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Public Access to Surgical Care

Studies on Timeliness, Capacity, Safety, and Affordability

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FACULTY OF MEDICINE | LUND UNIVERSITY

Public Access to Surgical Care
– Studies on Timeliness, Capacity, Safety, and Affordability

Public Access to Surgical Care

Studies on Timeliness, Capacity, Safety, and Affordability

Niclas Rudolfson

LUND UNIVERSITY

DOCTORAL DISSERTATION

By due permission of the Faculty of Medicine, Lund University, Sweden.
To be publicly defended on May 5th 2023, 13.00 at Segerfalkssalen in Lund

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Abstract:
Background. A once commonly held belief was that surgery is too complicated, too expensive, and too ineffectively addressing a too minor proportion of the burden of disease to deserve priority in a setting of scarce healthcare resources in low- and middle-income countries. Yet, essential surgical care can be as highly cost-effective as other common public health interventions, and surgical services are increasingly considered integral to health system strengthening for health-related sustainable development goals. It has been estimated that 9 out of 10 people in low and lower-middle income countries cannot access timely, safe, and affordable essential surgical care. However, little is known on the upstream determinants of access and of the downstream effects of insufficient surgical health systems.

Aims and methods. The overall purpose of this thesis is to expand knowledge on public access to surgical care along the axes of timeliness, capacity, safety, and affordability. Specifically;

I. To validate geographical information system (GIS) methods for calculation of geographical access, comparing patient-reported travel times to those derived by computational methods;
II. To quantify the migration of surgical specialists to South Africa from other low- and middle-income countries, and from South Africa to high-income countries, using a register-based, cross-sectional study design;
III. To assess the feasibility of task-shifting postoperative wound care and surgical site infections (SSI) surveillance to community health workers, analyzing under which conditions this could be beneficial, using a stochastic state transition model;
IV. To estimate the burden of out-of-pocket payments for cesarean sections in the context of community-based health insurance and determine if having it reduces catastrophic health expenditure, in a prospective observational study;
V. To expand measurement of catastrophic health expenditure to the postoperative period, comparing incidence at discharge to postoperative day 30, in a prospective observational study, and;
VI. To estimate the economic consequences of neurosurgical disease in low- and middle-income countries, using value of lost output and value of lost economic welfare methods.
VII. To quantify the relative contribution of timeliness, capacity, safety and affordability to the global lack of access to surgical care

Results and conclusions. Current methods utilized to measure timeliness to surgical care were shown to be overly optimistic in at least one context (I). South Africa acts as a regional hub for migration of surgical specialists, representing an important destination for sub-Saharan emigrating surgical specialists, whilst itself acting as an even larger exporter of surgical specialists to high-income countries (II). SSI diagnosis at home via CHWs represents a potential way to reduce SSI burden, both in terms of morbidity and undue financial hardship (III). Indeed, even with robust health insurance, cesarean section patients are at high risk of catastrophic health expenditure, and often need to borrow money or sell assets in order to afford care (IV). When the postoperative follow-up after discharge is accounted for, the incidence of financial catastrophe is even larger (V). The previously unaccounted burden of neurosurgical disease will lead to profound global macroeconomic losses in the coming decades (VI). Insufficient access to surgical care is highly multidimensional, and the majority of the billions of people who lack access to surgical care do so due to a combination of two or more factors (VII). Thus, any attempt to mitigate this ongoing public health crisis will need to be as multifactorial as the problem it seeks to solve.

Key words: Global Health; Public Health; Specialties, Surgical; Health Care Quality, Access, and Evaluation

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Niclas Rudolfson

LUND UNIVERSITY

Coverphoto by Niclas Rudolfson. The dots represent access to surgical care. Each one "a roll of the dice", with a probability of green equalling the estimated proportion with access to surgical care in the IHME region.

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“Medicine is a social science, and politics is nothing but medicine on a larger scale”

- *Rudolf Virchow, 1848*

“All models are wrong. Some are useful.”

- *George Box, 1976*

“People often call me an optimist, because I show them the enormous progress they didn't know about. That makes me angry. I'm not an optimist. That makes me sound naive. I'm a very serious “possibilist”. That’s something I made up. It means someone who neither hopes without reason, nor fears without reason, someone who constantly resists the overdramatic worldview. As a possibilist, I see all this progress, and it fills me with conviction and hope that further progress is possible. This is not optimistic. It is having a clear and reasonable idea about how things are. It is having a worldview that is constructive and useful.”

- *Hans Rosling, 2018*

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III. Assessing cesarean-associated surgical site infection screening paradigms post-discharge in rural Africa: A modeling study
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VI. The economic consequences of neurosurgical disease in low- and middle-income countries
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Journal of Neurosurgery, 2018, **54**: 1–8

VII. Modelling why 70 per cent of the world's population lack access to surgery
Rudolfson N, Shrime MG, Alkire BC
British Journal of Surgery, 2023.

