, failing to incorporate the public health perspective, and in particular concerns connected to access to health care services.

A very simplified model for the estimated 5.4 % of pregnancies with a maternal indication for a CS in West Africa (Dumont 2001) is used for the purposes of illustration (**Table 7**). In this hypothetical scenario, for simplicity, maternal deaths are the only measure of interest. Assuming MDs in Sierra Leone have a post-CS mortality of 1.4 %, which equals the mean mortality among 19 publications on outcomes of CSs from Sub-Saharan West Africa (Uribe-Leitz 2016), and the SACHOs have twice as high a mortality of 2.8 %. The underlying assumptions for the calculation are:

i. Both SACHOs and MDs apply only maternal indication for the operation.
ii. Assume that 25 % of those with a maternal indication that do not have the CSs performed dies.
iii. MDs continue to perform the same number of CSs, while operations conducted by the SACHOs are additionally performed procedures.

With an estimated population in 2012 of 6,039,000 (Statistics Sierra Leone 2006) and a crude birth rate of 38 (The World Bank 2017), Sierra Leone was expected to have 229,482 births that year. A maternal mortality ratio of 1,165 per 100,000 live births equals 2,673 maternal deaths in 2012 (Statistics Sierra Leone 2013). A maternal indication for CSs of 5.4 % (Dumont 2001) yields a needed 12,392 CSs in Sierra Leone for 2012. The MD-only model (4,868 CSs performed (Bolkan 2015)) and the model where SACHOs perform an additional 4,578 CSs (task-sharing model) are compared, and, fully recognizing the limitations and simplifications of this model, the task-sharing approach means there are more than 1000 fewer maternal deaths per year.

Table 7 Hypothetical calculation of maternal death and survival for Sierra Leone in 2012 with a doctor-only and a task sharing model

	MD-only	Task sharing
Performed CS	4,868	9,446
CS not performed	7,524	2,946
Deaths from CS performed	68[*]	196[†]
Deaths from CS not performed	1,881	737
Maternal survival	10,443	11,459
Maternal deaths	**1,949**	**933**

CS: Caesarean section; [*]1.4 % mortality; [†]1.4 % mortality for MDs, 2.8 % for SACHOs

Embracing a perspective beyond the operation room where gains from increased access are weighed against potential losses in quality of care both must be part of the discourse when countries are considering task-sharing strategies. Both surgeons and public health practitioners need to have an understanding of surgery's role within the health system (Spiegel 2015). A potential bonus of surgeons looking beyond their operation room and public health practitioners actively partaking in the development of surgical systems may be better informed discussions and strengthening of other areas of the health care system (Meara 2015).

Productivity – Increasing the Output of the Existing Workforce

The use of productivity within health system planning and monitoring is not commonly applied. We would claim that productivity of surgical providers is a relevant measure in health system planning. The global model proposed by the LCoGS suggested a universal minimum of 5,000 operations to be performed per 100,000 population per year and a minimum number of SAOs between 20 and 40 per 100,000 populations (Meara 2015). For simplicity, we assume all SAOs conduct operations, which by this model implies an annual production of each individual SAO to be between 125 (40 SAO/100,000) and 250 (20 SAO/100,000) operations per year, or 2.4 to 4.8 weekly operations to meet universal targets for volumes of surgery.

Average weekly productivity for the surgical providers in Sierra Leone was 2.8 operations, which is towards the lower end of the aforementioned rough calculation. Productivity varied noticeably between work location and cadres of surgical providers. Specialists performed an average of 3.7 operations per week, while non-specialist MDs carried out 2.1. Up till now, planning of expanding surgical services in LICs has primarily concentrated on annual volumes of surgery and the number of surgical providers per population (Meara 2015, Mock 2015, Henry 2015) - productivity has not been taken into account. Knowing that most operations performed in Sierra Leone, and likely in many other LICs, are conducted by non-specialist MDs with a broad range of non-surgical competing clinical duties (Bolkan 2015, Beard 2014), productivity may also be a relevant measure for how surgical care is prioritized at the facility level.

The low productivity of 2.2 weekly operations by non-specialist MDs at public hospitals in Sierra Leone combined with the high unmet need supports previously identified low political priority for surgical care in Sierra Leone (Dare 2016). The most productive surgical providers in the country were specialists working in rural areas (8.5 operations/week) and specialists working in private non-profit hospitals (5.1 operations/week). The findings on productivity estimated a case like this; if all surgical providers in Sierra Leone were as productive as the specialists working in private non-profit hospitals (5.1 operations/week), the national volume of operations might increase as much as 85 %. Surgical productivity is therefore a highly relevant measure for provision of surgical services.

The surgeons' volumes may also be a central component of safe surgery in LICs. The association between surgeon volumes and improved outcomes is well-established in high-income countries (Liu 2015, Archampong 2012). It is not inordinate to imagine the same relationship between greater surgeons' volumes and enhanced outcomes also applies to poor-resource environments. This makes productivity of the surgical providers pertinent not only as a strategy to expand volumes of surgery, but to maintain and improve quality of care, as well.

Whatever surgery will be prioritised in highly underserved settings like Sierra Leone depends on many factors (Dare 2015, Grimes 2011). Compared with several of the larger vertical or disease-specific global health initiatives during the last decades, the uniqueness and challenging nature of expanding surgical care is defined by the need to take a health-systems

approach instead of developing standalone silos of care added on to an existing system. Any health-systems approach is complex, challenging to implement, costly, requires long-term perspective and clearly measureable outcomes are hard to delineate. For politicians facing short electoral cycles, such initiatives may be less attractive than vertical programmes with shorter horizons (Dare 2015).

An important opportunity for reinforcing surgical systems lies with integration into the larger health care systems. Strengthening of surgical services obliges investment in human resources, infrastructure, information technologies and equipment, which will fortify many other aspects of the health care system (Weiser 2015). Surgical providers engaged in strengthening of surgical systems need to be aware of this and the responsibility involved and broaden their perspectives, looking beyond traditional and strict surgical systems.

Several recent developments may offer a cautious optimism. Firstly, the West African Ebola outbreak revealed that weak health systems may be an underlying cause for epidemics developing into global public health concerns (United Nations Security Council 2014). Health system-bolstering initiatives, particularly in West Africa, have gained momentum as a consequence of the Ebola outbreak (The World Bank 2015). Secondly, the adoption of the 2015 World Health Assembly resolution on enhancing emergency and essential surgical care may supply Ministers of Health the necessary policy backing to include surgery in national health plans. Thirdly, the incorporation of six surgical indicators among the World Bank development indictors may encourage politicians to enhance surgical services in their home countries (Ng-Kamstra 2016). Lastly, the large-scale global surgical initiatives recently lauded by the LCoGS (Meara 2015) and the third edition of Disease Control Priorities (Mock 2015) have likely united the global surgical community around common goals, and hopefully also inspired the next generation of surgical advocates.

Task Sharing and Contributions to Future Volumes of Surgery

The SACHOs in the work presented here performed a median of 173 operations per year, which made them almost twice as productive as surgical providers at governmental hospitals in 2012 (Bolkan 2016). This might be a conservative estimate of their future surgical contributions as most of SACHOs were newly graduated and likely needed time to settle

within their new work locations and gain trust among their surgical provider colleagues. Excepting one SACHO, all were employed at district hospitals. As more than 70 % of the patients operated upon were females with a median age of 30 years, the programme seemed to address health needs of a vulnerable part of the population - woman at reproductive age living in the provinces. The conservative estimate of 10,400 annual surgical procedures this programme will deliver by 2021 resembles an increase of more than 110 % compared with the 9,500 operations performed at all governmental hospitals in 2012 (Bolkan 2015). An estimated 4,578 additional CSs signifies an increase of 160 % from the 2012 level of activity of governmental hospitals (Bolkan 2015).

If annual population growth in Sierra Leone remains at 2.2 % (like for the period 2010-2015) (United Nations Statistics Division 2016) for the rest of this decade, and the MDs maintain the quantities of operations as was the case in 2012 (Bolkan 2015), the country will progress from 400 to 470 operations per 100,000 between 2012 and 2021. Even if the present STP more than doubles the volume of operations in the public sector, the substantial population growth will absorb most of the gains and the country will still be far off the targeted 5,000 annual operations per 100,000 as suggested by the LCoGS (Meara 2015). Africa is expected to account for more than half of the world's population growth between 2015 and 2050 (United Nations - Department for Economic and Social Affairs 2015), which emphasizes the importance of new initiatives aimed at fortifying the health sector in this region in particular. Surgical task sharing is by many considered a stop-gap measure until the number of MDs is satisfactory (Galukande 2013). Given the currently low output of MDs and surgical specialists (West African College of Surgeons 2017, Samai 2014) juxtaposed with the substantial population growth in Sierra Leone, most likely, there will be an ever-increasing gap to be filled over the next several decades.

Safety of Surgical Task Sharing in Sierra Leone and Beyond

Both trainees and SACHOs were demonstrated to experience lower in-hospital mortality for operations they conducted under indirect supervision versus the observed operations carried out by their trainers and supervisors. A selective distribution of high-risk patients to MDs was previously described within hospitals practicing task sharing (White 1987). In high-income settings, where trainers have recorded poorer outcomes than trainees for the same procedures (Kelly 2014), selection bias has likewise been suggested. The probable selection bias in the

present study, reflected in higher mortality rates for operations performed by trainers and supervisors, is thus reassuring. High-risk cases seem less employed for training purposes, as the more experienced supervisors seem to assume responsibility for operations where the risk is greater and the SACHOs refer or call for assistance when needed. Another explanation for those results is that the task-shared surgical providers perform better than their supervisors, however the methodology utilised herein is not conducive to such a conclusion.

The postoperative mortality of indirectly supervised CSs carried out by trainees (0.7 %) and SACHOs (0.4 %) was not higher than previously reported mortality from Sierra Leone (1.2 %, 4/338) (Chu 2015) or a median 1.4 % described in a systematic review (Uribe-Leitz 2016) that assessed 19 publications from Western SSA. Further, postoperative mortality of indirectly supervised laparotomies conducted by trainees (4.3 %) and SACHOs (8.0 %) was not observed to be greater than mortality in Sierra Leone documented earlier (10.4 %, 18/178) (McConkey 2002) or a recently established 30-day mortality (8.6 %, 114/1,316) (GlobalSurg 2016) from a multi-country low-human development index environment. These outcomes, together with a sound distribution of operative risk both during and after training, may suggest that surgical task sharing, as introduced with the presented training scheme, to this point appears to be a safe strategy for expansion of the surgical workforce in Sierra Leone.

From the 25 publications mentioned earlier that were identified to report outcomes of surgery performed by ACs (**Table 1**), 12 included emergency obstetric care or general surgery. **Table 8** provides an overview of the 12 studies, including details surrounding study design, participants, patient cohorts and outcomes. Fenton and co-workers determined an in-hospital mortality of 1.3 % for 5,256 CSs performed by ACs, more than twice as high as for the SACHOs in Sierra Leone. In-hospital mortality of CSs performed by ACs ranged from 0.6 % (Gessessew 2011) to 3.6 % (Hounton 2009) among the 12 identified studies. Only one previous study from Tanzania described laparotomy outcomes when performed by ACs and therein, observed an in-hospital mortality of 7.1 % (7/106) (Beard 2014), well within the range of the present findings from trainees (4.3 %, 7/164) and SACHOs (8.0 %, 11/137). White and colleagues reported a 13 % (2/16) mortality for nurses performing laparotomies in Zaire (White 1987), however the number of included patients was small.

Table 8 Overview of studies examining outcomes of operations performed by ACs

Subject	Author (year)	Study design	Study participants		Controls		Patient cohort	Outcomes	Adjust conf.
			Cadre	#	Cadre	#			
Emerg. obstetric care	Chilopora (2007)	RC	AC	1,875	MD	256	Obstetric operations	In-hospital mortality (maternal and neonatal), fever, wound infection, dehiscence, re-operation	No
	Fenton (2003)	PC	AC	5,256	MD, OB/ GYN	2,814	CS	In-hospital mortality (maternal and neonatal)	Yes
	Gessessew (2011)	RC	AC	1,574	OB/ GYN	1,261	CS	In-hospital mortality (maternal and neonatal)	No
	Hounton (2009)	RC	AC	733	MD, OB/ GYN	1,572	CS	In-hospital mortality (maternal and neonatal), haemorrhage, wound dehiscence and infection	No
	McCord (2009)	PC	AC	945	MD	143	Obstetric operations	In-hospital mortality (maternal and neonatal), uterus rupture, wound dehiscence, VVF	No
	Pereira (1996)	RC	AC	958	OB/ GYN	1,113	CS	In-hospital mortality (maternal), LOS, wound dehiscence, new-born condition	No
	White (1987)	RC	Nurse	310	MD	43	CS	In-hospital mortality	No
General surgery	Beard (2014)	RC	AC	944	SS, MD	750	Major general surgery, adult	In-hospital mortality, reoperation, readmission, wound infection, other	Yes
	Tyson (2014)	RC	AC	378	SS	507	Any surgery, paediatric	In-hospital mortality, reoperation, length of stay	no
	Vaz (1999)	RC	AC	10,258	No control	0	Major general surgery, adult	In-hospital mortality, complications (not specified)	n/a
	Wilhelm (2011)	RC	AC	195	SS	184	Selected major general surgery	In-hospital mortality, length of stay, procedure specific complications	No
	White (1987)	RC	Nurse	16	MD	21	Laparotomy, ruptured uterus	In-hospital mortality	No

RC: Retrospective cohort; PC: Prospective cohort; AC: Associate Clinician; MD: Medical Doctor; OB/GYN: Obstetrician/Gynaecologist; SS: Surgical Specialist; VVF: Vesico-Vaginal Fistula; LOS: Length of Stay; Adjust. conf.: Adjusted for confounders.

Previously reported mortality rates for operations performed by ACs continue to be scarce, and the studies that feature them are largely based on a retrospective design without adjustment for confounders, rendering the findings unreliable. Blinded randomized controlled trials comparing MDs and ACs are questionable, partly because it could be unethical not to disclose the identity and qualifications of the surgical provider and partly because

randomisation can be difficult when considering the high proportion of emergency operations (Vaz 1999).

Surgery as a Health Systems Indicator

Non-EVD admissions and volume of operations performed during the Ebola epidemic did not diminish in governmental hospitals to the extent they did in private non-profit hospitals. This may imply that many of the activities in governmental hospitals functioned better or were given higher a priority compared to private non-profit hospitals. Both an absolute and relative increase in the number of acute CSs and decrease in the non-acute inguinal hernia repair procedure suggested that governmental hospitals adapted better in terms of being able to prioritize the most necessary surgeries. Factors outside of a hospital, like improved telephone service for medical emergencies, wider use of ambulances that tended to refer patients to governmental hospitals and the unwillingness of traditional birth attendants to conduct deliveries because of the fear of contracting EVD are all potential contributors to the rise in CSs at governmental hospitals.

It would not have been possible for governmental hospitals to increase their volumes of CSs during the EVD outbreak without internal factors, which were outside the scope of the quantitative methods applied in *Paper III* to identify. A qualitative survey performed as a follow-up to the data collection for *Paper III* sought to explore why Sierra Leonean surgeons continued to operate during the Ebola outbreak (unpublished, Gustav Drevin, *At risk of Ebola! Why Sierra Leonean surgeons continued to operate - A qualitative health system approach to the continuation of caesarean sections during Ebola,* Department of Public Health Sciences, Karolinska Institute, Stockholm, 2017). This survey identified four key findings: (i) surgical activity often depended on sole individuals with surgical skills; (ii) staff were highly motivated to perform CSs despite the risks; (iii) surgical decision-makers prioritised emergency obstetric surgery; and (iv) an improved referral system compensated in part for the closure of private hospitals. Three of these findings point towards individual human resource factors, which stresses the importance of individual providers within the health system. It is not unreasonable to assume that a smaller group of crucial individuals are of more significance for the function of a less developed health system versus more mature systems. With the strong concentration on health system enhancement in West Africa

subsequent to the Ebola outbreak, this needs to be considered when health system bolstering approaches are deployed.

Resilience refers to *the health care system's ability to absorb disturbance, adapt and respond with the provision of needed services during a crisis* (Kruk 2015). Accounting for only the provision of CSs in the governmental hospitals during the EVD outbreak, elements of resilience seemed to be present. The considerable drop in both admissions and operations performed in the largely internationally supported private non-profit hospitals implied that limited foreign assets were made available for maintaining routine health care at the hospital level (Kieny 2014). Several private hospitals closed during the peak of the epidemic, while others actively stopped or reduced admissions of non-Ebola patients and admitted solely those with EVD. The outbreak instigated major additional challenges to the operation of hospitals, most pronounced during the early phase of the epidemic before designated Ebola treatment units were adequately established. Revision of the hospital triage systems, increased isolation capacity, new infection prevention measures and the development of supply chains for EVD-related commodities became imperative for routine health care services (Elston 2015). Hospitals' challenges in providing safe environments were the most common reason supplied when a private hospital closed. Governmental facilities, however, remained open for emergency admissions and operations throughout the outbreak, despite difficulties in safeguarding hospital environments. The brave undertaking by governmental health care workers in continuing to offer essential hospital services was not accomplished without cost. By May 2015, almost 7 % of the country's doctors, nurses and midwives had died of EVD (Evans 2015), a rate of 100 times higher cumulative incidence than the general population (Kieny 2014). Hospitals catering to non-EVD patients were associated with 47 % of the EVD infections among health care workers versus 11 % for designated EVD facilities (Olu 2015). In the absence of appropriate tools to monitor hospital functioning during a disaster in resource-limited settings (McNatt 2015), the application of available routine data was a forthright and affordable alternative that should be explored further. Evaluating hospital functioning based on volumes of operations is by no means a simplification, but has proven feasible and relevant for addressing disaster response priorities during the EVD outbreak (Bolkan 2014).

Strengths and Weaknesses of this Thesis

It is important to disclose that the PhD candidate is a founding member of CapaCare and has a leading role in the development of the STP, from planning and fundraising to execution of the various steps of the programme. Concerning limitations, it is therefore sensible to question the objectivity of the candidate. To ensure a successful programme outcome, it could have been in the interest of CapaCare to describe a poorly functioning surgical health care system before the intervention and favourable conclusions of the STP and its graduates. Meanwhile, the methodology applied in *Papers I* to *III* and the strict quantitative outcomes should offer limited space for subjective understanding of the results. However, when interpreting the results of a potential predefined agenda, it is always possible to highlight certain findings and under-communicate others.

Paper IV is therefore most at risk of a potential subjective selection of results put forward as the study can be seen as an evaluation of the first 5.5 years of the STP. No doubt it is in the interest of the PhD candidate, and CapaCare, as well, to describe a favourable scenario. On the contrary, the PhD candidate together with the supervisors, who all are external to CapaCare, have strived for high levels of methodological transparency, prudent reporting of results, openness with regards to strengths and limitations and discussions and conclusions solely based on objective findings. The PhD candidate will not be in a position to conclude if this was achieved, thus it lay in the hands of referees, editors and, ultimately, the reader. Affiliation with the training programme has been disclosed for editors and reviewers for all the included papers that comprise this thesis.

The major strength of the work presented herein is the large volume of high-quality data made available for all papers included despite of a very exigent context. The nation-wide data on surgery and surgical human resources obtained for *Papers I* and *II* included a very high proportion of facilities performing surgery in an entire LIC. This was achievable because of the long-standing relationship with key health care leaders in the MOHS and the network of surgical training hospitals. Close collaborations with the partner hospitals was also why multi-centre collaborations were feasible for *Paper IV*. The broad connections to both the surgical community and key directors within the MOHS in Sierra Leone could not have been developed and sustained without repeated visits and engagements over many years. This again demanded a strong personal motivation and firm belief in the criticality of new and

innovative strategies to expand surgical services in Sierra Leone, which again comes back to the objectivity of the PhD candidate.

Another strength of this work is the application of and link between the capacity assessments (*Papers I* and *II*) and the development, execution and monitoring of a very targeted intervention (*Paper IV*). Such a relationship between a capacity assessment and a targeted surgical intervention in a LIC has, according to a recent paper, been glaringly absent in the global surgical literature (Carlson 2015).

Conclusions

This thesis has demonstrated a substantial unmet need for surgery in Sierra Leone (*Paper I*). The urban-to-rural area inequity is substantial with a 30-fold higher rate of operations performed in the capital, Freetown, compared to the poorest-served districts (*Paper I*). There are few surgical providers in Sierra Leone and considerably less in rural areas versus those that are urban (*Paper II*). There was a significantly positive correlation between the level of qualifications and likelihood of working in urban areas (*Paper I*). Surgical provider productivity varied between cadres and work location (*Paper II*). Evaluating hospital functions based on volumes of operations is a simplification, albeit proved feasible and may be relevant in highly underserved areas during a disaster (*Paper III*). Task sharing was demonstrably valuable in Sierra Leone and surgical training of ACs within a consortium of governmental and private non-profit district hospitals appears to be safe (*Paper IV*). The de-centralised model of training provides large-scale exposure to surgical training episodes (*Paper IV*). With this, the programme is on track to deliver 60 additional surgical providers by 2021, all bestowed with the ability to be more productive than the existing surgical workforce without compromising safety of surgical services offered (*Paper IV*). The potential gains are substantial, and it seems the most vulnerable part of the population - women of reproductive age living in the provinces – will be reached (*Paper IV*). Integration of a broader public health framework within a surgical task sharing training initiative has been highly necessary for the establishment and the absorption of the programme and the graduates within the Sierra Leonean health care system (*Papers I-IV*). This will likely be equally important in the years to come if task sharing as a strategy to increase coverage shall take on its share of improving access to surgical services in Sierra Leone.

This Thesis has Documented

i. 400 operations performed per 100,000 population in Sierra Leone in 2012 (*Paper I*).
ii. a 30-fold difference in rates of surgery between the most- and least-served districts (*Paper I*).
iii. that private, non-profit institutions were responsible for 54.0 % of the national operative volume (*Paper I*).
iv. close to 65 % of the total surgical volumes in governmental hospitals were comprised of three procedures - hernia repair, CS and appendectomy (*Paper I*).
v. the Sierra Leonean surgical workforce featured 164.4 FTPs, of which 35.6 % were specialists, 52.3 % were MDs without specialist training, 3.8 % were nurses and 8.4 % were ACs (*Paper II*).
vi. that density of surgical providers was eight times higher in urban areas versus rural areas (*Paper II*).
vii. an average productivity for all surgical providers in Sierra Leone to be 2.8 operations per week with considerable variations between the cadres and work locations (*Paper II*).
viii. if all surgical providers were as productive as the specialists at private non-profit hospitals, the national volume of surgery would rise by 85 % (*Paper I*).
ix. there was a 51 % reduction in non-Ebola admissions during the EVD outbreak compared with before the onset of the epidemic (*Paper III*).
x. that governmental hospitals reduced admissions by 45 % during the EVD outbreak, significantly less than the 60 % reduction observed at private non-profit hospitals.
xi. that all hospitals performed 41 % less operations during the EVD outbreak compared with 2012 (*Paper III*).
xii. the drop in surgical volumes during the EVD outbreak was greater at private non-profit hospitals compared with governmental facilities (53 % versus 31 %) (*Paper III*).
xiii. that private non-profit hospitals performed 43 % fewer CSs during the EVD outbreak (*Paper III*).
xiv. that CSs rose in number at governmental hospitals by 45 % during the EVD outbreak (*Paper III*).
xv. that 48 trainees and nine graduates enrolled in the STP logged 27,216 operative training and service delivery episodes between 2011 and 2016 and SACHOs performed 173 indirectly supervised operations annually (*Paper IV*).

xvi. that 58.1 % of the SACHOs' operations were conducted at governmental hospitals and 69 % were emergency operations (*Paper IV*).

xvii. that adjusted for patient sex, surgical procedure, urgency and hospital, the risk of fatal outcomes was significantly lower for operations the trainees performed under indirect supervision compared with operations the trainers carried out (*Paper IV*).

xviii. that crude in-hospital mortality for CSs performed by trainees was 0.7 % when indirectly supervised (*Paper IV*).

xix. that crude in-hospital mortality of laparotomies conducted by trainees was 4.3 % when indirectly supervised (*Paper IV*).

xx. the adjusted analysis of surgical procedures performed by the SACHOs under indirect supervision showed there was a significantly lower risk of fatal outcomes versus operations the SACHOs observed (*Paper IV*).

xxi. that postoperative mortality for indirectly supervised CSs for SACHOs was 0.4 % (*Paper IV*).

xxii. that postoperative mortality for indirectly supervised laparotomies was 8.0 % (*Paper IV*).

xxiii. that if graduates of the STP's productivity remained at 173 operations per year, 60 graduates will perform 10,404 operations annually in Sierra Leone in 2021 (*Paper IV*).

Key Recommendations

i. The MOHS must urgently strengthen its provision of surgical services in Sierra Leone. Deprived access to surgery leads to excessive mortality and morbidity. Recent reports states that investments in surgical health care systems are highly favourable investments in LICs. Initiatives aimed to bolster surgical services needs to include all levels of the health care system from policy development at the central level to expansion of the surgical workforce at hospital level. Introduction of a national surgical plan as suggested by the LCoGS supported with targeted funding are urgently needed.

ii. Surgical task sharing in Sierra Leone is a safe strategy, but still a frail endeavour that need to be actively supported both within hospitals and at the central level. At hospitals, task-shared providers have to be supervised and mentored by specialists and non-specialist MDs. At the central level, task-shared surgical providers should be regulated by a legal regulating body. The new cadre of surgical providers must be included in the health care worker scheme of service and remunerated according to tasks performed and responsibilities resumed.

iii. Initiatives intended to build capacity in surgery need to make better use of the high surgical volume and available expertise in the private non-profit sector. The newly introduced Service Level Agreements all foreign health care institutions and organisations renegotiate on an annual basis offers opportunities for the MOHS to bolster the training aspect of their activities.

iv. Orthopaedic capacity within governmental health care facilities needs to be built. This is of particular importance for the development of a trauma system. Local orthopaedic champions are necessary and targeted stipends for young MDs to obtain specialisation in orthopaedic surgery may be a sustainable solution for enhancing this service within governmental service.

v. The surgical human resource indicator suggested by the LCoGS that only includes specialist providers is inadequate and need to be reconsidered. The current indicator offers inadequate significance in countries like Sierra Leone where the majority of operations are carried out by providers other than specialists. A subnational distribution of all cadres performing operations will yield a greater understanding of human resources shortages and are likely to be of higher value for health system planning in LICs.

Further Studies

This thesis has offered a new and better understanding of the surgical system in Sierra Leone, possible strategies to expand the health care workforce and provided insights into the role and possible contributions of task sharing. There are many aspects related to surgical services in Sierra Leone not covered in this thesis, such as surgical infrastructure and logistics, surgical support functions, like radiology, laboratory and anaesthesia services, information management, barriers to surgical care, and finances. They are all in in need of further investigation.

Further research related to the topics examined here could include improved surveillance of surgery offered in the country. The devastating Ebola outbreak has changed the scope and focus of, in particular, the private non-profit sector. Preferable to on-off examinations of surgical activity, as presented in *Paper I*, would be continuous standardized reporting at the hospital level to a central policy and information entity, a process that for a long time has been available with primary health care in Sierra Leone (Braa 2010).

More research with methodology adapted to assess the surgical outcomes of operations performed by task-shared providers is necessary. Studies including postoperative morbidity events related to surgical procedures will better expose the quality of operative skills, and adjustments for comorbidity and factors associated with technically challenging operations will allow better comparisons between MDs and SACHOs. The long-term implications of introducing task sharing necessitate further investigation, particularly the effects on referral patterns, optimal mixes of surgical health cadres and how barriers to access surgical care are affected.

Studies exploring the relationship between provision of surgery and the hospitals' capacity to deliver other essential health care services, as well as the pertinence of surgical volumes as an indicator of hospital functions in resource-constrained areas all merit additional inquiry.

Finally, better monitoring and evaluation of the quality of all surgical care in Sierra Leone is sorely required. Investigations that can identify and later attenuate the risks of surgical care are of utmost importance.

References

A

Ahmed, A. 2007. Childhood circumcision: a planned approach. *Trop Doct,* 37**,** 239-41.

Alex Jones, A. M., Nouria Brikci, Richard Williams, Sarah Keen, Sophie Witter. 2016. *Sierra Leone Free Health Care Initiative (FHCI): Process and Effectiveness Evaluation* [Online]. Available: http://www.opml.co.uk/publications/sierra-leone-free-health-care-initiative-fhci-process-and-effectiveness-evaluation [Accessed 27. May 2016].

Alkire, B. C., Raykar, N. P., Shrime, M. G., Weiser, T. G., Bickler, S. W., Rose, J. A., et al. 2015. Global access to surgical care: a modelling study. *Lancet Glob Health,* 3**,** e316-23.

Alkire, B. C., Shrime, M. G., Dare, A. J., Vincent, J. R. & Meara, J. G. 2015. Global economic consequences of selected surgical diseases: a modelling study. *Lancet Glob Health,* 3 Suppl 2**,** S21-7.

Archampong, D., Borowski, D., Wille-Jorgensen, P. & Iversen, L. H. 2012. Workload and surgeon's specialty for outcome after colorectal cancer surgery. *Cochrane Database Syst Rev,* 3**,** CD005391.

Atiyeh, B. S., Gunn, S. W. & Hayek, S. N. 2010. Provision of essential surgery in remote and rural areas of developed as well as low and middle income countries. *Int J Surg,* 8**,** 581-5.

B

Bailey, R. C., Moses, S., Parker, C. B., Agot, K., Maclean, I., Krieger, J. N., et al. 2007. Male circumcision for HIV prevention in young men in Kisumu, Kenya: a randomised controlled trial. *Lancet,* 369**,** 643-56.

Baine, S. O. & Kasangaki, A. 2014. A scoping study on task shifting; the case of Uganda. *BMC Health Serv Res,* 14**,** 184.

Barden-O'fallon, J., Barry, M. A., Brodish, P. & Hazerjian, J. 2015. Rapid Assessment of Ebola-Related Implications for Reproductive, Maternal, Newborn and Child Health Service Delivery and Utilization in Guinea. *PLoS Curr,* 7.

Beard, J. H., Oresanya, L. B., Akoko, L., Mwanga, A., Mkony, C. A. & Dicker, R. A. 2014. Surgical task-shifting in a low-resource setting: outcomes after major surgery performed by nonphysician clinicians in Tanzania. *World J Surg,* 38**,** 1398-404.

Beard, J. H., Oresanya, L. B., Ohene-Yeboah, M., Dicker, R. A. & Harris, H. W. 2013. Characterizing the global burden of surgical disease: a method to estimate inguinal hernia epidemiology in Ghana. *World J Surg,* 37**,** 498-503.

Bergstrom, S. 2015. Training non-physician mid-level providers of care (associate clinicians) to perform caesarean sections in low-income countries. *Best Pract Res Clin Obstet Gynaecol,* 29**,** 1092-101.

Bergstrom, S., Mcpake, B., Pereira, C. & Dovlo, D. 2015. Workforce Innovations to Expand the Capacity for Surgical Services. *In:* DEBAS, H. T., DONKOR, P., GAWANDE, A., JAMISON, D. T., KRUK, M. E. & MOCK, C. N. (eds.) *Essential Surgery: Disease Control Priorities, Third Edition (Volume 1).* Washington (DC).

Bickler, S., Ozgediz, D., Gosselin, R., Weiser, T., Spiegel, D., Hsia, R., et al. 2010. Key concepts for estimating the burden of surgical conditions and the unmet need for surgical care. *World J Surg,* 34**,** 374-80.

Bjerring, A. W., Lier, M. E., Rod, S. M., Vestby, P. F., Melf, K., Endreseth, B. H., et al. 2015. Assessing cesarean section and inguinal hernia repair as proxy indicators of the total number of surgeries performed in Sierra Leone in 2012. *Surgery,* 157**,** 836-42.

Bolkan, H. A., Bash-Taqi, D. A., Samai, M., Gerdin, M. & Von Schreeb, J. 2014. Ebola and indirect effects on health service function in sierra leone. *PLoS Curr,* 6.

Bolkan, H. A., Hagander, L., Von Schreeb, J., Bash-Taqi, D., Kamara, T. B., Salvesen, O., et al. 2015. Who is performing surgery in low-income settings: a countrywide inventory of the surgical workforce distribution and scope of practice in Sierra Leone. *Lancet,* 385**,** 44-44.

Bolkan, H. A., Hagander, L., Von Schreeb, J., Bash-Taqi, D., Kamara, T. B., Salvesen, O., et al. 2016. The Surgical Workforce and Surgical Provider Productivity in Sierra Leone: A Countrywide Inventory. *World J Surg,* 40**,** 1344-51.

Bolkan, H. A., Von Schreeb, J., Samai, M. M., Bash-Taqi, D. A., Kamara, T. B., Salvesen, O., et al. 2015. Met and unmet needs for surgery in Sierra Leone: A comprehensive, retrospective, countrywide survey from all health care facilities performing operations in 2012. *Surgery,* 157**,** 992-1001.

Bolkan, H. A., Von Schreeb, J., Samai, M. M., Bash-Taqi, D. A., Kamara, T. B., Salvesen, O., et al. 2015. Rates of caesarean section and total volume of surgery in Sierra Leone: a retrospective survey. *Lancet,* 385 Suppl 2**,** S19.

Braa, J., Kanter, A. S., Lesh, N., Crichton, R., Jolliffe, B., Saebo, J., et al. 2010. Comprehensive yet scalable health information systems for low resource settings: a collaborative effort in sierra leone. *AMIA Annu Symp Proc,* 2010**,** 372-6.

Brolin Ribacke, K. J., Van Duinen, A. J., Nordenstedt, H., Hoijer, J., Molnes, R., Froseth, T. W., et al. 2016. The Impact of the West Africa Ebola Outbreak on Obstetric Health Care in Sierra Leone. *PLoS One,* 11**,** e0150080.

Buwembo, D. R., Musoke, R., Kigozi, G., Ssempijja, V., Serwadda, D., Makumbi, F., et al. 2012. Evaluation of the safety and efficiency of the dorsal slit and sleeve methods of male circumcision provided by physicians and clinical officers in Rakai, Uganda. *BJU Int,* 109**,** 104-8.

C

Carlson, L. C., Lin, J. A., Ameh, E. A., Mulwafu, W., Donkor, P., Derbew, M., et al. 2015. Moving from data collection to application: a systematic literature review of surgical capacity assessments and their applications. *World J Surg,* 39**,** 813-21.

Chao, T. E., Sharma, K., Mandigo, M., Hagander, L., Resch, S. C., Weiser, T. G., et al. 2014. Cost-effectiveness of surgery and its policy implications for global health: a systematic review and analysis. *Lancet Glob Health,* 2**,** e334-45.

Chilopora, G., Pereira, C., Kamwendo, F., Chimbiri, A., Malunga, E. & Bergstrom, S. 2007. Postoperative outcome of caesarean sections and other major emergency obstetric surgery by clinical officers and medical officers in Malawi. *Hum Resour Health,* 5**,** 17.

Choo, S., Perry, H., Hesse, A. A., Abantanga, F., Sory, E., Osen, H., et al. 2010. Assessment of capacity for surgery, obstetrics and anaesthesia in 17 Ghanaian hospitals using a WHO assessment tool. *Trop Med Int Health,* 15**,** 1109-15.

Chowdhury, S. & Chowdhury, Z. 1975. Tubectomy by paraprofessional surgeons in rural Bangladesh. *Lancet,* 2**,** 567-9.

Chu, K., Cortier, H., Maldonado, F., Mashant, T., Ford, N. & Trelles, M. 2012. Cesarean section rates and indications in sub-Saharan Africa: a multi-country study from Medecins sans Frontieres. *PLoS One,* 7**,** e44484.

Chu, K., Maine, R. & Trelles, M. 2015. Cesarean section surgical site infections in sub-Saharan Africa: a multi-country study from Medecins Sans Frontieres. *World J Surg,* 39**,** 350-5.

Chu, K., Rosseel, P., Gielis, P. & Ford, N. 2009. Surgical task shifting in Sub-Saharan Africa. *PLoS Med,* 6**,** e1000078.

Cia World Factbook. 2016. Available: https://www.cia.gov/library/publications/the-world-factbook/geos/sl.html [Accessed July 14 2016].
Cumbi, A., Pereira, C., Malalane, R., Vaz, F., Mccord, C., Bacci, A., et al. 2007. Major surgery delegation to mid-level health practitioners in Mozambique: health professionals' perceptions. *Hum Resour Health,* 5**,** 27.

D
Dare, A. J., Bleicher, J., Lee, K. C., Elobu, A. E., Kamara, T. B., Liko, O., et al. 2015. Generation of national political priority for surgery: a qualitative case study of three low-income and middle-income countries. *Lancet,* 385 Suppl 2**,** S54.
Dare, A. J., Grimes, C. E., Gillies, R., Greenberg, S. L., Hagander, L., Meara, J. G., et al. 2014. Global surgery: defining an emerging global health field. *Lancet,* 384**,** 2245-7.
Dare, A. J., Lee, K. C., Bleicher, J., Elobu, A. E., Kamara, T. B., Liko, O., et al. 2016. Prioritizing Surgical Care on National Health Agendas: A Qualitative Case Study of Papua New Guinea, Uganda, and Sierra Leone. *PLoS Med,* 13**,** e1002023.
De Brouwere, V., Dieng, T., Diadhiou, M., Witter, S. & Denerville, E. 2009. Task shifting for emergency obstetric surgery in district hospitals in Senegal. *Reprod Health Matters,* 17**,** 32-44.
Debas, H. T., Gosselin, R., Mccord, C. & Thind, A. 2006. *Disease Control Priorities in Developing Countries. 2nd edition - Ch 67 - Surgery*.
Delamou, A., Hammonds, R. M., Caluwaerts, S., Utz, B. & Delvaux, T. 2014. Ebola in Africa: beyond epidemics, reproductive health in crisis. *Lancet,* 384**,** 2105.
Devries Cr, P. R. 2012. *Global surgery and public health: a new paradigm.*, Sudbury, MA: Jones & Bartlett Learning.
Dumont, A., De Bernis, L., Bouvier-Colle, M. H., Breart, G. & Group, M. S. 2001. Caesarean section rate for maternal indication in sub-Saharan Africa: a systematic review. *Lancet,* 358**,** 1328-33.
Dusitsin, N., Chalapati, S., Varakamin, S., Boonsiri, B., Ningsanon, P. & Gray, R. H. 1980. Post-partum tubal ligation by nurse-midwives and doctors in Thailand. *Lancet,* 1**,** 638-9.

E
Elston, J. W., Moosa, A. J., Moses, F., Walker, G., Dotta, N., Waldman, R. J., et al. 2015. Impact of the Ebola outbreak on health systems and population health in Sierra Leone. *J Public Health (Oxf)*.
Evans, C. L., Maine, D., Mccloskey, L., Feeley, F. G. & Sanghvi, H. 2009. Where there is no obstetrician--increasing capacity for emergency obstetric care in rural India: an evaluation of a pilot program to train general doctors. *Int J Gynaecol Obstet,* 107**,** 277-82.
Evans, D. K., Goldstein, M. & Popova, A. 2015. Health-care worker mortality and the legacy of the Ebola epidemic. *Lancet Glob Health,* 3**,** e439-40.

F
Faierman, M. L., Anderson, J. E., Assane, A., Bendix, P., Vaz, F., Rose, J. A., et al. 2015. Surgical patients travel longer distances than non-surgical patients to receive care at a rural hospital in Mozambique. *Int Health,* 7**,** 60-6.
Farmer, P. E. & Kim, J. Y. 2008. Surgery and global health: a view from beyond the OR. *World J Surg,* 32**,** 533-6.

Federspiel, F., Mukhopadhyay, S., Milsom, P., Scott, J. W., Riesel, J. N. & Meara, J. G. 2015. Global surgical and anaesthetic task shifting: a systematic literature review and survey. *Lancet,* 385 Suppl 2**,** S46.
Fenton, P. M., Whitty, C. J. & Reynolds, F. 2003. Caesarean section in Malawi: prospective study of early maternal and perinatal mortality. *BMJ,* 327**,** 587.
Fesseha, N., Getachew, A., Hiluf, M., Gebrehiwot, Y. & Bailey, P. 2011. A national review of cesarean delivery in Ethiopia. *Int J Gynaecol Obstet,* 115**,** 106-11.
Ford, N., Chu, K. & Mills, E. J. 2012. Safety of task-shifting for male medical circumcision: a systematic review and meta-analysis. *AIDS,* 26**,** 559-66.
Forrester, J. D., Forrester, J. A., Kamara, T. B., Groen, R. S., Shrestha, S., Gupta, S., et al. 2016. Self-reported Determinants of Access to Surgical Care in 3 Developing Countries. *JAMA Surg,* 151**,** 257-63.
Frajzyngier, V., Odingo, G., Barone, M., Perchal, P. & Pavin, M. 2014. Safety of adult medical male circumcision performed by non-physician clinicians in Kenya: a prospective cohort study. *Glob Health Sci Pract,* 2**,** 93-102.
Fulton, B. D., Scheffler, R. M., Sparkes, S. P., Auh, E. Y., Vujicic, M. & Soucat, A. 2011. Health workforce skill mix and task shifting in low income countries: a review of recent evidence. *Hum Resour Health,* 9**,** 1.

G

Galukande, M., Kaggwa, S., Sekimpi, P., Kakaire, O., Katamba, A., Munabi, I., et al. 2013. Use of surgical task shifting to scale up essential surgical services: a feasibility analysis at facility level in Uganda. *BMC Health Serv Res,* 13**,** 292.
Gessessew, A., Barnabas, G. A., Prata, N. & Weidert, K. 2011. Task shifting and sharing in Tigray, Ethiopia, to achieve comprehensive emergency obstetric care. *Int J Gynaecol Obstet,* 113**,** 28-31.
Ghorbani, F. S. 1979. The use of paramedics in family planning services in Iran. *Int J Gynaecol Obstet,* 17**,** 135-8.
Glenshaw, M. & Madzimbamuto, F. D. 2005. Anaesthesia associated mortality in a district hospital in Zimbabwe: 1994 to 2001. *Cent Afr J Med,* 51**,** 39-44.
Globalsurg, C. 2016. Mortality of emergency abdominal surgery in high-, middle- and low-income countries. *Br J Surg,* 103**,** 971-88.
Gopichandran, V., Luyckx, V. A., Biller-Andorno, N., Fairchild, A., Singh, J., Tran, N., et al. 2016. Developing the ethics of implementation research in health. *Implement Sci,* 11**,** 161.
Gordon-Maclean, C., Nantayi, L. K., Quinn, H. & Ngo, T. D. 2014. Safety and acceptability of tubal ligation procedures performed by trained clinical officers in rural Uganda. *Int J Gynaecol Obstet,* 124**,** 34-7.
Gostin, L. O. & Friedman, E. A. 2015. A retrospective and prospective analysis of the west African Ebola virus disease epidemic: robust national health systems at the foundation and an empowered WHO at the apex. *Lancet,* 385**,** 1902-9.
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 J Surg,* 35**,** 941-50.
Grimes, C. E., Henry, J. A., Maraka, J., Mkandawire, N. C. & Cotton, M. 2014. Cost-effectiveness of surgery in low- and middle-income countries: a systematic review. *World J Surg,* 38**,** 252-63.
Groen, R. S., Samai, M., Stewart, K. A., Cassidy, L. D., Kamara, T. B., Yambasu, S. E., et al. 2012. Untreated surgical conditions in Sierra Leone: a cluster randomised, cross-sectional, countrywide survey. *Lancet,* 380**,** 1082-7.

H

Haagsma, J. A., Graetz, N., Bolliger, I., Naghavi, M., Higashi, H., Mullany, E. C., et al. 2016. The global burden of injury: incidence, mortality, disability-adjusted life years and time trends from the Global Burden of Disease study 2013. *Inj Prev,* 22**,** 3-18.

Hales, S., Lesher-Trevino, A., Ford, N., Maher, D., Ramsay, A. & Tran, N. 2016. Reporting guidelines for implementation and operational research. *Bull World Health Organ,* 94**,** 58-64.

Hall, R. C., Hall, R. C. & Chapman, M. J. 2008. The 1995 Kikwit Ebola outbreak: lessons hospitals and physicians can apply to future viral epidemics. *Gen Hosp Psychiatry,* 30**,** 446-52.

Henry, J. A., Frenkel, E., Borgstein, E., Mkandawire, N. & Goddia, C. 2015. Surgical and anaesthetic capacity of hospitals in Malawi: key insights. *Health Policy Plan,* 30**,** 985-94.

Hider, P., Wilson, L., Rose, J., Weiser, T. G., Gruen, R. & Bickler, S. W. 2015. The role of facility-based surgical services in addressing the national burden of disease in New Zealand: An index of surgical incidence based on country-specific disease prevalence. *Surgery,* 158**,** 44-54.

Hoestermann, C. F., Ogbaselassie, G., Wacker, J. & Bastert, G. 1996. Maternal mortality in the main referral hospital in The Gambia, west Africa. *Trop Med Int Health,* 1**,** 710-7.

Holmer, H., Lantz, A., Kunjumen, T., Finlayson, S., Hoyler, M., Siyam, A., et al. 2015. Global distribution of surgeons, anaesthesiologists, and obstetricians. *Lancet Glob Health,* 3 Suppl 2**,** S9-11.

Holmer, H., Shrime, M. G., Riesel, J. N., Meara, J. G. & Hagander, L. 2015. Towards closing the gap of the global surgeon, anaesthesiologist, and obstetrician workforce: thresholds and projections towards 2030. *Lancet,* 385 Suppl 2**,** S40.

Holt, G., Feurer, I. D. & Schwartz, H. S. 1998. An analysis of concordance among hospital databases and physician records. *Ann Surg Oncol,* 5**,** 553-6.

Hounton, S. H., Newlands, D., Meda, N. & De Brouwere, V. 2009. A cost-effectiveness study of caesarean-section deliveries by clinical officers, general practitioners and obstetricians in Burkina Faso. *Hum Resour Health,* 7**,** 34.

Hoyler, M., Finlayson, S. R., Mcclain, C. D., Meara, J. G. & Hagander, L. 2014. Shortage of doctors, shortage of data: a review of the global surgery, obstetrics, and anesthesia workforce literature. *World J Surg,* 38**,** 269-80.

Hoyler, M., Hagander, L., Gillies, R., Riviello, R., Chu, K., Bergstrom, S., et al. 2015. Surgical care by non-surgeons in low-income and middle-income countries: a systematic review. *Lancet,* 385 Suppl 2**,** S42.

I

Iddriss, A., Shivute, N., Bickler, S., Cole-Ceesay, R., Jargo, B., Abdullah, F., et al. 2011. Emergency, anaesthetic and essential surgical capacity in the Gambia. *Bull World Health Organ,* 89**,** 565-72.

Imbert, P., Berger, F., Diallo, N. S., Cellier, C., Goumbala, M., Ka, A. S., et al. 2003. [Maternal and infant prognosis of emergency cesarean section: prospective study of the Principal Hospital in Dakar, Senegal]. *Med Trop (Mars),* 63**,** 351-7.

Internews 2014. REPORTING ON HUMANITARIAN CRISES - A Manual for Trainers & Journalists and an Introduction for Humanitarian Workers.

J

Jejeebhoy, S. J., Kalyanwala, S., Zavier, A. J., Kumar, R., Mundle, S., Tank, J., et al. 2011. Can nurses perform manual vacuum aspiration (MVA) as safely and effectively as physicians? Evidence from India. *Contraception,* 84**,** 615-21.

Jewkes, R., Brown, H., Dickson-Tetteh, K., Levin, J. & Rees, H. 2002. Prevalence of morbidity associated with abortion before and after legalisation in South Africa. *BMJ,* 324**,** 1252-3.

K

Kaboro, M., Djibril, M. A., Zoumenou, E., Assouto, P., Lokossou, T. & Chobli, M. 2012. L'anesthésie en urgence à la maternité de l'hôpital général de référence nationale de N'Djamena (Tchad). *Publié dans Médecine d'Afrique Noire,* Avril 2012**,** 211-220.

Kelly, M., Bhangu, A., Singh, P., Fitzgerald, J. E. & Tekkis, P. P. 2014. Systematic review and meta-analysis of trainee- versus expert surgeon-performed colorectal resection. *Br J Surg,* 101**,** 750-9.

Kieny, M. P., Evans, D. B., Schmets, G. & Kadandale, S. 2014. Health-system resilience: reflections on the Ebola crisis in western Africa. *Bull World Health Organ,* 92**,** 850.