Abbreviations

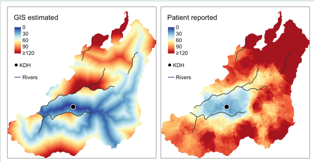
CHE	Catastrophic health expenditure
CHW	Community health worker
DALY/QALY	Disability/Quality-adjusted life year
DCP3	Disease Control Priorities 3rd edition
GBD	Global Burden of Disease
GDP	Gross domestic product
GIS	Geographical Information System
GNI	Gross national income
HDI	Human Development Index
IHME	Institute for Health Metrics and Evaluation
LCoGS	Lancet Commission on Global Surgery
LMIC/HIC	Low- and middle-income countries/High-income countries
POMR	Perioperative mortality rate
PPP	Purchasing power parity
SAO	Surgery, Anaesthesiology and Obstetrics
SDG	Sustainable Development Goals
SSI	Surgical site infection
UHC	Universal Health Coverage
VLO/VLW	Value of lost output/value of lost welfare
VSL	Value of a statistical life
WDI	World Development Indicators
WHO	World Health Organization

Thesis at a glance

	Research aim	Methods	Key Results
I	To validate geographical information system (GIS) methods for calculation of geographical access, comparing patient-reported travel times to those derived by computational methods	Comparative GIS study, using prospective patient survey data and GIS modelling	Patient-reported times were longer than those yielded by GIS modelling by a factor of 1.49 (95% CI 1.40 – 1.57).
II	To quantify the migration of surgical specialists in and out of South Africa, in relation to the size of the workforce	Cross-sectional observational study of National registries of surgical providers	16% of surgical specialist from South Africa have migrated to a high-income country, whilst 6% of surgical specialists in South Africa were from another LMIC
III	To assess the feasibility of task-shifting postoperative wound care and surgical site infections (SSI) surveillance to community health workers, analyzing under which conditions this could be beneficial	State transition modelling study	Sensitivity of community health workers affect health outcomes, while specificity affects financial outcomes
IV	To estimate the burden of out-of-pocket payments for cesarean sections in the context of community-based health insurance and determine if having it reduces catastrophic health expenditure	Prospective observational study from patient questionnaires and hospital billing data	The rate of catastrophic health expenditure was 5.3% from direct medical costs, 15.4% from all direct costs, and 22.6% with indirect costs. Health insurance greatly affected the risk.
V	To expand measurement of catastrophic health expenditure to the postoperative period, comparing incidence at discharge to postoperative day 30	Prospective observational study from patient questionnaires and hospital billing data	The risk of catastrophic health expenditure was 27% when accounting for direct and indirect costs up until hospital discharge, and 77% by post-operative day 30
VI	To estimate the economic consequences of neurosurgical disease in low- and middle-income countries	Macroeconomic modelling study utilizing country-level datasets on health and economic parameters	A cumulative total of $4.4 trillion in GDP are estimated to be lost to neurosurgical disease during 2015 – 2030
VII	To quantify the relative contribution of timeliness, capacity, safety and affordability to the global lack of access to surgical care	Global modelling study, utilizing country-level health systems indicators	Of the billions of people estimated to lack access to surgery, 60% do so due to a lack of 2 or more factors, 27% due to a lack of 3 or more factors, and 13% due to all four

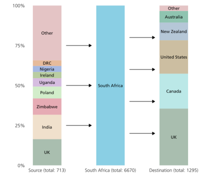
Conclusion and significance

I



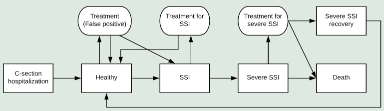
Current methods utilized to measure timeliness to surgical care were shown to be overly optimistic in at least one context

II



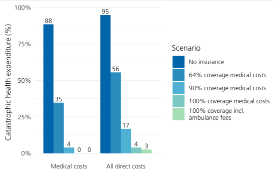
South Africa acts as a regional hub for migration of surgical specialists, representing an important destination for sub-Saharan emigrating surgical specialists, whilst itself acting as an ever larger exporter of surgical specialists to high-income countries

III



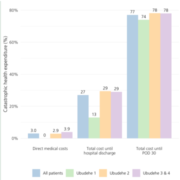
The parameters under which community health worker led surgical site surveillance would be feasible were outlined, and can inform future interventional studies

IV



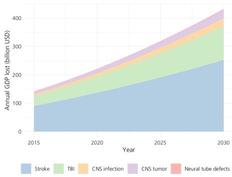
Even with robust health insurance, cesarean section patients are at high risk of catastrophic health expenditure, and often need to borrow money or sell assets in order to afford care

V



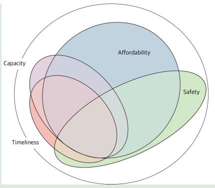
When the postoperative follow-up after discharge is accounted for, the incidence of financial catastrophe is even larger

VI



The burden of neurosurgical disease will lead to profound global macroeconomic losses in the coming decades

VII



Universal health coverage is a continuum rather than a binary headcount, and solutions will need to be as multifactorial as the problem they seek to solve

Abstract

Background. A once commonly held belief was that surgery is too complicated, too expensive, and too ineffectively addressing a too minor proportion of the burden of disease to deserve priority in a setting of scarce healthcare resources in low- and middle-income countries. Yet, essential surgical care can be as highly cost-effective as other common public health interventions, and surgical services are increasingly considered integral to the health system strengthening necessary for reaching health-related sustainable development goals.