Kim, J. Y., Farmer, P. & Porter, M. E. 2013. Redefining global health-care delivery. *Lancet,* 382**,** 1060-9.

Kingham, T. P., Kamara, T. B., Cherian, M. N., Gosselin, R. A., Simkins, M., Meissner, C., et al. 2009. Quantifying surgical capacity in Sierra Leone: a guide for improving surgical care. *Arch Surg,* 144**,** 122-7; discussion 128.

Knowlton, L. M., Chackungal, S., Dahn, B., Lebrun, D., Nickerson, J. & Mcqueen, K. 2013. Liberian surgical and anesthesia infrastructure: a survey of county hospitals. *World J Surg,* 37**,** 721-9.

Koetsawang, S., Varakamin, S., Satayapan, S., Srisupandit, S. & Apimas, S. J. 1981. Postpartum sterilization by operating-room nurses in Thailand. *Int J Gynaecol Obstet,* 19**,** 201-4.

Kouanda, S., Coulibaly, A., Ouedraogo, A., Millogo, T., Meda, B. I. & Dumont, A. 2014. Audit of cesarean delivery in Burkina Faso. *Int J Gynaecol Obstet,* 125**,** 214-8.

Kruk, M. E. & Freedman, L. P. 2008. Assessing health system performance in developing countries: a review of the literature. *Health Policy,* 85**,** 263-76.

Kruk, M. E., Myers, M., Varpilah, S. T. & Dahn, B. T. 2015. What is a resilient health system? Lessons from Ebola. *Lancet,* 385**,** 1910-2.

Kruk, M. E., Pereira, C., Vaz, F., Bergstrom, S. & Galea, S. 2007. Economic evaluation of surgically trained assistant medical officers in performing major obstetric surgery in Mozambique. *BJOG,* 114**,** 1253-60.

Kushner, A. L., Groen, R. S. & Kingham, T. P. 2010. Percentage of cesarean sections among total surgical procedures in sub-Saharan Africa: possible indicator of the overall adequacy of surgical care. *World J Surg,* 34**,** 2007-8.

L

Landry, E., Pett, C., Fiorentino, R., Ruminjo, J. & Mattison, C. 2014. Assessing the quality of record keeping for cesarean deliveries: results from a multicenter retrospective record review in five low-income countries. *BMC Pregnancy Childbirth,* 14**,** 139.

Lange, M. M. 2014. Vulnerability as a concept for health systems research. *Am J Bioeth,* 14**,** 41-3.

Lebrun, D. G., Saavedra-Pozo, I., Agreda-Flores, F., Burdic, M. L., Notrica, M. R. & Mcqueen, K. A. 2012. Surgical and anesthesia capacity in Bolivian public hospitals: results from a national hospital survey. *World J Surg,* 36**,** 2559-66.

Leuenberger, D., Hebelamou, J., Strahm, S., De Rekeneire, N., Balestre, E., Wandeler, G., et al. 2015. Impact of the Ebola epidemic on general and HIV care in Macenta, Forest Guinea, 2014. *AIDS,* 29**,** 1883-7.
Lillie, E. M., Holmes, C. J., O'donohoe, E. A., Bowen, L., Ngwisha, C. L., Ahmed, Y., et al. 2015. Avoidable perioperative mortality at the University Teaching Hospital, Lusaka, Zambia: a retrospective cohort study. *Can J Anaesth,* 62**,** 1259-67.
Litorp, H., Kidanto, H. L., Roost, M., Abeid, M., Nystrom, L. & Essen, B. 2014. Maternal near-miss and death and their association with caesarean section complications: a cross-sectional study at a university hospital and a regional hospital in Tanzania. *BMC Pregnancy Childbirth,* 14**,** 244.
Liu, C. J., Chou, Y. J., Teng, C. J., Lin, C. C., Lee, Y. T., Hu, Y. W., et al. 2015. Association of surgeon volume and hospital volume with the outcome of patients receiving definitive surgery for colorectal cancer: A nationwide population-based study. *Cancer,* 121**,** 2782-90.
Loubet, P., Mabileau, G., Baysah, M., Nuta, C., Taylor, M., Jusu, H., et al. 2015. Likely effect of the 2014 Ebola epidemic on HIV care in Liberia. *AIDS,* 29**,** 2347-51.
Loudon, I. 1995. Medical education and medical reform. *Clio Med,* 30**,** 229-49.
Lozano, R., Naghavi, M., Foreman, K., Lim, S., Shibuya, K., Aboyans, V., et al. 2012. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet,* 380**,** 2095-128.
Lyon, T. G. 1914. THE BARBER-SURGEONS' COMPANY: An Address delivered to the Hunterian Society of London. *Br Med J,* 2**,** 781-4.

M

Maaloe, N., Bygbjerg, I. C., Onesmo, R., Secher, N. J. & Sorensen, B. L. 2012. Disclosing doubtful indications for emergency cesarean sections in rural hospitals in Tanzania: a retrospective criterion-based audit. *Acta Obstet Gynecol Scand,* 91**,** 1069-76.
Mathers, C. D. & Loncar, D. 2006. Projections of global mortality and burden of disease from 2002 to 2030. *PLoS Med,* 3**,** e442.
Mcconkey, S. J. 2002. Case series of acute abdominal surgery in rural Sierra Leone. *World J Surg,* 26**,** 509-13.
Mccord, C., Mbaruku, G., Pereira, C., Nzabuhakwa, C. & Bergstrom, S. 2009. The quality of emergency obstetrical surgery by assistant medical officers in Tanzanian district hospitals. *Health Aff (Millwood),* 28**,** w876-85.
Mcnatt, Z., Linnander, E., Endeshaw, A., Tatek, D., Conteh, D. & Bradley, E. H. 2015. A national system for monitoring the performance of hospitals in Ethiopia. *Bull World Health Organ,* 93**,** 719-726.
Mcqueen, K., Watters, D. A. & Tangi, V. 2017. Resolutions and Declarations in an Era of Global Surgery. *World J Surg,* 41**,** 5-6.
Meara, J. G., Leather, A. J., Hagander, L., Alkire, B. C., Alonso, N., Ameh, E. A., et al. 2015. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *Lancet,* 386**,** 569-624.
Meo, G., Andreone, D., De Bonis, U., Cometto, G., Enrico, S., Giustetto, G., et al. 2006. Rural surgery in southern Sudan. *World J Surg,* 30**,** 495-504.
Miller, S., Abalos, E., Chamillard, M., Ciapponi, A., Colaci, D., Comande, D., et al. 2016. Beyond too little, too late and too much, too soon: a pathway towards evidence-based, respectful maternity care worldwide. *Lancet,* 388**,** 2176-2192.
Mills, A. 2014. Health care systems in low- and middle-income countries. *N Engl J Med,* 370**,** 552-7.

Ministry of Health. 2012. *Annuaire statistique 2012* [Online]. Available: http://www.sante.gov.bf/index.php/publications-statistiques/file/338-annuaire-statistique-2012 [Accessed February 13 2017].
Ministry of Health and Sanitation. 2009. *National Health Sector Strategic Plan 2010 - 2015* [Online]. Freetown. Available: http://sierraleone.unfpa.org/sites/default/files/pub-pdf/nhssp_2010_15.pdf [Accessed 22 March 2017].
Ministry of Health and Sanitation. 2012. *Sierra Leone Service Availability and Readiness Assessment 2011* [Online]. Freetown. Available: http://apps.who.int/healthinfo/systems/datacatalog/index.php/catalog/25 [Accessed 22 March 2017].
Ministry of Health and Sanitation. 2015. *Sierra Leone Basic Package of Essential Health Services 2015 - 2020* [Online]. Available: http://www.mamaye.org.sl/sites/default/files/evidence/GoSL_2015_Basic Package of Essential Health Services 2015-2020.pdf [Accessed March 22 2017].
Mock, C. N., Donkor, P., Gawande, A., Jamison, D. T., Kruk, M. E., Debas, H. T., et al. 2015. Essential surgery: key messages from Disease Control Priorities, 3rd edition. *Lancet,* 385**,** 2209-19.
Mullan, F. & Frehywot, S. 2007. Non-physician clinicians in 47 sub-Saharan African countries. *Lancet,* 370**,** 2158-63.
Murray, C. J., Vos, T., Lozano, R., Naghavi, M., Flaxman, A. D., Michaud, C., et al. 2012. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet,* 380**,** 2197-223.

N

Ng-Kamstra, J. S., Greenberg, S. L., Kotagal, M., Palmqvist, C. L., Lai, F. Y., Bollam, R., et al. 2015. Use and definitions of perioperative mortality rates in low-income and middle-income countries: a systematic review. *Lancet,* 385 Suppl 2**,** S29.
Ng-Kamstra, J. S., Raykar, N. P., J.G., M. & Shrime, M. 2016. *Measuring surgical systems: a new paradigm for health systems strengthening* [Online]. blogs.worldbank.org. Available: http://blogs.worldbank.org/opendata/measuring-surgical-systems-new-paradigm-health-systems-strengthening [Accessed 11 December 2016].
Nuffield Council on Bioethics 2005. The ethics of research related to healthcare in developing countries. *In:* BIOETHICS, N. C. O. (ed.).

O

Oecd. 2016. *OECD Health Data: Health care resources* [Online]. Available: http://dx.doi.org/10.1787/data-00541-en [Accessed July 14 2016].
Okafor, U. V. & Okezie, O. 2005. Maternal and fetal outcome of anaesthesia for caesarean delivery in preeclampsia/eclampsia in Enugu, Nigeria: a retrospective observational study. *Int J Obstet Anesth,* 14**,** 108-13.
Okezie, A. O., Oyefara, B. & Chigbu, C. O. 2007. A 4-year analysis of caesarean delivery in a Nigerian teaching hospital: one-quarter of babies born surgically. *J Obstet Gynaecol,* 27**,** 470-4.
Oladapo, O. T., Lamina, M. A. & Sule-Odu, A. O. 2007. Maternal morbidity and mortality associated with elective Caesarean delivery at a university hospital in Nigeria. *Aust N Z J Obstet Gynaecol,* 47**,** 110-4.
Ologunde, R., Maruthappu, M., Shanmugarajah, K. & Shalhoub, J. 2014. Surgical care in low and middle-income countries: burden and barriers. *Int J Surg,* 12**,** 858-63.

Olu, O., Kargbo, B., Kamara, S., Wurie, A. H., Amone, J., Ganda, L., et al. 2015. Epidemiology of Ebola virus disease transmission among health care workers in Sierra Leone, May to December 2014: a retrospective descriptive study. *BMC Infect Dis,* 15**,** 416.

Oyerinde, K., Harding, Y., Amara, P., Kanu, R., Shoo, R. & Daoh, K. 2011. The status of maternal and newborn care services in Sierra Leone 8 years after ceasefire. *Int J Gynaecol Obstet,* 114**,** 168-73.

Ozumba, B. C. & Anya, S. E. 2002. Maternal deaths associated with cesarean section in Enugu, Nigeria. *Int J Gynaecol Obstet,* 76**,** 307-9.

P

Parpia, A. S., Ndeffo-Mbah, M. L., Wenzel, N. S. & Galvani, A. P. 2016. Effects of Response to 2014-2015 Ebola Outbreak on Deaths from Malaria, HIV/AIDS, and Tuberculosis, West Africa. *Emerg Infect Dis,* 22**,** 433-41.

Pereira, C., Bugalho, A., Bergstrom, S., Vaz, F. & Cotiro, M. 1996. A comparative study of caesarean deliveries by assistant medical officers and obstetricians in Mozambique. *Br J Obstet Gynaecol,* 103**,** 508-12.

Pereira, C., Cumbi, A., Malalane, R., Vaz, F., Mccord, C., Bacci, A., et al. 2007. Meeting the need for emergency obstetric care in Mozambique: work performance and histories of medical doctors and assistant medical officers trained for surgery. *BJOG,* 114**,** 1530-3.

Petroze, R. T., Groen, R. S., Niyonkuru, F., Mallory, M., Ntaganda, E., Joharifard, S., et al. 2013. Estimating operative disease prevalence in a low-income country: results of a nationwide population survey in Rwanda. *Surgery,* 153**,** 457-64.

Plucinski, M. M., Guilavogui, T., Sidikiba, S., Diakite, N., Diakite, S., Dioubate, M., et al. 2015. Effect of the Ebola-virus-disease epidemic on malaria case management in Guinea, 2014: a cross-sectional survey of health facilities. *Lancet Infect Dis,* 15**,** 1017-23.

Pratt, B. & Hyder, A. A. 2015. Global justice and health systems research in low- and middle-income countries. *J Law Med Ethics,* 43**,** 143-61.

R

Rahlenbeck, S. & Hakizimana, C. 2002. Deliveries at a district hospital in Rwanda, 1997-2000. *Int J Gynaecol Obstet,* 76**,** 325-8.

Rasch, V. 2011. Unsafe abortion and postabortion care - an overview. *Acta Obstet Gynecol Scand,* 90**,** 692-700.

Renner, R. M., Brahmi, D. & Kapp, N. 2013. Who can provide effective and safe termination of pregnancy care? A systematic review*. *BJOG,* 120**,** 23-31.

Rodriguez, M. I. & Gordon-Maclean, C. 2014. The safety, efficacy and acceptability of task sharing tubal sterilization to midlevel providers: a systematic review. *Contraception,* 89**,** 504-11.

Rose, J., Chang, D. C., Weiser, T. G., Kassebaum, N. J. & Bickler, S. W. 2014. The role of surgery in global health: analysis of United States inpatient procedure frequency by condition using the Global Burden of Disease 2010 framework. *PLoS One,* 9**,** e89693.

Rose, J., Weiser, T. G., Hider, P., Wilson, L., Gruen, R. L. & Bickler, S. W. 2015. Estimated need for surgery worldwide based on prevalence of diseases: a modelling strategy for the WHO Global Health Estimate. *Lancet Glob Health,* 3 Suppl 2**,** S13-20.

Rutgers, R. A. & Van Eygen, L. 2008. Mortality related to caesarean section in rural Matebeleland North Province, Zimbabwe. *Cent Afr J Med,* 54**,** 24-7.

S

Samai, D. M. 2014. COMAHS has made noticeable achievements – Acting Provost. *In:* JAWARD, K. M. (ed.). Awoko Newspaper.

Satyapan, S., Varakamin, S., Suwannus, P., Chalapati, S., Onthuam, Y. & Dusitsin, N. 1983. Postpartum tubal ligation by nurse--midwives in Thailand: a field trial. *Stud Fam Plann,* 14**,** 115-8.

Sekirime, W. K. & Lule, J. C. 2008. Maternal morbidity following emergency caesarean section in asymptomatic HIV-1 infected patients in Mulago Hospital Kampala, Uganda. *J Obstet Gynaecol,* 28**,** 703-9.

Shrime, M. G., Bickler, S. W., Alkire, B. C. & Mock, C. 2015. Global burden of surgical disease: an estimation from the provider perspective. *Lancet Glob Health,* 3 Suppl 2**,** S8-9.

Shrime, M. G., Sleemi, A. & Ravilla, T. D. 2015. Charitable platforms in global surgery: a systematic review of their effectiveness, cost-effectiveness, sustainability, and role training. *World J Surg,* 39**,** 10-20.

Sidel, V. W. 1972. The barefoot doctors of the People's Republic of China. *N Engl J Med,* 286**,** 1292-300.

Sorbye, I. K., Vangen, S., Oneko, O., Sundby, J. & Bergsjo, P. 2011. Caesarean section among referred and self-referred birthing women: a cohort study from a tertiary hospital, northeastern Tanzania. *BMC Pregnancy Childbirth,* 11**,** 55.

Special Programme for Research and Training in Tropical Diseases (Tdr - Who) 2014. Implementation research toolkit. Geneva, Switzerland.

Spiegel, D. A., Misra, M., Bendix, P., Hagander, L., Bickler, S. W., Saleh, C. O., et al. 2015. Surgical Care and Health Systems. *World J Surg,* 39**,** 2132-9.

Statistics Sierra Leone. 2006. *Sierra Leone Population and Housing Census 2004* [Online]. Available: http://www.statistics.sl/2004_population_and_housing_census.htm [Accessed July 14 2016].

Statistics Sierra Leone. 2009. *Sierra Leone Demographic and Health Survey 2008* [Online]. Calverton, Maryland, USA:. Available: https://dhsprogram.com/pubs/pdf/SR171/SR171.pdf [Accessed 22 March 2017].

Statistics Sierra Leone. 2013. *Sierra Leone Demographic and Health Survey* [Online]. Available: http://ghdx.healthdata.org/record/sierra-leone-demographic-and-health-survey-2013 [Accessed 22 March 2017].

Stewart, B., Wong, E., Papillon-Smith, J., Trelles Centurion, M. A., Dominguez, L., Ao, S., et al. 2015. An Analysis of Cesarean Section and Emergency Hernia Ratios as Markers of Surgical Capacity in Low-Income Countries Affected by Humanitarian Emergencies from 2008 - 2014 at Medecins sans Frontieres Operations Centre Brussels Projects. *PLoS Curr,* 7**,** ecurrents.dis.5e30807568eaad09a3e23282ddb41da6.

Stewart, B. T., Tansley, G., Gyedu, A., Ofosu, A., Donkor, P., Appiah-Denkyira, E., et al. 2016. Mapping Population-Level Spatial Access to Essential Surgical Care in Ghana Using Availability of Bellwether Procedures. *JAMA Surg,* 151**,** e161239.

Sullivan, R., Alatise, O. I., Anderson, B. O., Audisio, R., Autier, P., Aggarwal, A., et al. 2015. Global cancer surgery: delivering safe, affordable, and timely cancer surgery. *Lancet Oncol,* 16**,** 1193-224.

T

Takahashi, S., Metcalf, C. J., Ferrari, M. J., Moss, W. J., Truelove, S. A., Tatem, A. J., et al. 2015. Reduced vaccination and the risk of measles and other childhood infections post-Ebola. *Science,* 347**,** 1240-2.

The Equator Network. 2016. Available: http://www.equator-network.org/about-us/ [Accessed October 15 2016].

The World Bank. 2015. *Ebola: World Bank Group Provides New Financing to Help Guinea, Liberia and Sierra Leone Recover from Ebola Emergency* [Online]. Available: http://www.worldbank.org/en/news/press-release/2015/04/17/ebola-world-bank-group-provides-new-financing-to-help-guinea-liberia-sierra-leone-recover-from-ebola-emergency [Accessed 22 March 2017].

The World Bank. 2016. *World Development Indicators* [Online]. The World Bank Group. Available: http://data.worldbank.org/data-catalog/world-development-indicators [Accessed 10 December 2016].

The World Bank. 2017. *Data* [Online]. Available: http://data.worldbank.org/indicator/SP.DYN.CBRT.IN?locations=SL-AE [Accessed 22 March 2017].

Tyson, A. F., Msiska, N., Kiser, M., Samuel, J. C., Mclean, S., Varela, C., et al. 2014. Delivery of operative pediatric surgical care by physicians and non-physician clinicians in Malawi. *Int J Surg,* 12**,** 509-15.

U

United Nation Population Fund. 2009. *Monitoring Emergency Obstetric Care* [Online]. Available: http://www.unfpa.org/publications/monitoring-emergency-obstetric-care [Accessed 22 March 2017].

United Nations. 2016. *Sustainable Development - Knowledge Platform* [Online]. Available: https://sustainabledevelopment.un.org/ [Accessed 14 November 2016].

United Nations - Department for Economic and Social Affairs. 2015. *2015 Revision of World Population Prospects* [Online]. Available: https://esa.un.org/unpd/wpp/ [Accessed 22 January 2017].

United Nations Centre for Human Settlement. 2001. *Compendium of Human Settlements Statistics 2001* [Online]. New York: United Nations. Available: https://unstats.un.org/unsd/demographic/sconcerns/housing/publications/Series_N6.pdf [Accessed 22 March 2017].

United Nations in Sierra Leone. 2016. *Sierra Leone's 2015 Census Provisional Results Launched* [Online]. Available: https://sl.one.un.org/2016/04/15/sierra-leones-2015-census-provisional-results-launched/ [Accessed July 14 2016].

United Nations Security Council. 2014. *Resolution 2177* [Online]. United Nation Security Council. Available: http://www.un.org/en/ga/search/view_doc.asp?symbol=S/RES/2177(2014) [Accessed 20. June 2016].

United Nations Statistics Division. 2016. *World Statistics Pocketbook - Sierra Leone* [Online]. Available: http://data.un.org/CountryProfile.aspx?crName=sierra%20leone [Accessed January 17 2017].

Uribe-Leitz, T., Jaramillo, J., Maurer, L., Fu, R., Esquivel, M. M., Gawande, A. A., et al. 2016. Variability in mortality following caesarean delivery, appendectomy, and groin hernia repair in low-income and middle-income countries: a systematic review and analysis of published data. *Lancet Glob Health,* 4**,** e165-74.

V

Van Amelsfoort, J. J., Van Leeuwen, P. A., Jiskoot, P. & Ratsma, Y. E. 2010. Surgery in Malawi--the training of clinical officers. *Trop Doct,* 40**,** 74-6.

Vaughan, E., Sesay, F., Chima, A., Mehes, M., Lee, B., Dordunoo, D., et al. 2015. An assessment of surgical and anesthesia staff at 10 government hospitals in Sierra Leone. *JAMA Surg,* 150**,** 237-44.

Vaz, F., Bergstrom, S., Vaz Mda, L., Langa, J. & Bugalho, A. 1999. Training medical assistants for surgery. *Bull World Health Organ,* 77**,** 688-91.

Von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gotzsche, P. C., Vandenbroucke, J. P., et al. 2007. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet,* 370**,** 1453-7.

Vygen, S., Tiffany, A., Rull, M., Ventura, A., Wolz, A., Jambai, A., et al. 2016. Changes in Health-Seeking Behavior Did Not Result in Increased All-Cause Mortality During the Ebola Outbreak in Western Area, Sierra Leone. *Am J Trop Med Hyg,* 95**,** 897-901.

W

Walker, P. G., White, M. T., Griffin, J. T., Reynolds, A., Ferguson, N. M. & Ghani, A. C. 2015. Malaria morbidity and mortality in Ebola-affected countries caused by decreased health-care capacity, and the potential effect of mitigation strategies: a modelling analysis. *Lancet Infect Dis,* 15**,** 825-32.

Warriner, I. K., Meirik, O., Hoffman, M., Morroni, C., Harries, J., My Huong, N. T., et al. 2006. Rates of complication in first-trimester manual vacuum aspiration abortion done by doctors and mid-level providers in South Africa and Vietnam: a randomised controlled equivalence trial. *Lancet,* 368**,** 1965-72.

Watters, D. A. & Bayley, A. C. 1987. Training doctors and surgeons to meet the surgical needs of Africa. *Br Med J (Clin Res Ed),* 295**,** 761-3.

Weiser, T. G. & Gawande, A. 2015. Excess Surgical Mortality: Strategies for Improving Quality of Care. *In:* DEBAS, H. T., DONKOR, P., GAWANDE, A., JAMISON, D. T., KRUK, M. E. & MOCK, C. N. (eds.) *Essential Surgery: Disease Control Priorities, Third Edition (Volume 1).* Washington (DC).

Weiser, T. G., Haynes, A. B., Molina, G., Lipsitz, S. R., Esquivel, M. M., Uribe-Leitz, T., et al. 2015. Estimate of the global volume of surgery in 2012: an assessment supporting improved health outcomes. *Lancet,* 385 Suppl 2**,** S11.

Weiser, T. G., Haynes, A. B., Molina, G., Lipsitz, S. R., Esquivel, M. M., Uribe-Leitz, T., et al. 2016. Size and distribution of the global volume of surgery in 2012. *Bull World Health Organ,* 94**,** 201-209F.

Weiser, T. G., Makasa, E. M. & Gelb, A. W. 2015. Improving perioperative outcomes in low-resource countries: It can't be fixed without data. *Can J Anaesth,* 62**,** 1239-43.

Weiser, T. G., Regenbogen, S. E., Thompson, K. D., Haynes, A. B., Lipsitz, S. R., Berry, W. R., et al. 2008. An estimation of the global volume of surgery: a modelling strategy based on available data. *Lancet,* 372**,** 139-44.

West African College of Surgeons. 2017. *Advert for Primary Examinations* [Online]. Available: http://www.wacscoac.org/index.php/examinations/examination-forms [Accessed 7 January 2017].

White, S. M., Thorpe, R. G. & Maine, D. 1987. Emergency obstetric surgery performed by nurses in Zaire. *Lancet,* 2**,** 612-3.

Wilhelm, T. J., Thawe, I. K., Mwatibu, B., Mothes, H. & Post, S. 2011. Efficacy of major general surgery performed by non-physician clinicians at a central hospital in Malawi. *Trop Doct,* 41**,** 71-5.

Wilson, A., Lissauer, D., Thangaratinam, S., Khan, K. S., Macarthur, C. & Coomarasamy, A. 2011. A comparison of clinical officers with medical doctors on outcomes of caesarean section in the developing world: meta-analysis of controlled studies. *BMJ,* 342**,** d2600.

World Health Organisation. 2007. *Everybody business : strengthening health systems to improve health outcomes : WHO's framework for action.* [Online]. Geneva, Switzerland. Available: http://www.who.int/healthsystems/strategy/everybodys_business.pdf [Accessed 22 March 2017].

World Health Organisation. 2008. *Safe Surgery Save Lives* [Online]. Geneva. Available: http://apps.who.int/iris/bitstream/10665/70080/1/WHO_IER_PSP_2008.07_eng.pdf [Accessed 22 March 2017].

World Health Organisation. 2008. *Task shifting: Rational redistribution of tasks among health workforce teams: global recommendations and guidelines* [Online]. Geneva, Switzerland. Available: http://www.who.int/healthsystems/TTR-TaskShifting.pdf?ua=1 [Accessed December 5 2016].

World Health Organisation. 2009. *World health statistics 2009* [Online]. Available: http://www.who.int/whosis/whostat/EN_WHS09_Full.pdf?ua=1 [Accessed 22 March 2017].

World Health Organisation. 2012. *Service Availability and Readiness Assessment* [Online]. Available: http://www.who.int/healthinfo/systems/sara_introduction/en/index.html [Accessed March 22 2017].

World Health Organisation. 2012. *WHO recommendations: optimizing health worker roles to improve access to key maternal and newborn health interventions through task shifting.* [Online]. Available: http://www.who.int/reproductivehealth/publications/maternal_perinatal_health/9789245048 43/en/index.html [Accessed December 5 2016].

World Health Organisation. 2015. *Trends in maternal mortality: 1990 to 2015: estimates by WHO, UNICEF, UNFPA, World Bank Group and the United Nations Population Division* [Online]. Geneva, Switzerland. Available: http://apps.who.int/iris/bitstream/10665/194254/1/9789241565141_eng.pdf?ua=1 [Accessed 22 March 2017].

World Health Organisation. 2015. *WHA reaches agreement on polio, International Health Regulations and strengthening surgical care* [Online]. Available: http://www.who.int/mediacentre/news/releases/2015/wha-22-may-2015/en/ [Accessed December 5 2016].

World Health Organisation. 2015. *WHO Statement on Caesarean Section Rates* [Online]. Geneva. Available: http://apps.who.int/iris/bitstream/10665/161442/1/WHO_RHR_15.02_eng.pdf [Accessed July 14 2016].

World Health Organisation. 2016. *Ebola data and statistics* [Online]. Available: http://apps.who.int/gho/data/node.ebola-sitrep.quick-downloads?lang=en [Accessed 01. July 2016].

World Health Organisation. 2016. *Global Health Observatory* [Online]. Available: http://www.who.int/gho/health_workforce/en/ [Accessed 22 March 2017].

World Medical Association. 2013. *Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects* [Online]. Available: http://www.wma.net/en/30publications/10policies/b3/ [Accessed 22 January 2017].

Wyber, R., Vaillancourt, S., Perry, W., Mannava, P., Folaranmi, T. & Celi, L. A. 2015. Big data in global health: improving health in low- and middle-income countries. *Bull World Health Organ,* 93**,** 203-8.

Y

Ystgaard, B. & Bolkan, H. 2013. Surgery and task shifting in the rainforest. *Tidsskr Nor Laegeforen,* 133**,** 1618-20.

Paper I – IV

Paper I

Met and unmet needs for surgery in Sierra Leone: A comprehensive, retrospective, countrywide survey from all health care facilities performing operations in 2012

Håkon A. Bolkan, MD,[a,b,c] Johan Von Schreeb, MD, PhD,[d] Mohamed M. Samai, MBBS, PhD,[e] Donald Alpha Bash-Taqi, MD,[f] Thaim B. Kamara, MD,[e,g] Øyvind Salvesen, PhD,[b] Brynjulf Ystgaard, MD,[a,c] *and* **Arne Wibe, MD, PhD,[a,b,c]** *Trondheim, Norway, Stockholm, Sweden, and Freetown, Sierra Leone*

Background. *Understanding a country's baseline operative actors and capacity is critical to improving the quality of services and outcomes. The aim of this study was to describe all operative providers and national operative production, to evaluate district and nationwide population rates for operations, and to estimate unmet operative need in Sierra Leone.*

Methods. *A nationwide, exhaustive, retrospective, facility-based study of operative actors and surgical procedures was performed in Sierra Leone. Between January and May 2013, 4 teams of 12 medical students collected data on the characteristics of the institutions and of the operations performed in 2012. Data were retrieved from the log books of operations, anesthesia, and delivery.*

Results. *A total of 24,152 operative procedures were identified, equal to a national rate of 400 operative procedures per 100,000 inhabitants (district range 32–909/100,000, interquartile range 95–502/100,000). Hernia repair was the most common operative procedure at 86.1 per 100,000 inhabitants (22.4% of the total national volume) followed by cesarean delivery at 80.6 per 100,000 (21.0% of the total). Private, nonprofit facilities performed 54.0% of the operations, compared with 39.6% by governmental and 6.4% by private for-profit facilities. More than 90% of the estimated operative need in Sierra Leone was unmet in 2012.*

Conclusion. *The unmet operative need in Sierra Leone is very high. The 30-fold difference in operative output between districts also is very high. As the main training institution, operative services within the governmental sector need to be strengthened. An understanding of the existing operative platform is a good start for expanding operative services. (Surgery 2015;157:992-1001.)*

From the Department of Cancer Research and Molecular Medicine,[a] Norwegian University of Science and Technology, Trondheim, Norway; CapaCare,[b] Trondheim, Norway; Department of Surgery,[c] St. Olavs Hospital, Trondheim University Hospital, Trondheim, Norway; Department of Public Health Sciences,[d] Health System and Policy, Karolinska Institute, Stockholm, Sweden; College of Medicine and Allied Health Sciences,[e] University of Sierra Leone, Freetown, Sierra Leone; Ministry of Health and Sanitation,[f] Freetown, Sierra Leone; and Department of Surgery,[g] Connaught Hospital, Freetown, Sierra Leone

Norwegian University of Science and Technology has funded all parts of the study. The funding source had no role in any aspect pertinent to the survey.

Accepted for publication December 17, 2014.

Reprint requests: Håkon A. Bolkan, MD, Department of Cancer Research and Molecular Medicine, Norwegian University of Science and Technology, PO 8905, N-7491 Trondheim, Norway. E-mail: hakon.bolkan@capacare.org.

0039-6060/$ - see front matter

http://dx.doi.org/10.1016/j.surg.2014.12.028

THE GREATEST UNMET NEED FOR OPERATIVE CARE is found where the burden of operative disease per capita is greatest.[1-4] Leaders in global health advocate that operative care must be an essential component of the recently adopted policy of universal health coverage.[5] The great need for operative care, in combination with global inequity, has called on governments, policy makers, and donor agencies, as part of strengthening health systems, to adopt operative health care delivery as a priority in low-income countries (LICs).[6]

To meet this priority, a massive expansion of operative care within LICs is needed. To plan for and identify priority interventions, there is need for more comprehensive data on the current operative actors and production from countries with the greatest surgical needs.[7] With a few exceptions, such data are scarce, and we still need more insights into the complexity and function of surgical health care systems in LICs.[4,8-11] A better understanding of all operative actors within a country, as well as how they complement each other, is needed to improve the delivery of operative health care.[8]

The distribution of operative actors and operative production varies greatly between regions and countries.[4] Identifying these variations makes it possible to target interventions toward populations that are most in need of operative services. Estimating the unmet need for surgery in a LIC serves to visualize the scale of the challenge in underdeveloped operative health care systems, and it might contribute to the development of aspirational targets for surgical services.[12] The primary aim of this study was to describe all operative providers, eg, governmental, private for-profit, and private nonprofit actors, and also the number of operations performed at the district and national level in Sierra Leone in 2012. The second aim was to estimate the unmet need of surgery in Sierra Leone in 2012.

MATERIALS AND METHODS

Because there was no available mapping of operative providers outside the governmental sector in Sierra Leone before this study, this retrospective study intended to collect data from all facilities performing operations in the country during 2012.[13] The study was a collaboration between the Sierra Leonean Ministry of Health and Sanitation, the Nongovernmental Organization CapaCare, and the Norwegian University of Science and Technology.

Sierra Leone is a West-African, low-income country, with 14 districts and 6 million inhabitants, of whom 60% live in rural areas.[14] Life expectancy is 49 years, and infant and maternal mortality remain high at 89 per 1,000 live births and 857 per 100,000 live births, respectively.[15] Total expenditure on health care per capita in 2012 was 96 US dollars.[16] The health care system consists of 1,054 peripheral health units and 51 hospitals, 20 of which are governmental.[17]

Facilities performing surgery were identified by triangulation at 3 levels. First, at the capital level, where the director of hospitals and laboratory services and the director of research and noncommunicable diseases of the Ministry of Health and Sanitation, the chief surgeon at the highest governmental surgical referral hospital, and the Nongovernmental Organization-liaison officer individually listed facilities that possibly performed operations. Second, District Medical Officers in the 4 largest districts (Western Area Urban, Bo, Bombali, and Kenema) were consulted to identify additional operative providers within their districts. Third, these facilities were supplemented by the list of registered health care facilities in Sierra Leone, which was obtained on January 5, 2013, from the national regulatory body, the Sierra Leone Medical and Dental Council. This process identified 164 institutions that possibly could perform operations.

Facilities performing operations were defined as those that performed one or more of the 21 surgical procedures listed as comprehensive in the health facility assessment tool "Service Availability and Readiness Assessment," developed by the World Health Organization.[18] An operative procedure was defined as any procedure requiring anesthesia, performed within an operation theater, and listed in any of the records for the operation theater.[4]

A total of 12 fourth- and fifth-year medical students from the College of Medicine and Health Sciences in Freetown and the Norwegian University of Science and Technology collected the data. Data collectors received a 1-day training, during which definitions and a written guide to data entry were presented. Simulation interviews with a hospital director and recording of operation log books were rehearsed before the facilities were visited. Data of operative activity data were entered into an Excel Spreadsheet (Microsoft Corp, Redmond, WA), and photos of the logbooks were taken as backup and for crosschecking procedures.

Data were collected from all available sources in which operative procedures were logged. The institutions used log books from the operating theater, anesthesia, and delivery. Some facilities used common log books for operations, anesthesia, and/or delivery procedures, whereas others had separate log books for each service. When separate log books existed, operating theater and delivery log books recorded different procedures, whereas anesthesia log books recorded the same procedure as delivery and operating theater log books, a form of double bookkeeping. When visiting a facility, all sources were examined, and duplicates were removed.

Facilities owned by the government or the armed forces were categorized as governmental,

whereas all others were listed as private. The private sector was further divided into for-profit, if profit generating was one of the aims; all others were nonprofit facilities. Facilities providing 24-hour emergency in-patient care were defined as hospitals; all others were listed as clinics. Hospitals offering highly differentiated clinical services were defined as referral hospitals, and all others were categorized as district hospitals.[1] After being presented with the definitions, the facility directors themselves decided the owner category and administrative level of their institution. For all operative procedures, age category, sex, home address, type of procedure, emergency vs elective procedure, and date of operation were recorded. Thirty-four predefined groups of the most commonly performed procedures were created. This included 4 categories labeled "other" in general surgery, obstetrics and gynecology, orthopedic surgery, and ophthalmic surgery.

Data were aggregated by administrative districts for analyses. The Western Area Urban and Western Area Rural districts were merged into one, because most records did not differentiate between them. The 2012 projections from the most recent census were used to estimate population-based rates for operations.[14]

NEED FOR SURGERY IN SIERRA LEONE

The annual unmet need was defined as the need subtracted from the met need in a given year. Because there is no established method of defining the need for operation in a population, the present analyses were based on two population surveys that were designed to measure surgical conditions that may necessitate a consultation or surgical intervention. Random samples of the population were asked about their perceived need for surgery in 2 similarly performed surveys from Rwanda in 2011[19] and Sierra Leone in 2012.[3] To estimate the annual need for surgery, only surgical conditions that had developed over a 12-month period were counted. In the Sierra Leonean survey, 13.5% (493/3,645) of the responders had developed an operative condition over the 12 months, while 14.8% (95% CI, 13.3–16.5) of the Rwandan responders developed surgical conditions, equivalent to an annual incidence of 14,800 (13,300–16,500)/100,000.

In the Rwandan survey, 34.3% of the operative conditions stated a disability, ie, the interviewee reported "significant shame" or "inability to work" and needed help with daily activities or transportation. Because not all self-reported operative conditions require operative care within an operating theater, the fraction of those with a disabling operative condition might better reflect those in need of an operative procedure. The annual need for surgery in Sierra Leone was estimated by use of the reported operative conditions with disabilities from Rwanda, which equals 34.3% of 14,800 (13,300–16,500)/100,000, giving an annual need of 5,100 (4,562–5,660)/100,000. For the 6 million people of Sierra Leone, the estimated need for surgery would be 307,000 (275,000–342,000).

The Statistical Package for the Social Science (SPSS), version 21 (SPSS, Armonk, NY), was used for descriptive statistics. Operative production, the met need, is presented per 100,000 inhabitants. Operative met need by district is presented by medians and interquartile range. The Sierra Leone Ethics and Scientific Review Committee and the Regional Committees for Medical and Health Research Ethics in central Norway (Ethical clearance number: 2012/2,187) granted ethical clearance for the study.

RESULTS

Operative actors. From the list of 164 institutions potentially providing operation, 89 were excluded because they did not perform operations in 2012, according to the local expert group or a telephone interview with the management of the facility. Four teams of data collectors visited the remaining 75 entities between January 14 and February 15 and May 10 and 20, 2013, (Fig 1). Of these, another 15 locations did not perform operations. Thus, 60 facilities performed operations in Sierra Leone, and 58 (97%) of these shared their annual records for 2012.

At 6 locations accounting for 21% (5,099/24,152) of the procedures, 3 separate sources were used to record surgical procedures. This approach gave the possibility to crosscheck anesthesia logbooks against operating theater and delivery logbooks. The consistency between the sources was fairly good; operating theater and delivery log books alone captured 90.1% of the procedures, whereas anesthesia log books captured 96.2%.

Private, nonprofit institutions performed 54.0% of the national operative volume, whereas the governmental sector performed 39.6% and the private for-profit institutions performed 6.4% of the operations (Table I). Most of the clinics (76.5%, 13/17) were private for-profit, whereas the hospitals were equally distributed between the governmental sector and the private nonprofit sector.

Met need for surgery. A total of 24,152 surgical procedures were recorded in Sierra Leone in 2012,

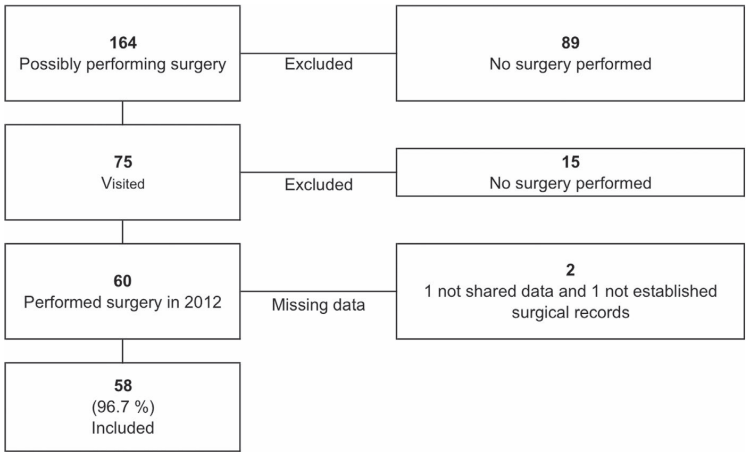

Fig 1. Identification of facilities performing surgery in Sierra Leone in 2012.

Table I. Operative facilities and procedures by owner category and organizational level

Facilities	*Number*	*%*	*Procedures*	*%*
Private nonprofit	22	37.9	13,050	54.0
Clinic	3		2,508	19.2
District hospital	16		7,418	56.8
Referral hospital	3		3,124	23.9
Private for-profit	17	29.3	1,537	6.4
Clinic	13		1,418	92.3
District hospital	4		119	7.7
Referral hospital	0		0	0.0
Governmental	19	32.8	9,565	39.6
Clinic	1		89	0.9
District hospital	14		4,574	47.8
Referral hospital	4		4,902	51.2

equal to 400 procedures per 100,000 inhabitants and a district median of 131 per 100,000 [interquartile range 95–502/100,000]. The volume of surgery varied considerably between districts, ranging from 32 to 909 procedures per 100,000. The western Area, including the capital Freetown, performed 30 times more procedures per 100,000 compared with the lowest served district (Fig 2, Table II).

Slightly more operations were performed on women (56.1%, 12,206/21,745). Information on emergency (65%) vs elective (35%) indications for surgery was available for less than 30% of the procedures. A few procedures were performed on foreigners (1.7%, 105/6,243). The majority (82%, 5,129/6,243) of those patients with a known home address underwent operation in the same district in which they resided.

The type of procedure was available in 96.1% (23,203/24,152) of the entries. Those procedures in which the type was unknown were attributable to illegible handwriting, the name of the procedure was unknown to the data collector, or no name of procedure was entered in the records. There were 11,002 (47.4%) procedures in general surgery; 7,361 (31.7%) procedures in obstetrics and gynecology; 2,526 (10.9%) in orthopedic surgery; and 2,314 (10%) in ophthalmic surgery (Table III). Hernia repair was the most common operative procedure (22.4%), performed at a rate of 86.1 per 100,000 inhabitants, followed by cesarean deliveries (21%), at 80.6 per 100,000 inhabitants.

More than half (56.3%, 5,290/9,383) of the operative procedures in the governmental sector were either cesarean deliveries or hernia repairs (Fig 3). Nearly every (96.2%, 872/906) operative fracture treatment and the vast majority of all orthopedic operations (86.3%, 2,224/2,576) were performed in the private nonprofit sector.

The age of the patient was available in 73.4% (17,708/24,152) of the procedures. Surgery in children younger than 1 year of age was rare (1.2%, 205/17,708), whereas 12.3% (2,176/17,708) of operations were performed on children between 1 and 15 years. Adults between 16 and 33 years represented 41.3% (7,306/17,708) of the operative patients, whereas 45.3% (8,022/17,708) of the patients were 34 years of age or older.

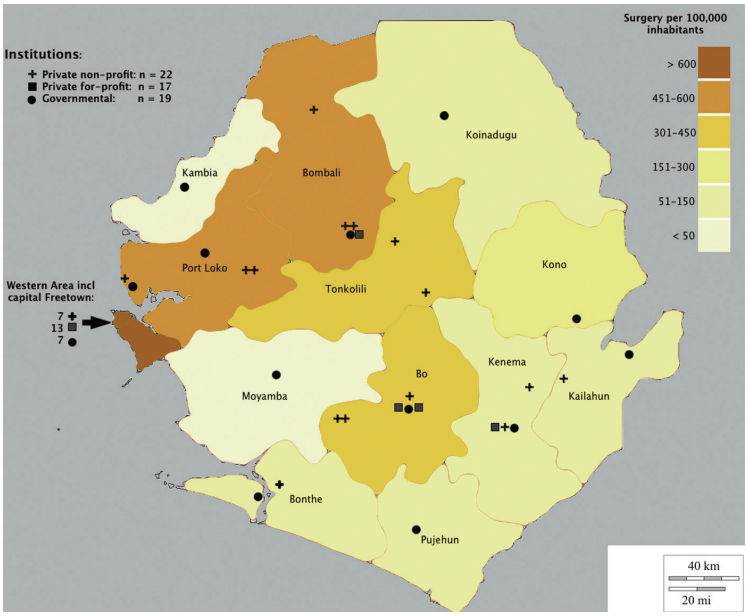

Fig 2. Location of 58 facilities providing surgery in Sierra Leone in 2012, and rate of surgery/100,000 by district.

Unmet need. The unmet need, calculated as the met need (24,152 performed procedures) subtracted from total need (307,000 [275,000–342,000] surgical procedures), was 283,000 (251,000–318,000), which equals to 4,700 (4,200–5,300) per 100,000 inhabitants. Thus, the unmet surgical need was 92.1% in Sierra Leone in 2012, and the district variation in the unmet need ranged from 82.1–99.4% (Table III).

DISCUSSION

A total of 400 operative procedures per 100,000 is very low, and at the lower end of previously published data on global operative volumes that range from 148 to 23,369 per 100,000 persons per year.[4] The rate of 400 per 100,000 is within the same range as of other studies from LICs, and equals 10% of the estimated average global rate for operations.[4,8] The 30-fold difference in operative production between the greatest and least served districts, ie, between predominantly urban and rural districts, highlights the degree to which rural populations are underserved. The scale of this domestic inequity in operative production is of the same proportion as the global inequity between the poorest and the richest parts of the world.[4]

The scale of domestic differences in surgical production is not well described, but greater operative volumes in referral hospitals, among urban populations and individuals with favorable economic status, are found in low and middle income countries.[20] Barriers to operative care in similar settings include lack of human resources, often the result of limited surgical training opportunities, poor operative health care infrastructure, long distances, the resultant costs related to operative care, and fear of undergoing surgery.[21-23]

Another intriguing finding was the division of operative activity between governmental and private actors. The fact that only 40% of all operations and almost no orthopedic operations were performed in public hospitals suggests that training opportunities are limited for the upcoming operative work force within governmental institutions. This lack is a particular concern, because the burden of trauma-related morbidities is increasing.[24] Targeted training programs for operative trauma care are needed at all levels of the health care system.

Because 54.0% of the total volume of operations in Sierra Leone was performed in the private nonprofit sector, this sector must be included in studies aspiring to establish population-based rates for surgical activity. To date, there is limited knowledge regarding the volume of operations performed by the private sector in low- and middle-income countries.[25,26] Furthermore, the

Table II. The estimated operative need, and met and unmet surgical needs by district

	District													
	Bo	*Bombali*	*Bonthe*	*Kailahun*	*Kambia*	*Kenema*	*Koinadugu*	*Kono*	*Moyamba*	*Port Loko*	*Pujehun*	*Tonkolili*	*Western area**	*Total*
Population (1,000)	624	469	160	443	325	622	319	306	263	530	321	413	1,244	6,039
Need of surgery†	31,700	23,800	8,100	22,500	16,500	31,600	16,200	15,500	13,300	26,900	16,300	21,000	63,100	307,000
Met need of surgery	3,057	2,405	152	497	124	815	340	631	83	3,134	304	1,305	11,305	24,152
Private nonprofit	69.6%	65.0%	82.9%	40.0%	—	16.8%	—	—	—	65.2%	—	100%	49.1%	54.0%
Private for-profit	15.9%	8.7%	—	—	—	4.5%	—	—	—	—	—	—	7.1%	6.4%
Governmental	14.6%	26.2%	17.1%	60.0%	100%	78.7%	100%	100%	100%	34.8%	100%	—	43.8%	39.6%
Surgery/100,000	490	513	95	112	38	131	107	206	32	591	95	316	909	400
Unmet need of surgery	28,600	21,400	8,000	22,000	16,400	30,800	15,900	14,900	13,300	23,800	16,000	19,700	51,800	282,000
% Unmet need	90.3	89.9	98.1	97.8	99.2	97.4	97.9	95.9	99.4	88.4	98.1	93.8	82.1	92.1

*Two districts, Western Area Rural and Western Area Urban, were combined as Western Area.
†Need estimate: 5,100 surgery/100,000.

potential of this sector in training and operative capacity building should not be underestimated.

More sophisticated methods of estimating the unmet need for surgery based on Disability-Adjusted Life Year calculations are suggested,[27] but a major obstacle when calculating the unmet need for surgery is to estimate the need, because there is no validated method. The lack of data on operative need in LICs is profound, but recently population studies from Rwanda, Sierra Leone, and Nepal[2,3,28] have described the need for surgery, and, thus, together with the present nationwide data on performed operations, the unmet need may be estimated.

The population studies used in this calculation have important limitations in estimating the need for surgical procedures within an operating theater. First, a self-reported need for operation is most likely different from a surgical need judged by a operative practitioner. Second, even some disabling operative conditions will not benefit from surgery, or the surgical condition can be treated outside an operating theater. Despite such limitations for estimating surgical need, however, there are no other good approaches, and the estimated annual need for surgery of 5,100/100,000, as used in this paper, seems reasonable and within the range of the average annual global surgical production rate of 4,000/100,000.[4] An operative need in Sierra Leone that is greater than the average global surgical production is also reasonable, because sub-Sahara Africa has the greatest burden of surgical diseases per capita.[1] For this reason, using the present model to estimate the need and the unmet need for surgery in Sierra Leone seems accurate. Our estimated unmet need for surgery of more than 90% is very high and demonstrates an urgent call to scale up surgical services in this country.

STRENGTHS AND LIMITATIONS

This study has limitations. It was retrospective, facility-based, and data were retrieved from registers. The distinction between clinic and hospital was a self-reported ability to provide 24-hour emergency service. We found that some very small private for-profit facilities categorize themselves as district hospitals, probably because they fell within the hospital definition because they offered 24-hour emergency in-patient services, although to a strictly selected subset of patients. The distinction between district hospital and referral hospital was equally difficult, as the definitions were not very clear.

Table III. Thirty-four predefined groups of the most commonly performed operative procedures, internal ranking, and percentage of the total volume of the procedures, and rates per 100,000 inhabitants

	General	*Obstetrics and Gynecology*	*Orthopedic*	*Ophthalmic*	*Percentage*	*Surgery/ 100,000*
Hernia Repair	5,202				22.4	86.1
Cesarean Delivery		4,868			21.0	80.6
General Surgery Other	2,417				10.4	40.0
Cataract Surgery				2,304	9.9	38.1
Appendectomy	1,630				7.0	27.0
Orthopedic Surgery Other			1,190		5.1	19.7
Laparotomy	1,036				4.6	17.2
Operative Fracture Treatment			906		3.9	15.0
Obstetrics and Gynecology Other		768			3.3	12.7
Dilation and Curretage		611			2.6	10.1
Hysterectomy		489			2.1	8.1
Incision and Drainage Abscess	384				1.7	6.4
Obstetric Fistula Repair		264			1.1	4.4
Amputation, Lower Limb			204		0.9	3.4
Salpingectomy Ectopic Pregnancy		174			0.7	2.9
General Cancer Surgery	174				0.7	2.9
Conservative Fracture Treatment			157		0.7	2.6
Manual Placenta Removal		122			0.5	2.0
Urethral Stricture Dilation	75				0.3	1.2
Amputation Upper Limb			60		0.2	1.0
Chest Tube	39				0.2	0.7
Cervical or Vaginal Laceration		27			0.1	0.4
Neonatal Surgery	18				0.1	0.3
Cystotomy	16				0.1	0.3
Tubal Ligation		14			0.1	0.2
Repair of Ruptured Uterus		12			0.1	0.2
Gynecology Cancer Surgery		11			0.0	0.2
Ophthalmic Surgery Other				10	0.0	0.2
Orthopedic Cancer Surgery			9		0.0	0.1
Tracheostomy	8				0.0	0.1
Cleft Lip Repair	2				0.0	0.0
Vasectomy	1				0.0	0.0
Episiotomy		1			0.0	0.0
Missing (949)					(3.9)	(15.8)
Total	11,002	7,361	2,526	2,314	100	400

The type of procedure was missing in 949 of the 24,152 entries (3.9%).

As opposed to a retrospective study, a prospective registration could be an option; however, it would have been considerably more resource-demanding and fewer locations could have been surveyed. A household study examining surgical procedures would include recall bias. Because data were collected from 96.7% of all surgical providers, it may be argued that population rates can be inferred.

Many sources for retrieving data on surgical procedures were considered. The surgeon's personal daily log, the operation theater log book, is considered by some to be the gold standard, and this was also the easiest data to obtain.[29] Personal variations in recording habits will always occur. On the contrary, inconsistencies in recording routines seems less likely in this study, because it used 3 potential sources to capture the operative procedure data.

The district rates are based on the notion that patients have their operation performed in the same district as they reside. A recent study from Mozambique revealed that patients undergoing operation travel greater distances than nonsurgical patients to receive care at a rural hospital.[30] Within this material, the patients' corresponding home addresses were available in only 26% (6,243/24,152) of the recorded procedures. Of these, 82% had their operation performed in the same district in which they were living. In a small country like Sierra Leone,

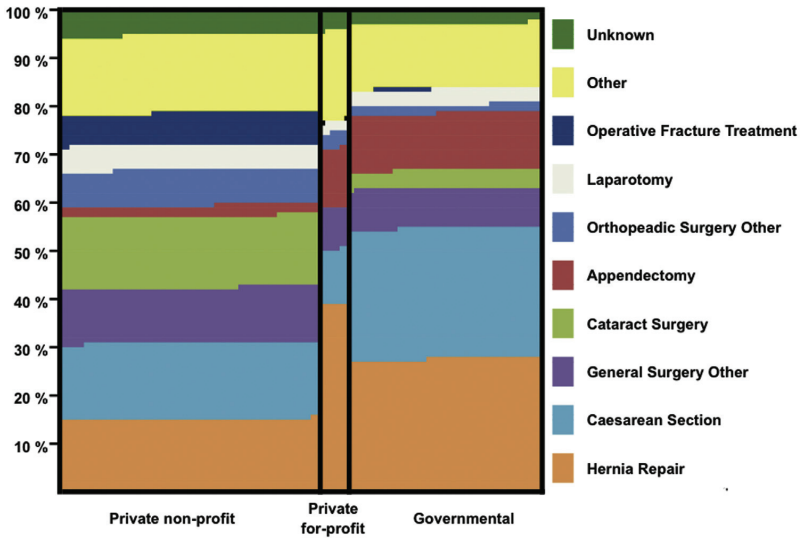

Fig 3. The rate of the most common procedures and their variation by owner category.

cross-district travel for operative health care is likely. This factor may decrease the differences between districts, and has to be taken into consideration when comparing rates of surgery at the district level. Cross-district travel will not affect national figures.

The challenge of calculating population rates from facility studies often is the difficulty in obtaining reliable catchment populations. The strength of this study is a trustworthy catchment population, as it equals the total population of Sierra Leone. Because foreigners represented only 1.7% of the patients with a known home address, immigration for operative care should be negligible. The emigration of Sierra Leonean operative patients crossing national borders was discussed with facility directors and surgical providers of hospitals located closest to the borders of neighboring countries. In the border regions, this was reported as unlikely at a larger scale; however, its extent is unknown.

Key implications. The main implication of this study is the finding of a very high unmet need for surgery in Sierra Leone. Since these data were collected, the Ebola epidemic has ravaged West Africa, with a considerable negative effect on hospital functioning, and it most likely further increased the unmet need. The finding that in-country variations in surgical output between the capital and the lowest served districts was as large as the differences between high- and low-income countries is important, because it demonstrates that a focus on operative care at the district hospital level still is important.[31] How can the findings in this study best support an expansion of surgical services in LICs? In the Sierra Leonean context, the following can be suggested based on this study:

1. Inclusion of the private for-profit and nonprofit sector when measuring the met need for surgery is important.
2. Strengthening district hospitals will balance out the large differences in operative output between the districts.
3. The monopolization of certain surgical services, such as orthopedic surgery, solely to the private sector should be avoided. Trauma care needs to be made available also in the governmental sector.
4. Because the private nonprofit sector is such a large contributor to the national surgical production, this sector needs to be included in surgical capacity building.
5. Because more than 55% of all operative procedures at governmental hospitals are either hernia repairs or cesarean sections, task-shifting of even a very narrow scope of the surgical practice would allow qualified surgeons, who are scarce, to use their knowledge and skills far more rationally, rather than performing basic surgical procedures in high numbers.

If operative care is to become an essential component of universal health coverage, there is a long way to go in Sierra Leone and, most likely, in

many other LICs. The fact that more than 90% of the operative need is unmet and that there is a very limited ability to provide trauma care, as well as a governmental sector that perform only a handful of operative procedures in large numbers, are major challenges that need to be addressed, if or when an expansion of surgical services is planned. A better understanding of the existing surgical platform is a good start to build upon.

We thank the Ministry of Health and Sanitation of Sierra Leone for supporting this study. We also thank all the in-charges of the 75 institutions that welcomed and shared their surgical activity data. We also thank the surgeons, gynecologists, medical officers, associate clinicians, and nurses who performed operations in Sierra Leone during 2012. We are very grateful to medical students from CHOMAS, Sierra Leone; Mustapha T. B. Kamara, Abdul Jibril Njai, Samuel L. Tarawally, Ibrahim Gassama, Komba K. Sonsiama, Yusuf Sheku Tejan, Aloysius Kalawa, Mohamed Sanusi Jalloh, and from NTNU, Norway; Siri Malene Rød, Pia Fiskaa Vestby, Anders W. Bjerring, and Marius Eknæs Lier for all their efforts in collecting data from 58 institutions in Sierra Leone in 2013. Thanks to Dr Klaus Melf for help with logistics and quality control during the data collection. Finally, we are grateful to Surgeons OverSeas (SOS) and Dr Groen in particular for sharing their data from the SOSAS survey performed in Sierra Leone in 2012. Finally, thanks to Thomas G Weiser and Lars Hagander for commenting on early drafts of the manuscript and for their invaluable advice on improvements.

REFERENCES

1. Debas HT, Gosselin R, McCord C, Thind A. Disease control priorities in developing countries. 2nd ed. Washington (DC): World Bank; 2006:1246-9.
2. Petroze RT, Groen RS, Niyonkuru F, Mallory M, Ntaganda E, Joharifard S, et al. Estimating operative disease prevalence in a low-income country: results of a nationwide population survey in Rwanda. Surgery 2013;153:457-64.
3. Groen RS, Samai M, Stewart KA, Cassidy LD, Kamara TB, Yambasu SE, et al. Untreated surgical conditions in Sierra Leone: a cluster randomised, cross-sectional, countrywide survey. Lancet 2012;380:1082-7.
4. Weiser TG, Regenbogen SE, Thompson KD, Haynes AB, Lipsitz SR, Berry WR, et al. An estimation of the global volume of surgery: a modelling strategy based on available data. Lancet 2008;372:139-44.
5. Meara JG, Hagander L, Leather AJ. Surgery and global health: a Lancet Commission. Lancet 2014;383:12-3.
6. Chirdan LB, Ameh EA. Untreated surgical conditions: time for global action. Lancet 2012;380:1040-1.
7. Ozgediz D, Jamison D, Cherian M, McQueen K. The burden of surgical conditions and access to surgical care in low- and middle-income countries. Bull World Health Organ 2008;86:646-7.
8. Henry JA, Frenkel E, Borgstein E, Mkandawire N, Goddia C. Surgical and anaesthetic capacity of hospitals in Malawi: key insights. Health Policy Plan 2014 Sep 26:1-10.
9. Knowlton LM, Chackungal S, Dahn B, LeBrun D, Nickerson J, McQueen K. Liberian surgical and anesthesia infrastructure: a survey of county hospitals. World J Surg 2013;37:721-9.
10. Lebrun DG, Saavedra-Pozo I, Agreda-Flores F, Burdic ML, Notrica MR, McQueen KA. Surgical and anesthesia capacity in Bolivian public hospitals: results from a national hospital survey. World J Surg 2012;36:2559-66.
11. Notrica MR, Evans FM, Knowlton LM, Kelly McQueen KA. Rwandan surgical and anesthesia infrastructure: a survey of district hospitals. World J Surg 2011;35:1770-80.
12. Grimes CE, Law RS, Borgstein ES, Mkandawire NC, Lavy CB. Systematic review of met and unmet need of surgical disease in rural sub-Saharan Africa. World J Surg 2012;36:8-23.
13. Kingham TP, Kamara TB, Cherian MN, Gosselin RA, Simkins M, Meissner C, et al. Quantifying surgical capacity in Sierra Leone: a guide for improving surgical care. Arch Surg 2009;144:122-7; discussion 8.
14. Statistics Sierra Leone. Sierra Leone Population and Housing Census 2004. 2004. Available from: http://www.sierra-leone.org/Census/ssl_final_results.pdf.
15. Sierra Leone Ministry of Health and Sanitation. 2010 Health Sector Performance Report. Freetown: Government of Sierra Leone; 2012.
16. World Health Organisation. The global health expenditure database 2014 [25.07.2014]. Available from: http://apps.who.int/nha/database/Select/Indicators/en.
17. Sierra Leone Ministry of Health and Sanitation. Sierra Leone Service Availability and Readiness Assessment 2011. Freetown: Sierra Leone Ministry of Health and Sanitation; 2012.
18. World Health Organization. Service Availability and Readiness Assessment 2012. Available from: http://www.who.int/healthinfo/systems/sara_introduction/en/index.html.
19. Kwon S, Groen RS, Kamara TB, Cassidy LD, Samai M, Yambasu SE, et al. Nationally representative household survey of surgery and mortality in Sierra Leone. World J Surg 2013;37:1829-35.
20. Zafar SN, Fatmi Z, Iqbal A, Channa R, Haider AH. Disparities in access to surgical care within a lower income country: an alarming inequity. World J Surg 2013;37:1470-7.
21. Hoyler M, Finlayson SR, McClain CD, Meara JG, Hagander L. Shortage of doctors, shortage of data: a review of the global surgery, obstetrics, and anesthesia workforce literature. World J Surg 2014;38:269-80.
22. Leow JJ, Brundage SI, Kushner AL, Kamara TB, Hanciles E, Muana A, et al. Mass casualty incident training in a resource-limited environment. Br J Surg 2012;99:356-61.
23. Grimes CE, Bowman KG, Dodgion CM, Lavy CB. Systematic review of barriers to surgical care in low-income and middle-income countries. World J Surg 2011;35:941-50.
24. Norton R, Kobusingye O. Injuries. N Engl J Med 2013;368:1723-30.
25. McQueen KA, Hyder JA, Taira BR, Semer N, Burkle FM Jr, Casey KM. The provision of surgical care by international organizations in developing countries: a preliminary report. World J Surg 2010;34:397-402.
26. Shrime MG, Sleemi A, Ravilla TD. Charitable platforms in global surgery: a systematic review of their effectiveness, cost-effectiveness, sustainability, and role training. World J Surg 2015;39:10-20.
27. Bickler S, Ozgediz D, Gosselin R, Weiser T, Spiegel D, Hsia R, et al. Key concepts for estimating the burden of surgical conditions and the unmet need for surgical care. World J Surg 2010;34:374-80.

28. Gupta S, Ranjit A, Shrestha R, Wong EG, Robinson WC, Shrestha S, et al. Surgical needs of Nepal: pilot study of population based survey in pokhara, Nepal. World J Surg 2014;38:3041-6.
29. Holt G, Feurer ID, Schwartz HS. An analysis of concordance among hospital databases and physician records. Ann Surg Oncol 1998;5:553-6.
30. Faierman ML, Anderson JE, Assane A, Bendix P, Vaz F, Rose JA, et al. Surgical patients travel longer distances than non-surgical patients to receive care at a rural hospital in Mozambique. Int Health 2015;7:60-6.
31. Luboga S, Macfarlane SB, von Schreeb J, Kruk ME, Cherian MN, Bergstrom S, et al. Increasing access to surgical services in sub-Saharan Africa: priorities for national and international agencies recommended by the Bellagio Essential Surgery Group. PLoS Med 2009;6: e1000200.

Paper II

World J Surg
DOI 10.1007/s00268-016-3417-1

ORIGINAL SCIENTIFIC REPORT

The Surgical Workforce and Surgical Provider Productivity in Sierra Leone: A Countrywide Inventory

Håkon A. Bolkan[1] · Lars Hagander[2] · Johan von Schreeb[3] · Donald Bash-Taqi[4] · Thaim B. Kamara[5] · Øyvind Salvesen[1] · Arne Wibe[1]

Abstract

Background Limited data exist on surgical providers and their scope of practice in low-income countries (LICs). The aim of this study was to assess the distribution and productivity of all surgical providers in an LIC, and to evaluate correlations between the surgical workforce availability, productivity, rates, and volume of surgery at the district and hospital levels.

Methods Data on surgeries and surgical providers from 56 (93.3 %) out of 60 healthcare facilities providing surgery in Sierra Leone in 2012 were retrieved between January and May 2013 from operation theater logbooks and through interviews with key informants.

Results The Sierra Leonean surgical workforce consisted of 164 full-time positions, equal to 2.7 surgical providers/100,000 inhabitants. Non-specialists performed 52.8 % of all surgeries. In rural areas, the densities of specialists and physicians were 26.8 and 6.3 times lower, respectively, compared with urban areas. The average individual productivity was 2.8 surgeries per week, and varied considerably between the cadres of surgical providers and locations. When excluding four centers that only performed ophthalmic surgery, there was a positive correlation between a facility's volume of surgery and the productivity of its surgical providers ($r_s = 0.642$, $p < 0.001$).

Conclusions Less than half of all of the surgery in Sierra Leone is performed by specialists. Surgical providers were significantly more productive in healthcare facilities with higher volumes of surgery. If all surgical providers were as productive as specialists in the private non-profit sector (5.1 procedures/week), the national volume of surgery would increase by 85 %.

✉ Håkon A. Bolkan
hakon.a.bolkan@ntnu.no

[1] Department of Cancer Research and Molecular Medicine, Norwegian University of Science and Technology, Box 8905, 7491 Trondheim, Norway

[2] Paediatric Surgery and Global Paediatrics, Department of Paediatrics, Clinical Sciences Lund, Lund University, Lund, Sweden

[3] Health System and Policy Research Group, Karolinska Institutet, 171 77 Stockholm, Sweden

[4] Ministry of Health and Sanitation, Freetown, Sierra Leone

[5] Department of Surgery, Connaught Hospital and College of Medicine Allied Health Sciences, University of Sierra Leone, Freetown, Sierra Leone

Introduction

To achieve universal health coverage, it is critical to distribute human resources for health to match the population's needs [1, 2]. In Sub-Saharan Africa, the surgeon density is reported to range from 0.2 to 1.0 per 100,000 people [3], which is between 15 and 450 times lower than in OECD countries [4]. The lack of skilled providers is considered a main barrier to the expansion of surgical care [5, 6], and there is a particular mismatch between the large unmet need for surgery and the shortage of surgical providers in rural areas in low-income countries (LICs) [7, 8].

To cover the surgical need in LICs only through fully certified surgeons is considered inconceivable in the

Published online: 28 January 2016

foreseeable future [9]. An increasingly applied and acknowledged strategy has been to share surgical tasks with other categories of health care workers [9, 10]. In LICs, a wide range of health care workers perform surgical procedures, including surgeons, obstetricians, non-specialist physicians, midwifes, nurses, and associate clinicians [11, 12]. Comprehensive data that on a national scale describe the full scope of such surgical providers in the setting of LICs are lacking [3].

In order to develop policies to make surgery more available in areas where needs are high, data on the domestic distribution and scope of practice of the surgical workforce are needed. The purpose of this study was to identify all surgical providers in an entire LIC, to map the distribution and productivity of this surgical workforce, and to evaluate correlations between the surgical workforce density, productivity, and rates of surgery.

Methods

This countrywide facility-based study included data on all surgical providers in Sierra Leone in 2012. The Sierra Leone Ministry of Health and Sanitation and the non-governmental organization CapaCare jointly collected the data in collaboration with the Norwegian University of Technology and Science (NTNU). Eligible for inclusion in the study were all health care facilities that performed one or more of the 21 surgical procedures defined in the World Health Organization (WHO) health facility assessment tool SARA [13]. Twelve 4th- and 5th-year medical candidates from the University of Sierra Leone and NTNU interviewed between January 14 and May 20, 2013 all of the facility directors regarding the workforce availability and collected data on the surgeries performed. Procedure-related surgical data were obtained from operation theater logbooks, maternity books, and anesthesia logbooks. The methodology and definitions of categories for the owner and administrative levels of the facilities have been described previously [14].

Of the 60 facilities identified to have performed surgical procedures in Sierra Leone in 2012, surgical records were available in 58 institutions, of which 56 (93.3 %, 56/60) also shared data on the surgical providers [14]. Of the 24,152 surgeries identified, information on the surgical provider category was available for 23,693 (98.1 %) surgeries.

Definitions

A *surgical procedure* was defined as any procedure requiring general, regional, or local anesthesia performed within an operation theater [15]. A *surgical provider* was defined as a person who, according to the log book, was the principal operator in the included facilities in 2012. A *specialist* was defined as a senior physician who had completed specialist training in surgery, orthopedics, gynecology/obstetrics, ophthalmology, or otolaryngology. A *physician* was defined as a non-specialist holder of a medical degree and included house officers, who are physicians in the 2-year obligatory postgraduation internship. A medical practitioner licensed by the Sierra Leone Nurses & Midwives Board was listed as a *nurse*. All others were defined as *associate clinicians*. A surgical provider with a Sierra Leonean passport was defined as a *domestic provider*; all others were defined as *foreigners*. The term *surgical workforce* refers to all surgical providers.

Surgical providers were quantified as equivalent *full-time positions*. A half-time position for 1 year and a full-time position (FTP) for 6 months both counted as a 0.5 FTP. *Productivity* was defined as the weekly number of surgical procedures performed per FTP. Villages with $<$50,000 inhabitants were considered rural [16]. The neighboring districts of Western Area Urban and Western Area Rural were merged into one district labeled Western Area because of difficulties in distinguishing between the two. The two facilities without surgical human resource data were both located in the country's smallest district, Bonthe; this resulted in the inclusion of 12 districts in the analysis.

Analysis

The 2012 projections from the most recent census were used to calculate the density of the workforce [17]. SPSS version 21 and R version 2.13.1 were used for descriptive statistics and statistical analysis. The Chi-square test for trends was used to assess if preference for working in rural areas decreased with higher degree of specialization. Spearman's rank correlation (r_s) was used to explore the relationship between the rate of surgery, the density, and the productivity of surgical providers. The Sierra Leone Ethics and Scientific Review Committee and the Regional Committee for Medical and Health Research Ethics in central Norway (No: 2012/2187) granted ethical clearance for this study.

Results

Distribution and density

The Sierra Leonean surgical workforce consisted of 164 FTPs, of which 35.6 % were specialists, 52.3 % were physicians, 3.8 % were nurses, and 8.4 % were associate clinicians. Less than one-quarter (24.8 %) of the total

Table 1 Distribution of surgical providers by full-time positions (FTP) in Sierra Leone in 2012

Variable	No. (%)[a]				
	All 164.4 (35.6)	Specialist 86.0 (52.3)	Physician 6.2 (3.8)	Nurse 13.8 (8.4)	Associate clinician
Organizational level					
Clinic	17.9 (10.9)	9.4 (16.1)	3.3 (3.9)	2.1 (35.1)	3 (21.8)
District hospital	75.7 (46.0)	19.2 (32.9)	43.7 (50.8)	2 (32.4)	10.7 (78.2)
Referral hospital	70.8 (43.1)	29.8 (51.0)	39 (45.3)	2 (32.4)	0 (–)
Owner					
Governmental	76.3 (46.4)	21.3 (36.3)	50.1 (58.2)	2 (32.4)	3 (21.8)
Private non-profit	71.8 (43.7)	26.4 (45.2)	32.6 (37.9)	4.1 (66.2)	8.8 (63.6)
Private for-profit	16.2 (9.9)	10.8 (18.5)	3.3 (3.9)	0.1 (1.4)	2 (14.5)
Urban/rural					
Urban	123.6 (75.2)	53.2 (90.9)	60.6 (70.4)	4.1 (66.2)	5.8 (41.8)
Rural	40.8 (24.8)	5.3 (9.1)	25.4 (29.6)	2.1 (33.8)	8 (58.2)
District[b]					
Bo	11 (6.7)	6.1 (10.4)	3.3 (3.9)	0.1 (1.4)	1.5 (10.9)
Bombali	12.4 (7.5)	2.4 (4.1)	6 (7.0)	1 (16.2)	3 (21.8)
Kailahun	6 (3.6)	0 (–)	4 (4.7)	1 (16.2)	1 (7.3)
Kambia	3.1 (1.9)	0 (–)	2.1 (2.4)	0 (–)	1 (7.3)
Kenema	7.4 (4.5)	2.3 (4.0)	5 (5.8)	0.1 (1.4)	0 (–)
Koinadugu	1.2 (0.7)	0.2 (0.3)	1 (1.2)	0 (–)	0 (–)
Kono	3 (1.8)	0 (–)	3 (3.6)	0 (–)	0 (–)
Moyamba	2 (1.2)	0 (–)	2 (2.3)	0 (–)	0 (–)
Port Loko	10.4 (6.3)	1.3 (2.3)	7.1 (8.2)	0 (–)	2 (14.5)
Pujehun	5 (3.0)	1 (1.7)	4 (4.7)	0 (–)	0 (–)
Tonkolili	7.6 (4.6)	0.3 (0.6)	3.3 (3.8)	0 (–)	4 (29.1)
Western Area[c]	95.3 (58.0)	44.8 (76.6)	45.3 (52.6)	4 (64.8)	1.25 (9.1)
Nationality					
Domestic	125.2 (76.1)	39.3 (67.2)	66 (76.7)	6.2 (100)	13.8 (100)
Foreign	39.2 (23.8)	19.2 (32.8)	20 (23.3)	0 (–)	0 (–)

[a] Because of rounding, percentages may not total 100

[b] Excluding Bonthe district

[c] Western Area Urban and Western Area Rural combined

surgical workforce and one-tenth (9.1 %) of the specialists worked in rural areas. More than three-quarters (76.1 %) of the surgical providers were Sierra Leonean nationals. The private non-profit sector employed 43.7 % of the surgical workforce and performed 53.8 % of the surgeries (Table 1).

Four of the 12 districts, accounting for more than 1.3 million people (22.1 % of the population), lacked a specialist surgical provider. Six of the districts, accounting for more than 2 million people (34.0 % of the population), had less than one full-time specialist position (Table 1). The national mean density of surgical providers was equivalent to 2.72 FTP per 100,000 inhabitants, of which there were 0.97 specialists, 1.42 physicians, 0.10 nurses, and 0.23 associate clinicians. The overall density of surgical providers was 8.0 times higher in urban areas than in rural areas. The densities of specialists and physicians were 26.8 and 6.3 times higher in urban compared with rural areas (Table 2). The more specialized the provider, the more likely they were to work in urban areas ($p < 0.001$). There was a positive correlation between the rate of surgery and the density of surgical providers at the district level ($r_s = 0.853$, $p < 0.001$) (Fig. 1a).

Scope of practice

Specialists performed 47.2 % of all surgeries, while physicians performed 39.4 %, nurses 6.6 %, and associate clinicians 6.8 %. Specialists had the most diverse surgical activity and performed a wider scope of procedures

Table 2 National, urban, and rural density of surgical providers by cadre and nationality

	Density		
	National	Urban	Rural
Cadres			
Specialist	0.97	3.21	0.12
Physician	1.42	3.65	0.58
Nurse	0.10	0.25	0.05
Associate clinician	0.23	0.35	0.18
Nationality			
Domestic	2.07	5.78	0.68
Foreign	0.65	1.68	0.26
All surgical providers	2.72	7.45	0.93

Density, number of surgical providers per 100,000 inhabitants

compared with less-specialized cadres. Fifty-three percent of the procedures performed by physicians and 62 % of the procedures performed by the associate clinicians were either a hernia repair or a cesarean delivery. Specialists and physicians performed 95.5 % of orthopedic surgeries. Forty-six percent of all surgical procedures performed by nurses were ophthalmic procedures, mostly cataract surgery (Table 3).

Productivity

Overall, the average productivity was 2.8 surgeries per week. By cadre, nurses were the most productive, performing 4.9 procedures per week, compared with physicians, who performed 2.1 procedures per week. Specialists working in the private non-profit sector performed a mean

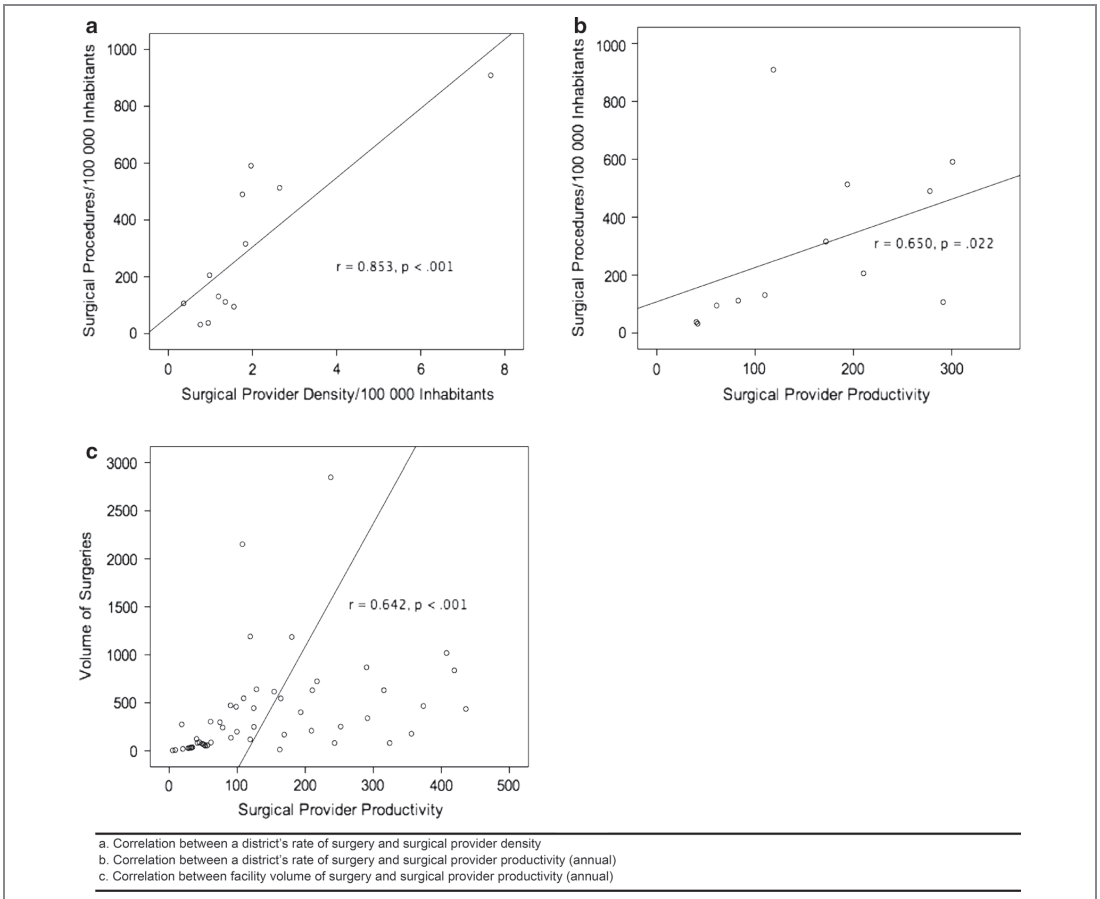

Fig. 1 **a** Correlation between a district's rate of surgery and surgical provider density. **b** Correlation between a district's rate of surgery and surgical provider productivity. **c** Correlation between a facility's volume of surgery and its surgical provider productivity

Table 3 Surgical procedures by surgical providers

Procedure	No. (%)[a]				
	All 23,693	Specialist 11,172 (47.2)	Physician 9328 (39.8)	Nurse 1574 (6.6)	Associate clinician 1619 (6.8)
General surgery					
Hernia repair	5127	1709 (33.3)	2511 (49.0)	240 (4.7)	667 (13.0)
Appendectomy	1599	460 (28.8)	1105 (69.1)	7 (0.4)	27 (1.7)
Laparotomy	1009	439 (43.5)	477 (47.3)	23 (2.3)	70 (6.9)
General surgery other	2329	1327 (57.0)	736 (31.6)	87 (3.7)	179 (7.7)
Malignancy surgical	173	156 (90.2)	15 (8.7)	0 (–)	2 (1.2)
Obstetric and gynecology					
Cesarean delivery	4737	1822 (38.5)	2458 (51.9)	118 (2.5)	339 (7.2)
Obgyn other	743	311 (41.9)	413 (55.6)	6 (0.8)	13 (1.7)
Dilatation and curettage	606	293 (48.3)	240 (39.6)	5 (0.8)	68 (11.2)
Hysterectomy	474	217 (45.8)	216 (45.6)	6 (1.3)	35 (7.4)
Incision and drainage abscess	370	168 (45.4)	124 (33.5)	6 (1.6)	72 (19.5)
Obstetric fistula repair	264	171 (64.8)	93 (35.2)	0 (–)	0 (–)
Salpingectomy ectopic pregnancy	172	93 (54.1)	74 (43.0)	1 (0.6)	4 (2.3)
Manual placenta removal	121	21 (17.4)	81 (66.9)	0 (–)	19 (15.7)
Orthopedic surgery					
Orthopedic surgery other	1169	752 (64.3)	334 (28.6)	8 (0.7)	75 (6.4)
Fracture operative	897	725 (80.8)	170 (19.0)	0 (–)	2 (0.2)
Amputation lower limb	203	115 (56.7)	68 (33.5)	1 (0.5)	19 (9.4)
Fracture conservative	154	82 (53.2)	69 (44.8)	0 (–)	3 (1.9)
Ophthalmic surgery	2304	1580 (68.6)	0 (–)	724 (31.4)	0 (–)
Other[b]	306	211 (69.0)	70 (22.9)	7 (2.3)	18 (5.9)
Unknown procedure	936	521 (55.6)	74 (7.9)	335 (35.8)	7 (0.7)

[a] Because of rounding, percentages may not total 100

[b] Procedures performed less than 100/year

number of 5.1 surgeries per week, almost twice that of specialists in the governmental sector (2.8/week). For physicians, the productivity was the same in the private non-profit sector and the governmental sector (2.1 and 2.2/week). Specialists performed 2.9 procedures per week in the referral hospitals, almost twice the productivity of the physicians (1.5/week) in the same hospitals. Physicians performed 60 % of all of their surgeries in the district hospitals, with a mean productivity of 2.7 surgeries per week (Table 4).

If the productivity of all surgical providers could be increased to the same level as that of the specialists in the private non-profit sector, the national volume of surgery in Sierra Leone would increase from 23,693 to ~43,500 (5.1 weekly surgeries × 52 weeks × 164 FTP), an increase of 85 %.

Districts with higher surgical rates had a significantly higher productivity per surgical provider ($r_s = 0.650$, $p = 0.022$) (Fig. 1b) [14]. When excluding the four centers that only performed ophthalmic surgery, there was also a positive correlation between a facility's volume of surgery and the productivity of its surgical providers ($r_s = 0.642$, $p < 0.001$) (Fig. 1c).

Discussion

The density of specialist surgical providers was very low, and within the range of other Sub-Saharan countries [18]. The current specialist surgical workforce represents less than 5 % of the targeted 20 surgical, anesthetic, and obstetric providers the Lancet Commission recommends per 100,000 population [11]. The urban to rural maldistribution of surgical providers was striking, and the imbalance increased with higher degree of medical specialization. As in other resource-poor settings of the world where fully trained surgeons are absent, the patients in Sierra Leone are either cared for by other surgical providers, or they are not cared for at all [3]. From a human resource perspective, strategies to increase surgical

Table 4 Annual volume of surgical procedures and productivity by organizational level and owner

Variable	No. (P)				
	All	Specialist	Physician	Nurse	Associate clinician
Organizational level					
Clinic	4012 (4.3)	2852 (5.8)	198 (1.1)	669 (5.9)	293 (1.9)
District hospital	11,743 (3.0)	3796 (3.8)	6123 (2.7)	498 (4.8)	1326 (2.4)
Referral hospital	7938 (2.2)	4524 (2.9)	3007 (1.5)	407 (3.9)	0 (–)
Owner					
Governmental	9408 (2.4)	3091 (2.8)	5700 (2.2)	406 (3.9)	211 (1.4)
Private non-profit	12,749 (3.4)	6999 (5.1)	3481 (2.1)	1148 (5.4)	1121 (2.5)
Private for-profit	1536 (1.8)	1082 (1.9)	147 (0.8)	20 (4.6)	287 (2.8)
Total	23,693 (2.8)	11,172 (3.7)	9328 (2.1)	1574 (4.9)	1619 (2.3)

P productivity, weekly number of surgical procedures per full-time position

capacity include training new surgical specialist providers, sharing surgical tasks with more healthcare workers, and using the entire workforce more efficiently. Our findings indicate that all three approaches are relevant in the Sierra Leonean context.

New surgical providers

Accredited postgraduate training by the West African College of Surgeons is not presently available in Sierra Leone [19]. Affording domestic physicians this opportunity is crucial, but most likely, it will primarily strengthen the surgical workforce in urban areas, at least initially. Surgical training of non-specialist physicians for the district hospitals remains essential, and surgical specialists play an important role as trainers in this process. It is therefore a concern that specialists perform the majority of their surgeries in the private non-profit sector that traditionally has prioritized service delivery [20]. Physicians perform as few as 1.5 surgeries per FTP per week in the main training hospitals, which are the referral hospitals. This indicates that the referral hospitals, that also provide postgraduate training of house officers might be better utilized as capacity builders for surgery in Sierra Leone. Training specialist surgeons and non-specialist physicians is limited by the country's low production and retention of medical doctors. As of 2013, a total of 257 had graduated since the establishment of the medical school in 1988, and a substantial proportion is practicing outside of Sierra Leone [21].

Increasing productivity

Districts with lower volumes of surgery not only had a lower workforce density, but also a less productive surgical workforce, which makes them even more marginalized in terms of surgical output. Surgical productivity also varied considerably between categories of health care workers and work locations, and there might be a potential to utilize the surgical workforce more efficiently. If the productivity of all surgical providers could be increased to the same level as that of the specialists in the private non-profit sector, the national volume of surgery in Sierra Leone would be almost doubled.

The positive correlation between volume of surgery at the district and facility levels and productivity per surgical provider may have several explanations, like quality of surgery, confidence among surgical providers to manage surgical cases, an acceptable infrastructure, and trust between patients and practitioners.

Task sharing

Due to the towering shortages of surgical providers in the rural areas of Sierra Leone, it is not sufficient to increase the productivity of the few working in this environment. Several findings in the present study support regulated delegation of surgical tasks to less-specialized health care workers. Firstly, surgery is already widely performed by non-specialist physicians, nurses, and associate clinicians. Secondly, all of the nurses and associate clinicians performing surgery are Sierra Leonean health care workers, and nearly all of the procedures performed by associate clinicians are performed at district hospitals, where the surgical need is highest. The retention of associate clinicians at district hospitals is described to be far better than for physicians [22]. Thirdly, hernia repair and cesarean delivery comprise more than 50 % of the surgical volume of physicians and 30 % for specialist providers, and sharing these standardized, high-volume procedures with less-trained providers would allow highly skilled surgical specialists to use their expertise more productively.

The density of specialist surgeons, anesthesiologists, and obstetricians is proposed as an indicator of the surgical workforce [11]. As the present study found that specialists performed fewer than half of the surgeries, it should be noted

that this human resource metric underestimates the full range of surgical providers in a low-income country such as Sierra Leone. Data on the subnational distribution of all cadres performing surgeries are required for a more comprehensive understanding of the national response to specialist shortages. Obviously, many other elements in a surgical health care system need to be addressed in order to increase surgical output, such as infrastructure, anesthesia care, supply chain management, affordability, and timely access for patients [11].

Limitations

This is a comprehensive nationwide inventory of the surgical workforce, but certain limitations exist that are related to the data collection, the definitions, and the volume of surgery. These limitations include the retrospective design, challenges in categorizing some of the health care facilities, and the fact that district rates of surgery were based on the notion that patients have their operation performed in the same district as they reside [14]. The population projection for 2012 is based on the most recent census, performed several years earlier, and represents a potential source of error. Applying FTP instead of headcounts made it possible to adjust for multiple work locations and high turnover rates, and it allowed us to calculate productivity, since the time dimension was included. There could be a potential for the facility directors to overestimate the size of the surgical provider positions, but our findings are consistent with headcounts from 10 governmental hospitals in Sierra Leone in 2012 [19].

When calculating productivity, all surgical procedures were weighted equally. Thus, it is not unexpected that nurses, who mostly performed cataract surgeries, were the most productive providers due to the nature of the surgery performed. The same will probably apply when comparing productivity between administrative levels, as the referral hospitals performed more complex and resource-intensive procedures compared with clinics and district hospitals. This effect is likely less relevant for productivity analysis related to the district level, since clinics with high productivity balance the referral hospital with lower productivity in the same larger urban areas.

Conclusion

The findings of this study can guide strategies to increase the capacity of the surgical workforce in an LIC. Postgraduate surgical training of specialists is crucial for developing professional champions. There seems to be a potential to improve the exposure and informal training of non-specialist physicians in the referral hospitals. The large untapped potential of using the existing surgical workforce more efficiently should be explored. Expanding the surgical workforce by regulated task sharing to associate clinicians and nurses will promote equity and may match population needs by increasing the surgical workforce where the needs are highest [14]. In short-term workforce planning, it is recommended to engage the private non-profit sector, where specialists currently perform the largest volume of surgeries.

Acknowledgments We are very grateful to Dr. Klaus Melf, Ph.D., University of Bergen, Norway for help with logistics and quality control during the data collection in Sierra Leone.

Compliance with ethical standards

Conflict of interest The first author, Dr. Bolkan, is chair of CapaCare, a non-profit organization that provides surgical training to physicians and associate clinicians in Sierra Leone. There are no other conflicts of interest reported from the other authors.

Appendix

Box/sidebar: surgery in Sierra Leone

Setting

- 14 districts, 6 million inhabitants, 60 % living in rural areas [17].
- Life expectancy is 45.6 years, infant mortality is 117/1,000 live births, and maternal mortality is 890/100,000 live births [23].
- Expenditure on health per capita is US $96 (2012) [24].
- 1054 primary health care units and 51 hospitals [24].

Surgical need

- 25 % of the population has a surgical condition requiring medical attention [25].
- 25 % of recent deaths could have been averted by timely surgical care [25].
- More than 90 % of the surgical need is unmet [14].
- There is a 30-fold difference in surgical production between the highest- and lowest-served districts [14].

Surgical infrastructure and production in 2012

- Ten consultant surgical providers, median age 60.5 years, were identified in 10 governmental hospitals; all worked in the capital [19].

- 60 facilities offer major surgery [14].
  - 34 district hospitals performed 50 % of the surgical procedures [14].
  - Seven referral hospitals performed 33 % of the surgical procedures [14].
- 54 % of all surgeries were performed by private non-profit actors [14].

References

1. UN General Assembly (2012) Resolution adopted by the General Assembly. Global Health and Foreign Policy A/RES/67/81. http://www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/67/81. Accessed 23 Sept 2015
2. Global Health Workforce Alliance, World Health Organization (2014) A universal truth: no health without a workforce. Forum Report, Third Global Forum on Human Resources for Health. http://www.who.int/workforcealliance/knowledge/resources/GHWA_AUniversalTruthReport.pdf. Accessed 23 Sept 2015
3. Holmer H, Lantz A, Kunjumen T et al (2015) Global distribution of surgeons, anaesthesiologists, and obstetricians. Lancet Glob Health 3(Suppl 2):S9–S11. doi:10.1016/S2214-109X(14)70349-3
4. Organisation for Economic Co-operation and Development (2015) OECD health data: health care resources. doi:10.1787/data-00541-en
5. Grimes CE, Bowman KG, Dodgion CM et al (2011) Systematic review of barriers to surgical care in low-income and middle-income countries. World J Surg 35:941–950. doi:10.1007/s00268-011-1010-1
6. Ozgediz D, Kijjambu S, Galukande M et al (2008) Africa's neglected surgical workforce crisis. Lancet 371:627–628. doi:10.1016/S0140-6736(08)60279-2
7. Knowlton LM, Chackungal S, Dahn B et al (2013) Liberian surgical and anesthesia infrastructure: a survey of county hospitals. World J Surg 37:721–729. doi:10.1007/s00268-013-1903-2
8. Henry JA, Frenkel E, Borgstein E et al (2015) Surgical and anaesthetic capacity of hospitals in Malawi: key insights. Health Policy Plan 30:985–994. doi:10.1093/heapol/czu102
9. Mock CN, Donkor P, Gawande A et al (2015) Essential surgery: key messages from disease control priorities, 3rd edition. Lancet 385:2209–2219. doi:10.1016/S0140-6736(15)60091-5
10. World Health Organisation (2008) Task shifting: rational redistribution of tasks among health workforce teams: global recommendations and guidelines. http://www.who.int/healthsystems/TTR-TaskShifting.pdf?ua=1. Accessed 23 Sept 2015
11. Meara JG, Leather AJ, Hagander L et al (2015) Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. Lancet 386:569–624. doi:10.1016/S0140-6736(15)60160-X
12. Bellagio Essential Surgery Group (2007) Conference on increasing access to surgical services in resource-constrained settings in Sub-Saharan Africa. http://essentialsurgery.org/bellagio/docs/bellagio_report.pdf. Accessed 23 Sept 2015
13. World Health Organization (2012) Service availability and readiness assessment health statistics and information systems. http://www.who.int/healthinfo/systems/sara_introduction/en/index.html. Accessed 23 Sept 2015
14. Bolkan HA, Von Schreeb J, Samai MM et al (2015) Met and unmet needs for surgery in Sierra Leone: a comprehensive, retrospective, countrywide survey from all health care facilities performing operations in 2012. Surgery 157:992–1001. doi:10.1016/j.surg.2014.12.028
15. Weiser TG, Regenbogen SE, Thompson KD et al (2008) An estimation of the global volume of surgery: a modelling strategy based on available data. Lancet 372:139–144. doi:10.1016/S0140-6736(08)60878-8
16. United Nations Centre for Human Settlement (2001) Compendium of human settlements statistics. ISBN: 92-1-161434-1
17. Statistics Sierra Leone (2006) Sierra Leone population and housing census 2004. http://www.statistics.sl/2004_population_and_housing_census.htm. Accessed 23 September 2015
18. Hoyler M, Finlayson SR, McClain CD et al (2014) Shortage of doctors, shortage of data: a review of the global surgery, obstetrics, and anesthesia workforce literature. World J Surg 38:269–280. doi:10.1007/s00268-013-2324-y
19. Vaughan E, Sesay F, Chima A et al (2015) An assessment of surgical and anesthesia staff at 10 government hospitals in Sierra Leone. JAMA Surg 150:237–244. doi:10.1001/jamasurg.2014.2246
20. Shrime MG, Sleemi A, Ravilla TD (2015) Charitable platforms in global surgery: a systematic review of their effectiveness, cost-effectiveness, sustainability, and role training. World J Surg 39:10–20. doi:10.1007/s00268-014-2516-0
21. Samai M (2014) COMAHS has made noticeable achievements—acting provost. Awoko Newspaper. http://awoko.org/2014/04/16/sierra-leone-news-comahs-has-made-noticeable-achievements-acting-provost/ Accessed 10 Nov 2015
22. Pereira C, Cumbi A, Malalane R et al (2007) Meeting the need for emergency obstetric care in Mozambique: work performance and histories of medical doctors and assistant medical officers trained for surgery. BJOG 114:1530–1533. doi:10.1111/j.1471-0528.2007.01489.x
23. United Nations Development Programme (2015) Human development report 2014. http://hdr.undp.org/en/rethinking-work-for-human-development. Accessed 23 Sept 2015
24. World Health Organisation (2015) The Global Health Expenditure Database. http://apps.who.int/nha/database/Select/Indicators/en. Accessed 23 Sept 2015
25. Groen RS, Samai M, Stewart KA et al (2012) Untreated surgical conditions in Sierra Leone: a cluster randomised, cross-sectional, countrywide survey. Lancet 380:1082–1087. doi:10.1016/S0140-6736(12)61081-2

Paper III

Is not included due to copyright

Paper IV

Original article

Safety, productivity and predicted contribution of a surgical task-sharing programme in Sierra Leone

H. A. Bolkan[1,2,3], A. van Duinen[1,2,3,4], B. Waalewijn[3,4], M. Elhassein[5], T. B. Kamara[6,8,9], G. F. Deen[7,8,9], I. Bundu[6,8,9], B. Ystgaard[2,3], J. von Schreeb[10] and A. Wibe[1,2]

[1]Institute of Cancer Research and Molecular Medicine, Norwegian University of Science and Technology (NTNU) and, [2]Department of Surgery, St Olav's Hospital, Trondheim University Hospital, Trondheim, Norway, [3]CapaCare, Trondheim, Norway and Freetown, Sierra Leone, [4]Royal Tropical Institute, Amsterdam, The Netherlands, [5]United Nations Population Fund, and Departments of [6]Surgery and [7]Medicine, Connaught Hospital, [8]Ministry of Health and Sanitation, and [9]College of Medicine and Allied Health Sciences, University of Sierra Leone, Freetown, Sierra Leone, and [10]Health System and Policy Research Group, Karolinska Institute, Stockholm, Sweden

Correspondence to: Dr H. A. Bolkan, Institute of Cancer Research and Molecular Medicine, Norwegian University of Science and Technology (NTNU), Post Box 8905, N-7491 Trondheim, Norway (e-mail: hakon.a.bolkan@ntnu.no)

Background: **Surgical task-sharing may be central to expanding the provision of surgical care in low-resource settings. The aims of this paper were to describe the set-up of a new surgical task-sharing training programme for associate clinicians and junior doctors in Sierra Leone, assess its productivity and safety, and estimate its future role in contributing to surgical volume.**

Methods: **This prospective observational study from a consortium of 16 hospitals evaluated crude in-hospital mortality over 5 years and productivity of operations performed during and after completion of a 3-year surgical training programme.**

Results: **Some 48 trainees and nine graduated surgical assistant community health officers (SACHOs) participated in 27 216 supervised operations between January 2011 and July 2016. During training, trainees attended a median of 822 operations. SACHOs performed a median of 173 operations annually. Caesarean section, hernia repair and laparotomy were the most common procedures during and after training. Crude in-hospital mortality rates after caesarean sections and laparotomies were 0·7 per cent (13 of 1915) and 4·3 per cent (7 of 164) respectively for operations performed by trainees, and 0·4 per cent (5 of 1169) and 8·0 per cent (11 of 137) for those carried out by SACHOs. Adjusted for patient sex, surgical procedure, urgency and hospital, mortality was lower for operations performed by trainees (OR 0·47, 95 per cent c.i. 0·32 to 0·71; $P < 0·001$) and SACHOs (OR 0·16, 0·07 to 0·41; $P < 0·001$) compared with those conducted by trainers and supervisors.**

Conclusion: **SACHOs can rapidly and safely achieve substantial increases in surgical volume in Sierra Leone.**

Preliminary results presented to the 54th Annual Conference of the West African College of Surgeons, Kumasi, Ghana, February 2014, and the 56th Annual Conference of the West African College of Surgeons, Yaoundé, Cameroon, February 2016

Paper accepted 6 March 2017

Published online in Wiley Online Library (www.bjs.co.uk). **DOI:** 10.1002/bjs.10552

Introduction

One of the significant barriers to expansion of surgical care in low-income countries is a shortage of human resources[1]. Task-sharing is defined as a rational redistribution of tasks among healthcare workers to maximize the efforts of the existing workforce[2], and is recommended by the WHO for several tasks, including certain surgical procedures[3]. Expanding the surgical workforce in low-resource settings by task-sharing has been found to be cost- and time-effective[4–6] without corrupting surgical outcomes[7,8]. In addition, it probably improves retention of the workforce at the district level[9]. Although task-sharing in surgery is applied commonly in several East and Central African countries[10,11], it has not been adopted to the same extent in West Africa[12]. The 2015 World Health Assembly[13] resolution aiming to strengthen emergency and essential surgical care worldwide urges member states to make: '… more effective use of the health care workforce

through task-sharing … '. Although task-sharing in surgery has been widely debated and described in key publications in recent years[1,4], there are limited data on the safety of surgical task-sharing programmes and the productivity of associate clinicians as surgical providers.

Sub-Saharan West Africa has the highest unmet surgical needs in the world[4]. Before the Ebola outbreak, there were ten specialist surgical providers in government (public) hospitals[14] and 26 in private non-profit hospitals[15] in Sierra Leone. This corresponds to less than 5 per cent of the minimum threshold of 20 specialist surgeons, obstetricians and anaesthetists per 100 000 population, recently recommended by the Lancet Commission on Global Surgery[4]. To address the shortage of surgical providers, the Sierra Leonean Ministry of Health and Sanitation (MoHS) and the non-profit organization CapaCare initiated a surgical task-sharing training programme in 2011. The implementation strategy was to improve access to emergency surgical care among rural populations by enabling non-specialized medical doctors (MDs) and associate clinicians to manage surgical and obstetric emergencies safely. A surgical training programme (STP) was developed that made optimal use of the limited surgical trainers available in the country. The goal was to train 60 associate clinicians and junior MDs by 2021, such that they could deliver surgical services safely in government district hospitals and be as productive as the existing surgical workforce. Five years after initiation of this programme, the aim of the present article was to describe the set-up of the STP, assess productivity and safety, and estimate its future role in contributing to surgical volume in Sierra Leone.

Methods

Surgical training programme

The STP was planned in 2009 as Sierra Leone was recovering from a devastating civil war. This country, with 5·5 million inhabitants, at that time had only 167 MDs in clinical practice[16], poor output from the medical school and no formal postgraduate training available in surgery or obstetrics[14]. Surgical care was not prioritized in the national health agenda[17], despite an extensive surgical disease burden and mortality[18], and there was more than 90 per cent unmet surgical need[19]. In rural areas, where the majority of the population resides, 30-fold fewer operations were performed compared with urban areas[15].

The STP is located principally at district hospitals to promote post-training retention in the provinces and avoid diverting resources from any informal training of MDs in the main teaching hospitals in the capital, Freetown. The curriculum is based on the WHO Integrated Management for Emergency and Essential Surgical Care tool kit, developed by the Global Initiative for Emergency and Essential Surgical Care[20]. The training lasts 3 years and the graduates are meant to be absorbed by the MoHS and posted to district government hospitals on completion of training.

Trainers and training sites were identified by visiting and assessing the surgical activity and infrastructure of all provincial hospitals with 24-h availability of MDs performing surgery[19]. The most surgically active were invited to take part as partner hospitals and a memorandum of understanding granted trainees supervised access to all surgical and obstetric care (*Appendix S1*, supporting information). Initially, all partner hospitals were run by private non-profit organizations, based on limited capacity and personnel in government district hospitals. Several government hospitals subsequently became partners (*Fig. 1*).

All associate clinicians (known as community health officers (CHOs) in Sierra Leone) and junior MDs who meet the minimum entry criteria are eligible for the STP. CHOs have 3-year basic medical diploma training to be in charge of community health centres[21], but many also work as medical operatives in hospitals. CHOs must complete 2 years of postgraduate clinical practice before applying for the STP. MDs can apply directly after internship. Applicants are interviewed by CapaCare and the MoHS; a more rigorous full-day assessment was added in 2014. Positive discrimination favours women and applicants from highly underserved districts among equally qualified candidates. Trainee salaries are paid by the MoHS or CapaCare. There are no tuition fees, but a 4-year postgraduate binding agreement with the MoHS has been introduced to promote retention in public service. Two trainees began in January 2011 and, since then, between four and seven have been admitted biannually.

Fig. 2 outlines the training content and time frame. For 6 months, trainees undergo an introductory course at the central teaching facility, Masanga Hospital in Tonkolili district[22]. The theoretical training has evolved and matured over the past 5 years, and now comprises six intensive modules lasting 2–4 weeks (*Appendix S2*, supporting information). These modules are taught by teams of one to three international trainers, who are all specialists in surgery, obstetrics, anaesthesia, orthopaedics and radiology, in addition to midwives, and anaesthesia and operating theatre nurses. Local specialist surgeons provide theoretical and practical training during shorter courses (2–3 days). Training encompasses predefined or problem-based lectures, e-learning, grand rounds,

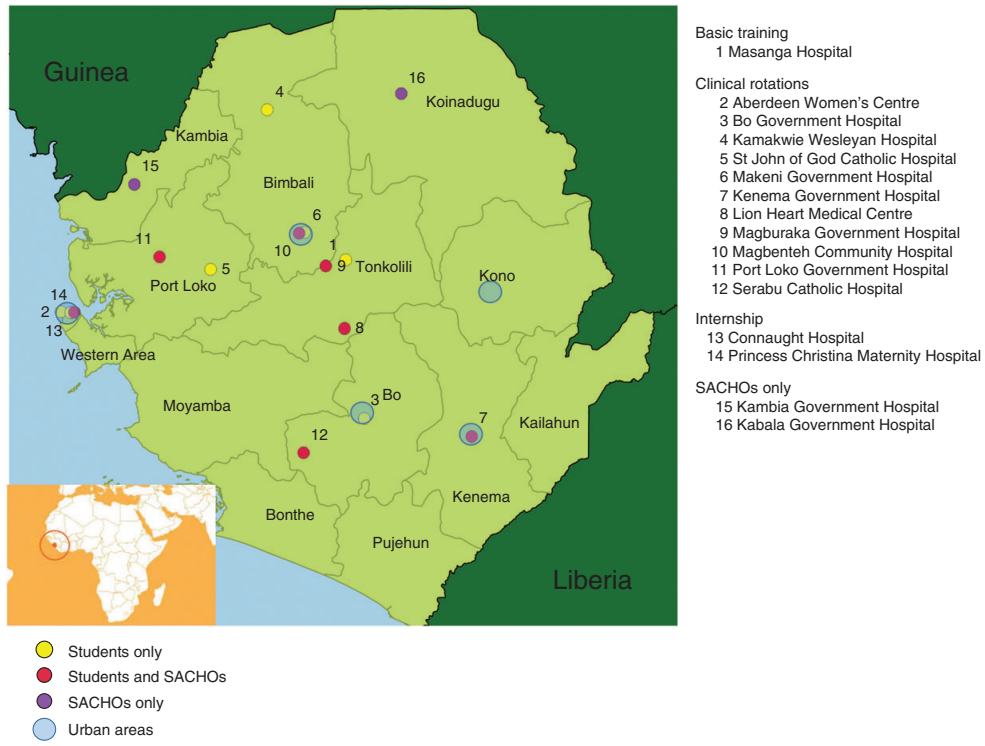

Fig. 1 Hospitals as of July 2016 taking part in the surgical training programme or that have employed surgical assistant community health officers (SACHOs)

case presentations, journal clubs, mortality and morbidity reviews, bedside clinical teaching, outpatient clinics, radiology conferences, basic ultrasound training, surgical audits, surgical skills laboratories, veterinary laboratories for emergency and trauma procedures, and hands-on operative training to master context-adapted and resource-poor surgery.

After successful completion of the introductory course, trainees undergo three 6-month clinical rotations in partner hospitals, engaging in all aspects of care of the surgical patient. Trainees are assigned to a local supervisor, a MD or specialist in surgery and/or obstetrics. At specific intervals (*Appendix S2*, supporting information), they are called back to Masanga Hospital for refresher training. A monitoring and evaluation officer, and national and international training coordinators supervise trainees and trainers at all training sites.

Trainee progression is gauged by informal guidance, formal written evaluations, biannual review of surgical logbooks, and written and oral examinations. Local specialist surgeons and obstetricians, all faculty at the College of Medicine and Allied Health Sciences of the University of Sierra Leone, assess the results of the final written and oral examinations after 2 years. A successful outcome grants a diploma in Emergency Surgery, Obstetrics and Gynaecology. The MDs are then posted to a government hospital. CHOs complete a 1-year internship in the main tertiary surgical and maternity training hospitals in Freetown, which, if completed satisfactorily, leads to appointment as a surgical assistant community health officer (SACHO) at a government district hospital. All operations performed by trainees and SACHOs require the supervision of a MD.

Data collection

A prospective observational registry began with the initiation of the STP. Data were obtained from trainees' and SACHOs' surgical logbooks. Twenty items related to patient demographics, operation, surgical provider,

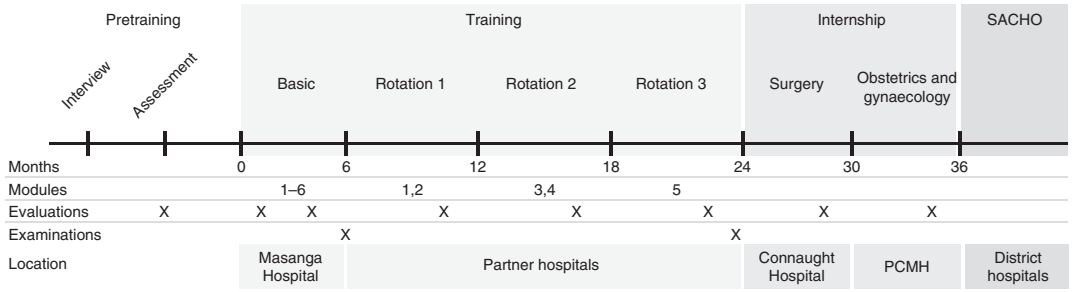

Fig. 2 Content and time frame for the surgical training programme. SACHO, surgical assistant community health officer; PCMH, Princess Christina Maternity Hospital

Table 1 Key performance indicators of the surgical training programme until July 2016

	2010	2011	2012	2013	2014	2015	2016*	Total
Trainees								
Applicants	1	11	45	36	24	39	14	170
New trainees enrolled	0	5	9	11	6	12	5	48
MDs graduated	–	–	–	1	0	0	0	1
CHOs graduated	–	–	–	0	4	5	3	12
Dropout	–	0	2	1	5	2	1	11
Trainer resources								
Modules taught	1	6	7	13	6	7	7	47
International trainers	3	10	13	20	12	11	9	78†
Partner hospitals	0	2	7	11	12	15	16	16
Operations attended/performed								
Trainees	–	849	3321	6865	4765	5010	3462	24 272 (89·2)
SACHOs	–	–	–	–	260	1575	1109	2944 (10·8)

Values in parentheses are percentages. *January to July. †A total of 44 international trainees made 78 training visits. MD, medical doctor; CHO, community health officer; SACHO, surgical assistant community health officer.

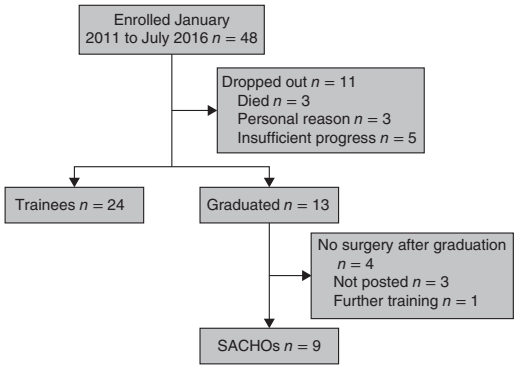

Fig. 3 Status of trainees and surgical assistant community health officers (SACHOs) by July 2016

hospital and outcomes were recorded for all operations between January 2011 and July 2016 (*Appendix S3*, supporting information).

Table 2 Annual volume of surgical procedures

	Annual no. of surgical procedures	
	During training (13 graduated)	After training (9 SACHOs)
Caesarean section	83 (67–94)	96 (62–108)
Hernia repair	72 (64–85)	41 (35–68)
Laparotomy	22 (18–30)	9 (8–10)
Appendicectomy	8 (7–11)	7 (5–18)
Dilatation and curettage	9 (6–13)	9 (1–16)
Hysterectomy	8 (5–10)	3 (2–8)
Other	84 (76–96)	46 (23–57)
Overall	274 (237–322)	204 (128–266)

Values are median (i.q.r.). SACHO, surgical assistant community health officer.

Logbook recording of roles during an operation builds upon the supervision definitions approved by the Joint Committee on Surgical Training (JCST) in the UK and Ireland[23]. Observed is a procedure observed by an unscrubbed trainee. Assisted is where a trainer performs the key components of a procedure. Directly supervised

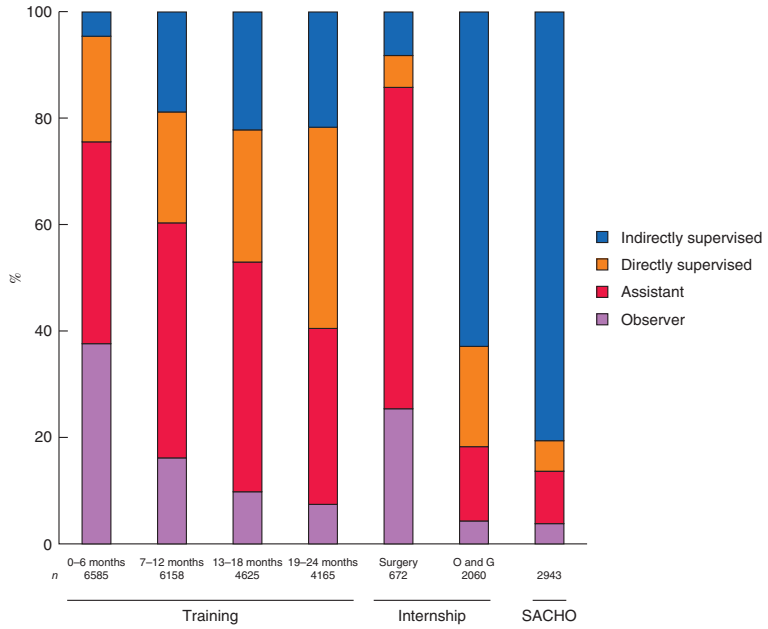

Fig. 4 Role during surgical procedures by 6-month intervals during training (training + internship) and after graduation (surgical assistant community health officer, SACHO). O and G, obstetrics and gynaecology

(JCST category S-TS) is when the trainee performs key components of the procedure with the trainer scrubbed. Indirectly supervised (JCST category S-TU and P) is when the trainee completes the procedure from start to finish and the trainer is unscrubbed. Paper logbooks were signed and validated by trainers after each procedure and uploaded monthly (Microsoft® Excel format; Microsoft, Redmond, Washington USA) to a cloud server for review.

Crude in-hospital mortality, the most commonly used definition of perioperative risk in low-resource settings[24], was used as a pragmatic marker of safety. Mortality rates following trainees' and SACHOs' indirectly supervised operations were compared with previously documented mortality from Sierra Leone[25,26]. In addition, mortality associated with the operations performed under indirect supervision was compared with that of operations conducted by the trainers and supervisors (observed). Progression towards surgical maturity was evaluated based on how trainees' roles during operations developed throughout training. Annual volume of operations performed (indirectly supervised) by the SACHOs was employed as a measure of productivity and to calculate potential future contributions to surgical volume. Productivity was compared against previously documented surgical productivity in Sierra Leone[15,19].

Results are reported in accordance with guidelines for implementation and operational research[27]. All hospitals that took part in the training agreed to share the surgical data (*Table S1*, supporting information). Trainees and SACHOs supplied written informed consent to share non-identifiable logbook data. The Sierra Leone Ethics and Scientific Review Committee granted ethical approval.

Statistical analysis

Differences in volumes of surgery between trainees and SACHOs and in-hospital mortality risk were tested using the Pearson χ^2 test. Age of patients was compared between groups by means of a *t* test. Factors associated with in-hospital mortality were determined by univariable and multivariable logistic regression analysis. The multivariable analysis was adjusted for trainee role, patient sex, urgency of surgery, operation and hospital type. Odds ratios (ORs) are reported with 95 per cent confidence intervals. All tests were two-tailed and statistical significance

Table 3 Operative data during training and after graduation

	During training† ($n = 24\,272$)	After graduation‡ ($n = 2944$)	P§
Role of trainee or SACHO			< 0·001
Observer	4515 (18·6)	114 (3·9)	
Assistant	9311 (38·4)	290 (9·9)	
Directly supervised	5724 (23·6)	170 (5·8)	
Indirectly supervised	4715 (19·4)	2369 (80·5)	
Missing	7 (0·0)	1 (0·0)	
Age of patient (years)*	32·6(16·5)	30·3(14·0)	< 0·001¶
Sex			< 0·001
M	10 244 (42·2)	853 (29·0)	
F	14 016 (57·7)	2090 (71·0)	
Missing	12 (0·1)	1 (0·0)	
Urgency			< 0·001
Planned	13 031 (53·7)	905 (30·7)	
Emergency	11 222 (46·2)	2037 (69·2)	
Missing	19 (0·1)	2 (0·1)	
Surgical procedure			< 0·001
Caesarean section	6438 (26·5)	1290 (43·8)	
Hernia repair	6471 (26·7)	610 (20·7)	
Laparotomy	2142 (8·8)	232 (7·9)	
Appendicectomy	834 (3·4)	134 (4·6)	
Dilatation and curettage	866 (3·6)	100 (3·4)	
Hysterectomy	667 (2·7)	67 (2·3)	
Other	6854 (28·2)	511 (17·4)	
Hospital			< 0·001
Government	6577 (27·1)	1709 (58·1)	
Private non-profit	17 643 (72·7)	1235 (41·9)	
Missing	52 (0·2)	0 (0)	

Values in parentheses are percentages unless indicated otherwise; *values are mean(s.d.). †Forty-eight trainees; ‡nine surgical assistant community health officers (SACHOs). §Pearson χ^2 test, except ¶two-sample t test.

was set at $P < 0{\cdot}050$. Missing data were excluded from the analyses.

Results

Forty-eight trainees, two junior MDs and 46 CHOs, enrolled in the STP between January 2011 and July 2016 (*Table 1*). Three died (Ebola 2, motor accident 1) and three left for personal reasons (chronic sickness 1, emigration 1, lack of motivation 1). Five were removed from the programme because of insufficient progress, mostly during the initial 6 months (*Fig. 3*). Forty-four international trainers conducted 78 training visits to Sierra Leone, delivering 47 training modules. Twelve CHOs and one MD graduated, of whom eight are currently posted as SACHOs in district hospitals and one in a referral hospital. Four graduates have not yet recorded any operations (1 MD continued postgraduate surgical training in Ghana, 3 graduates were posted after July 2016).

Productivity

Forty-eight trainees and nine SACHOs logged 27 216 operative training and service delivery episodes during the study period, 24 272 as trainees and 2944 as SACHOs. Those who completed the programme (13 graduates) took part in a median of 274 (237–322) surgical procedures annually, a median total of 822 per trainee during the 3 years of training (*Table 2*). The nine posted SACHOs took part in a median of 204 surgical procedures annually, and 173 (i.q.r. 109–226) were supervised indirectly. Caesarean section, hernia repair and laparotomy were the most frequent operations both during training and after graduation. Except for the surgical internship, the proportion of procedures performed by the trainees increased the further they were into the training (*Fig. 4*). Some 80·5 per cent of operations recorded by the SACHOs were indirectly supervised (2369 of 2944). Caesarean sections accounted for 43·8 per cent of the SACHO operations (1290 of 2944).

Compared with the trainees, the SACHOs participated in more operations in government hospitals (27·1 *versus* 58·1 per cent; $P < 0{\cdot}001$) and more emergency operations (46·2 *versus* 69·2 per cent; $P < 0{\cdot}001$), operated on younger patients ($P < 0{\cdot}001$) and were more likely to operate on female patients (57·7 *versus* 71·0 per cent; $P < 0{\cdot}001$) (*Table 3*).

Table 4 Logistic regression analysis to identify factors associated with in-hospital mortality during training (48 trainees, 24 272 surgical training episodes)

				Univariable analysis		Multivariable analysis	
	Alive	Died*	Missing	Odds ratio†	*P*	Odds ratio†	*P*
Student role							
Observer	4397	116 (2·6)	2	1·00 (reference)		1·00 (reference)	
Assistant	9075	225 (2·4)	11	0·94 (0·75, 1·18)	0·592	0·99 (0·78, 1·25)	0·915
Directly supervised	5633	89 (1·6)	2	0·60 (0·45, 0·79)	< 0·001	0·74 (0·55, 0·99)	0·045
Indirectly supervised	4678	36 (0·8)	1	0·29 (0·20, 0·42)	< 0·001	0·47 (0·32, 0·71)	< 0·001
Missing	7	0	0				
Sex							
M	9974	262 (2·6)	8	1·00 (reference)		1·00 (reference)	
F	13 804	204 (1·5)	8	0·56 (0·47, 0·68)	< 0·001	0·43 (0·35, 0·54)	< 0·001
Missing	12	0	0				
Urgency							
Planned	12 907	120 (0·9)	4	1·00 (reference)		1·00 (reference)	
Emergency	10 865	345 (3·1)	12	3·42 (2·77, 4·21)	< 0·001	4·05 (3·18, 5·15)	< 0·001
Missing	18	1	0				
Surgical procedure							
Caesarean section	6383	54 (0·8)	1	1·00 (reference)		1·00 (reference)	
Hernia repair	6435	33 (0·5)	3	0·61 (0·39, 0·94)	0·024	0·68 (0·41, 1·13)	0·135
Laparotomy	1937	199 (9·3)	6	12·14 (8·95, 16·48)	< 0·001	7·14 (5·06, 10·08)	< 0·001
Appendicectomy	826	8 (1·0)	0	1·14 (0·54, 2·41)	0·722	0·93 (0·44, 2·00)	0·861
Dilatation and curettage	860	6 (0·7)	0	0·82 (0·35, 1·92)	0·655	0·97 (0·41, 2·23)	0·917
Hysterectomy	654	13 (1·9)	0	2·34 (1·28, 4·33)	0·006	3·62 (1·93, 6·79)	< 0·001
Other	6695	153 (2·2)	6	2·70 (1·98, 3·69)	< 0·001	2·78 (1·96, 3·95)	< 0·001
Hospital							
Government	6510	67 (1·0)	0	1·00 (reference)		1·00 (reference)	
Private non-profit	17 228	399 (2·3)	16	2·25 (1·73, 2·92)	< 0·001	1·54 (1·16, 2·03)	0·003
Missing	52	0	0				

Values in parentheses are *percentages and †95 per cent confidence intervals.

Safety

The crude in-hospital mortality rate for all operations recorded as involving trainees was 1·9 per cent (466 of 24 256); it was 2·6 per cent (116 of 4513) for observed operations and 0·8 per cent (36 of 4714) for indirectly supervised operations (*Table 4*). Mortality following observed caesarean sections was 1·2 per cent (8 of 688) and 0·7 per cent (13 of 1915) for indirectly supervised procedures. The mortality rate was 7·5 per cent (53 of 703) after observed and 4·3 per cent (7 of 164) for indirectly supervised laparotomies. The risk of a fatal outcome after adjustment for patient sex, surgical procedure, urgency and hospital type was significantly lower for operations the trainees performed under indirect supervision *versus* observed operations (OR 0·47, 95 per cent c.i. 0·32 to 0·71; $P < 0·001$). A comparison of case mix between the observed and indirectly supervised surgical procedures for trainees and SACHOs is provided in *Table S1* (supporting information).

The SACHOs recorded an overall mortality rate of 1·7 per cent (51 of 2944), 9·6 per cent (11 of 114) for observed operations and 0·8 per cent (20 of 2369) per cent for indirectly supervised procedures (*Table 5*). Adjusted analysis of operations conducted by the SACHOs under indirect supervision showed a significantly lower risk of a fatal outcome compared with operations the SACHOs observed (OR 0·16, 95 per cent c.i. 0·07 to 0·41; $P < 0·001$). Postoperative mortality for procedures carried out by SACHOs with indirect supervision was 0·4 per cent (5 of 1169) for caesarean sections and 8·0 per cent (11 of 137) for laparotomies.

Future contributions to surgical volume

If the productivity of the SACHOs remains at a median of 173 (i.q.r. 109–226) operations a year, 60 SACHOs will perform 10 404 (6528–13 566) operations annually in Sierra Leone in 2021. If 44 per cent of the operations

Table 5 Logistic regression analysis to identify factors associated with in-hospital mortality after graduation (9 surgical assistant community health officers, 2944 operations)

			Univariable analysis		Multivariable analysis	
	Alive	Died*	Odds ratio†	*P*	Odds ratio†	*P*
Student role						
Observer	103	11 (9·6)	1·00 (reference)		1·00 (reference)	
Assistant	273	17 (5·9)	0·58 (0·26, 1·29)	0·182	0·65 (0·26, 1·65)	0·364
Directly supervised	167	3 (1·8)	0·17 (0·05, 0·62)	< 0·001	0·12 (0·02, 0·50)	0·004
Indirectly supervised	2349	20 (0·8)	0·11 (0·06, 0·20)	< 0·001	0·16 (0·07, 0·41)	< 0·001
Missing	1	0				
Sex						
M	819	34 (4·0)	1·00 (reference)		1·00 (reference)	
F	2073	17 (0·8)	0·20 (0·11, 0·36)	< 0·001	0·19 (0·09, 0·39)	< 0·001
Missing	1	0				
Urgency						
Planned	899	6 (0·7)	1·00 (reference)		1·00 (reference)	
Emergency	1992	45 (2·2)	3·38 (1·44, 7·96)	0·005	3·95 (1·48, 10·59)	0·006
Missing	2	0				
Surgical procedure						
Caesarean section	1284	6 (0·5)	1·00 (reference)		1·00 (reference)	
Hernia repair	607	3 (0·5)	1·06 (0·26, 4·24)	0·937	0·50 (0·10, 2·62)	0·412
Laparotomy	202	30 (12·9)	31·78 (13·06, 77·32)	< 0·001	10·51 (3·77, 29·26)	< 0·001
Appendicectomy	134	0 (0)	–	–	–	–
Dilatation and curettage	100	0 (0)	–	–	–	–
Hysterectomy	67	0 (0)	–	–	–	–
Other	499	12 (2·3)	5·14 (1·92, 13·78)	< 0·001	1·49 (0·44, 4·94)	0·513
Hospital						
Government	1694	15 (0·9)	1·00 (reference)		1·00 (reference)	
Private non-profit	1199	36 (2·9)	3·39 (1·85, 6·22)	< 0·001	1·50 (0·72, 3·11)	0·277
Missing	0	0				

Values in parentheses are *percentages and †95 per cent confidence intervals.

continue to be caesarean sections, they will carry out 4578 (2872–5969) sections annually.

Discussion

During training, the volume of surgical training episodes was high and there seemed to be progression towards surgical maturity, with exposure corresponding to procedures performed after graduation. Both trainees and SACHOs experienced lower in-hospital mortality for operations they conducted under indirect supervision than in the observed operations carried out by their trainers and supervisors. The programme has been able to train in private non-profit hospitals and transfer graduates to government district hospitals. The current productivity of the SACHOs indicates that task-shared surgical providers can perform a considerable volume of emergency surgery at district government hospitals in the near future.

The primary strength of this study is the large prospectively registered number of operative training episodes that were included. The major challenges were related to the Ebola outbreak, which not only caused the tragic deaths of two students, but also placed all those involved under such risk that the programme was forced to shut down for nearly a year during the peak of Ebola transmission[28]. Unstable access to trainers and rapid changes in healthcare priorities among the partner hospitals during and after the Ebola outbreak were also challenging.

The major limitations of the study are that participants themselves recorded the operations and their outcomes, with a potential for reporting bias. Negative outcomes may be reported less than positive ones, possibly contributing to a general underestimation of mortality. Validation of logbook entries by local trainers and supervisors, however, should counteract this. The same operation may have multiple attendants of this programme, as a trainee might observe while a SACHO carries out the operation under indirect supervision. Assessing the safety of surgery based on crude postoperative in-hospital mortality has its limitations, partly because crude mortality depends on many non-surgical factors and partly because the in-hospital mortality rate is often low. Morbidity outcomes, especially those more related to the surgical procedure, would better

expose quality of practice offered by the surgical provider, but such data were not available for this study.

Safety of surgery is of utmost importance in any training programme, no matter what resources are available[29]. The postoperative mortality of indirectly supervised caesarean sections carried out by trainees (0·7 per cent) and SACHOs (0·4 per cent) was no higher than the rate reported previously from Sierra Leone (1·2 per cent, 4 of 338)[25], or by a systematic review[30] (median 1·4 per cent) including 19 publications from western Sub-Saharan Africa. In addition, the postoperative mortality of indirectly supervised laparotomies performed by trainees (4·3 per cent) and SACHOs (8·0 per cent) was no greater than previously reported mortality in Sierra Leone (10·1 per cent, 18 of 178)[26] or a recently established 30-day mortality rate (8·7 per cent, 114 of 1316) from a multicountry low-Human Development Index setting[31].

Although the analyses were adjusted for sex, urgency, surgical procedure and hospital type, the observed operations as reference for mortality were still prone to selection bias as there was no adjustment for co-morbidity and severity of the surgical condition. Poorer outcomes for patients operated on by trainers compared with trainees are also found in high-income settings[32], and difference in case mix has been suggested as an explanation for this. The procedures conducted by the trainers and supervisors in the present study may have been more complex than those undertaken by trainees and SACHOs, limiting the comparability of performance between the groups. Safety in surgery has much to do with selection of who is to operate on whom, when and where. High-risk patients should be handled by the most competent providers. Comparing mortality between the supervision groups gives an indication on how operative risks are distributed, and is therefore a relevant measure of safety of the programme and the introduction of a new cadre. Procedures on high-risk patients seem to be used less often for training purposes, the more experienced supervisors seem to resume responsibility for the more challenging operations, and the SACHOs refer or call for assistance when needed.

SACHOs were almost twice as productive as surgical providers in government hospitals in 2012[15]. The high proportion of operations conducted with only indirect supervision indicates that task-sharing is accepted by the existing surgical providers in district government hospitals. As all (except 1) of the SACHOs work in district hospitals, and more than two-thirds of the patients operated on are women, it seems that the programme is able to target the most vulnerable part of the population – females of reproductive age living in the provinces. The 10 404 operations this programme is projected to complete annually by 2021 corresponds to an increase of 110 per cent compared with the 9500 operations performed in all government hospitals in 2012[19]. Assuming annual population growth continues at 1·9 per cent[33] for the second part of this decade and other surgical providers maintain levels of surgical activity found in 2012[19], the country will perform 435 operations per 100 000 inhabitants in 2021, still far below the universal target of 5000 annual operations the Lancet Commission on Global Surgery[4] recently suggested. An additional 4162 caesarean sections represent an increase of 160 per cent from the 2012 level of activity in government hospitals[19].

This programme could not have been established without the willingness of a broad range of diverse private non-profit hospitals to align under one common training scheme. There have been surgical training initiatives in Sierra Leone before the STP[34–38], but no systematic use of private non-profit hospitals, where the majority of the surgery in the country is performed[19]. As others have also suggested[39], the capacity and expertise among international institutions offering surgical services in low-income countries should be better utilized for capacity building and training.

Another important strategy has been the use of short-term international volunteers to supplement the insufficient volume of available local tutors. Short-term surgical missions might not be sustainable[40]; however, in the Sierra Leonean context, the extreme shortage of skilled surgical providers has necessitated importing a wide range of specialists with dedicated time for intensive teaching and training. As seen with repeated short-course training of laparoscopic skills in Mongolia[41], deployment undertaken in a systematic way over many years can be fruitful. The combination of engagement of tutor capacity in the private non-profit sector and the structured and long-term commitment of international volunteers on short-term visits could also be replicated in other highly underserved settings[42].

Introduction of surgical task-sharing must include regulation, mentoring and supervision of clinical activity, remuneration of professional development and acceptance of the new cadre[43]. If neglected, there is a considerable risk of drainage towards urban areas, the private non-profit sector or even non-clinical positions, if better rewarded[44]. Lack of remuneration and poor carrier pathways might be reasons for difficulties in attracting junior MDs to the STP. To date there is no legal protection for SACHOs in Sierra Leone, and there is no regulating body formally overseeing the medical practices of the CHO cadre. This makes clinical governance challenging, with both patient and healthcare practitioner safety poorly attended to. Currently, this is

resolved at the hospital level where individual MDs assume informal responsibility and supervisory duties for the work performed by SACHOs. High turnover of MDs in government district hospitals makes this system fragile and in need of continued surveillance. Hospital visits by CapaCare medical staff and trainers, together with an annual surgical meeting, offer some mentoring to the SACHOs; however, this needs further development and the involvement of senior Sierra Leonean specialists.

Further research on the outcomes of operations offered within task-sharing initiatives is required, with recording of postoperative morbidity events related to the surgical procedure, as this will better reveal the quality of operative skills. The long-term implications of introducing task-sharing, referral patterns, optimal mixes of surgical health cadres, and how barriers to access surgical care are affected, all need further investigation.

Overall, this study has indicated that the training of associate clinicians within a structure where government and private non-profit district hospitals are brought under one training umbrella, in combination with systematic deployment of international volunteer specialists on short-term rotations, is feasible and safe. The model provides high exposure to surgical training episodes and makes efficient use of limited local trainers. Currently, the programme is on track to deliver 60 additional surgical providers by 2021, all bestowed with the ability to be more productive than the existing surgical workforce without compromising the safety of surgical services offered. The potential gains are considerable, and it appears to reach the most vulnerable part of the population – women living in the provinces. Crucial for maintaining quality of care and retention in surgical service delivery in the provinces is to offer structured mentoring, adequate remuneration, and to strengthen clinical governance by developing more robust systems for regulation and supervision of surgical activities.

Acknowledgements

The authors acknowledge support in terms of planning of both the study and the training programme, surgical training provided and teaching the trainees to collect data. They thank the Sierra Leonean-based international coordinators of the training programme, D. van Leerdam and M. Grootjans; Dutch tropical doctors on long-term contracts at the main teaching location, Masanga Hospital: F. van Raaij, J. Westendorp, C. Bijen, M. Oostvogels and J. van Kesteren; the founders of the Masanga Hospital Rehabilitation Project for housing the STP, P. B. Jørgensen and S. Haas, who also acted as trainers; CapaCare's accountant, A. van Duinen, for administrative support regarding finances related to the study; and all the dedicated volunteer international trainers, in particular L. M. Hunt who also critically reviewed the manuscript. The programme and the study would never have been initiated without the support of D. A. Bash-Taqi (former Director of Hospitals and Laboratory Services of the MoHS), A. Conteh, Chief CHO (MoHS) and Chief Obstetrician, and A. P. Koroma, at Princess Christina Maternity Hospital, Freetown.

The Norwegian University of Science and Technology funded all parts of the study. The funding source had no role in any aspect of the study.

Disclosure: The authors declare no conflict of interest.

References

1 Bergström S, McPake B, Pereira C, Dovlo D. Workforce innovations to expand the capacity for surgical services. In *Disease Control Priorities, Third Edition (Volume 1): Essential Surgery*, Debas HT, Donkor P, Gawande A, Jamison DT, Kruk ME, Mock CN (eds). World Bank Publications: Washington, 2015; 307–316.

2 WHO. *Task Shifting: Rational Redistribution of Tasks among Health Workforce Teams: Global Recommendations and Guidelines*. http://www.who.int/healthsystems/TTR-TaskShifting.pdf?ua=1 [accessed 5 December 2016].

3 WHO. *Optimizing Health Worker Roles to Improve Access to Key Maternal and Newborn Health Interventions Through Task Shifting*. http://www.who.int/reproductivehealth/publications/maternal_perinatal_health/9789245048 43/en/index.html [accessed 5 December 2016].

4 Meara JG, Leather AJ, Hagander L, Alkire BC, Alonso N, Ameh EA *et al*. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *Lancet* 2015; **386**: 569–624.

5 Kruk ME, Pereira C, Vaz F, Bergström S, Galea S. Economic evaluation of surgically trained assistant medical officers in performing major obstetric surgery in Mozambique. *BJOG* 2007; **114**: 1253–1260.

6 Hoyler M, Hagander L, Gillies R, Riviello R, Chu K, Bergström S *et al*. Surgical care by non-surgeons in low-income and middle-income countries: a systematic review. *Lancet* 2015; **385**(Suppl 2): S42.

7 Beard JH, Oresanya LB, Akoko L, Mwanga A, Mkony CA, Dicker RA. Surgical task-shifting in a low-resource setting: outcomes after major surgery performed by nonphysician clinicians in Tanzania. *World J Surg* 2014; **38**: 1398–1404.

8 Wilson A, Lissauer D, Thangaratinam S, Khan KS, MacArthur C, Coomarasamy A. A comparison of clinical officers with medical doctors on outcomes of caesarean section in the developing world: meta-analysis of controlled studies. *BMJ* 2011; **342**: d2600.

9 Pereira C, Cumbi A, Malalane R, Vaz F, McCord C, Bacci A *et al*. Meeting the need for emergency obstetric care in Mozambique: work performance and histories of medical

doctors and assistant medical officers trained for surgery. *BJOG* 2007; **114**: 1530–1533.
10 Mkandawire N, Ngulube C, Lavy C. Orthopaedic clinical officer program in Malawi: a model for providing orthopaedic care. *Clin Orthop Relat Res* 2008; **466**: 2385–2391.
11 Chilopora G, Pereira C, Kamwendo F, Chimbiri A, Malunga E, Bergström S. Postoperative outcome of caesarean sections and other major emergency obstetric surgery by clinical officers and medical officers in Malawi. *Hum Resour Health* 2007; **5**: 17.
12 Mullan F, Frehywot S. Non-physician clinicians in 47 sub-Saharan African countries. *Lancet* 2007; **370**: 2158–2163.
13 WHO. *World Health Assembly Resolution A68/31: Strengthening Emergency and Essential Surgical Care and Anaesthesia as a Component of Universal Health Coverage*. http://apps.who.int/gb/ebwha/pdf_files/WHA68/A68_31-en.pdf [accessed 5 December 2016].
14 Vaughan E, Sesay F, Chima A, Mehes M, Lee B, Dordunoo D *et al.* An assessment of surgical and anesthesia staff at 10 government hospitals in Sierra Leone. *JAMA Surg* 2015; **150**: 237–244.
15 Bolkan HA, Hagander L, von Schreeb J, Bash-Taqi D, Kamara TB, Salvesen Ø *et al.* The surgical workforce and surgical provider productivity in Sierra Leone: a countrywide inventory. *World J Surg* 2016; **40**: 1344–1351.
16 Ministry of Health and Sanitation. *National Health Sector Strategic Plan 2010– 2015*; 2009. http://www.internationalhealthpartnership.net/fileadmin/uploads/ihp/Documents/Country_Pages/Sierra_Leone/NationalHealthSectorStrategicPlan_2010-15.pdf [accessed 5 December 2016].
17 Dare AJ, Lee KC, Bleicher J, Elobu AE, Kamara TB, Liko O *et al.* Prioritizing surgical care on national health agendas: a qualitative case study of Papua New Guinea, Uganda, and Sierra Leone. *PLoS Med* 2016; **13**: e1002023.
18 Groen RS, Samai M, Stewart KA, Cassidy LD, Kamara TB, Yambasu SE *et al.* Untreated surgical conditions in Sierra Leone: a cluster randomised, cross-sectional, countrywide survey. *Lancet* 2012; **380**: 1082–1087.
19 Bolkan HA, Von Schreeb J, Samai MM, Bash-Taqi DA, Kamara TB, Salvesen O *et al.* Met and unmet needs for surgery in Sierra Leone: a comprehensive, retrospective, countrywide survey from all health care facilities performing operations in 2012. *Surgery* 2015; **157**: 992–1001.
20 WHO. *Integrated Management for Emergency and Essential Surgical Care (IMEESC) Tool Kit*. http://www.who.int/surgery/publications/imeesc/en/ [accessed 5 December 2016].
21 Transformative Education for Health Professionals. *Sierra Leone's Community Health Officers*. http://whoeducationguidelines.org/content/sierra-leone's-community-health-officers [accessed 17 January 2017].
22 *Masanga Hospital*. https://en.wikipedia.org/wiki/Masanga_Hospital [accessed 5 December 2016].
23 *Supervision Code Help Guide – eLogbook*. https://www.elogbook.org/rcsed/messageboard/displayfile.aspx?attachmentId=539 [accessed 5 December 2016].
24 Ng-Kamstra JS, Greenberg SL, Kotagal M, Palmqvist CL, Lai FY, Bollam R *et al.* Use and definitions of perioperative mortality rates in low-income and middle-income countries: a systematic review. *Lancet* 2015; **385**: S29.
25 Chu K, Maine R, Trelles M. Cesarean section surgical site infections in sub-Saharan Africa: a multi-country study from Medecins Sans Frontieres. *World J Surg* 2015; **39**: 350–355.
26 McConkey SJ. Case series of acute abdominal surgery in rural Sierra Leone. *World J Surg* 2002; **26**: 509–513.
27 Hales S, Lesher-Trevino A, Ford N, Maher D, Ramsay A, Tran N. Reporting guidelines for implementation and operational research. *Bull World Health Organ* 2016; **94**: 58–64.
28 Milland M, Bolkan HA. Enhancing access to emergency obstetric care through surgical task shifting in Sierra Leone: confrontation with Ebola during recovery from civil war. *Acta Obstet Gynecol Scand* 2015; **94**: 5–7.
29 van der Leeuw RM, Lombarts KM, Arah OA, Heineman MJ. A systematic review of the effects of residency training on patient outcomes. *BMC Med* 2012; **10**: 65.
30 Uribe-Leitz T, Jaramillo J, Maurer L, Fu R, Esquivel MM, Gawande AA *et al*. Variability in mortality following caesarean delivery, appendectomy, and groin hernia repair in low-income and middle-income countries: a systematic review and analysis of published data. *Lancet Glob Health* 2016; **4**: e165–e174.
31 GlobalSurg Collaborative. Mortality of emergency abdominal surgery in high-, middle- and low-income countries. *Br J Surg* 2016; **103**: 971–988.
32 Kelly M, Bhangu A, Singh P, Fitzgerald JE, Tekkis PP. Systematic review and meta-analysis of trainee- *versus* expert surgeon-performed colorectal resection. *Br J Surg* 2014; **101**: 750–759.
33 UN Data. *World Statistics Pocketbook – Sierra Leone*. http://data.un.org/CountryProfile.aspx?crName=sierra%20leone [accessed 17 January 2017].
34 Mante SD, Gueye SM. Capacity building for the modified filarial hydrocelectomy technique in West Africa. *Acta Trop* 2011; **120**(Suppl 1): S76–S80.
35 Leow JJ, Groen RS, Kamara TB, Dumbuya SS, Kingham TP, Daoh KS *et al.* Teaching emergency and essential surgical care in Sierra Leone: a model for low income countries. *J Surg Educ* 2011; **68**: 393–396.
36 Bräuer MD, Antón J, George PM, Kuntner L, Wacker J. Handling postpartum haemorrhage – obstetrics between tradition and modernity in post-war Sierra Leone. *Trop Doct* 2015; **45**: 105–113.
37 Sivarajah V, Tuckey E, Shanmugan M, Watkins R. Surgical training during a voluntary medical-surgical camp in Sierra Leone. *Br J Surg* 2013; **100**: 156–157.
38 Kushner AL, Kamara TB, Groen RS, Fadlu-Deen BD, Doah KS, Kingham TP. Improving access to surgery in a

developing country: experience from a surgical collaboration in Sierra Leone. *J Surg Educ* 2010; **67**: 270–273.
39 Ng-Kamstra JS, Riesel JN, Arya S, Weston B, Kreutzer T, Meara JG *et al*. Surgical non-governmental organizations: global surgery's unknown nonprofit sector. *World J Surg* 2016; **40**: 1823–1841.
40 Nthumba PM. 'Blitz surgery': redefining surgical needs, training, and practice in sub-Saharan Africa. *World J Surg* 2010; **34**: 433–437.
41 Vargas G, Price RR, Sergelen O, Lkhagvabayar B, Batcholuun P, Enkhamagalan T. A successful model for laparoscopic training in Mongolia. *Int Surg* 2012; **97**: 363–371.
42 Grimes CE, Maraka J, Kingsnorth AN, Darko R, Samkange CA, Lane RH. Guidelines for surgeons on establishing projects in low-income countries. *World J Surg* 2013; **37**: 1203–1207.
43 Bergström S. Training non-physician mid-level providers of care (associate clinicians) to perform caesarean sections in low-income countries. *Best Pract Res Clin Obstet Gynaecol* 2015; **29**: 1092–1101.
44 Munga MA, Kilima SP, Mutalemwa PP, Kisoka WJ, Malecela MN. Experiences, opportunities and challenges of implementing task shifting in underserved remote settings: the case of Kongwa district, central Tanzania. *BMC Int Health Hum Rights* 2012; **12**: 27.

Supporting information

Additional supporting information may be found in the online version of this article:

Appendix S1 Template memorandum of understanding between CapaCare and partner hospital (Word document)

Appendix S2 Post-Graduate Surgical Training Curriculum – extracts from the student guide (Word document)

Appendix S3 Logbooks and evaluation schemes (Word document)

Table S1 Operative data for observed and indirectly supervised surgical procedures during training and after graduation (Word document)

Editor's comments

This paper is interesting and informative, and fits nicely in the current global research priorities of understanding individual countries' surgical systems and improving access to surgical care. *BJS* is an international journal with a global reach and supports well executed and comprehensive studies like this one. The authors managed to address important topics in their contribution including surgical workforce and sustainability within the framework of a training programme. They address issues that are relevant to other healthcare systems, also from more developed countries.

B. P. L. Wijnhoven
Editor, BJS