It has been estimated that 9 out of 10 people in low and lower-middle income countries cannot access timely, safe, and affordable essential surgical care. However, little is known on the upstream determinants of access and of the downstream effects of insufficient surgical health systems.

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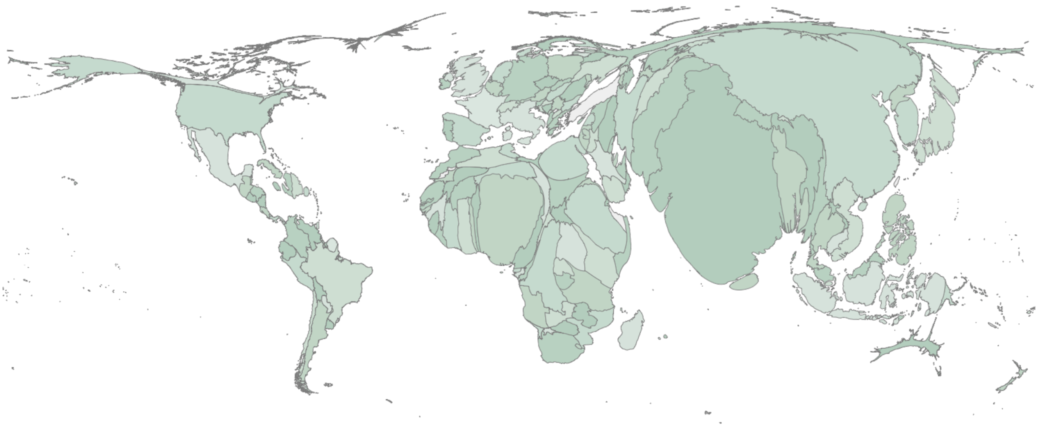
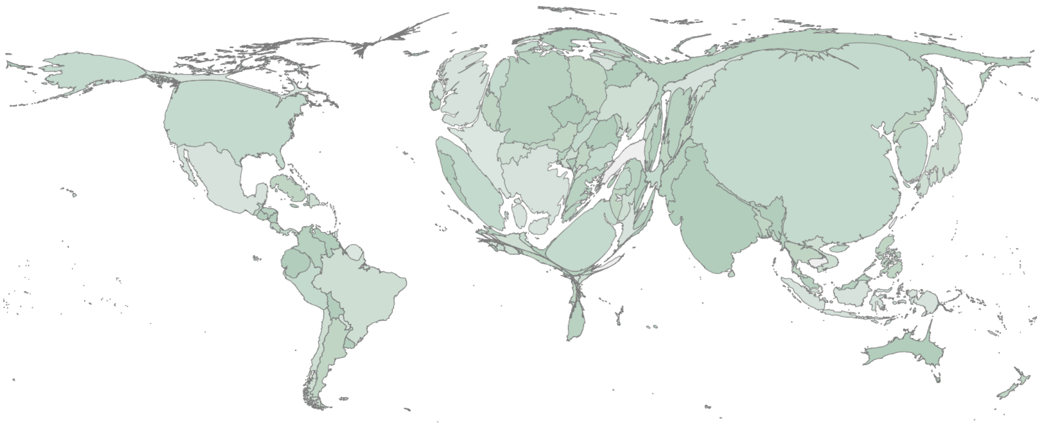
Need for surgical interventions



Distribution of surgeons, anesthesiologists, and obstetricians



Cartograms, in which the size of each country has been scaled to the estimated annual number of surgeries needed[13*] and to the size of the surgical workforce[10,11].

*Data from Rose et al, with kind permission from the authors

Background

Global surgery – an introduction

> *"Surgery is a practical affair. It has to be by its very nature. Does it have underlying philosophy? I think it does. It cannot escape the political, social, and economic factors that influence all human endeavours. Social injustice is socially unjust in any field of endeavour, and the world will not tolerate it for much longer. So the distribution of surgical resources in countries and throughout the world must come under scrutiny in the same way as any other intellectual, scientific, technical, social or economic commodity. The era of only the best for the few and nothing for the many is drawing to a close."*
>
> *Dr Halfdan Mahler, Director-General Of The World Health Organization, June 1980*[1]

During the last few decades, there has been substantial development of health and prosperity in the developing world, with major gains achieved in terms of e.g. child mortality, maternal mortality, and life expectancy. This progress has been realized primarily due to advancements in the treatment of infectious diseases, and as a consequence non-communicable diseases now account for the majority of morbidity and mortality globally (**Figure 1**).

As a result of this demographic shift, a new set of health challenges emerge, not least of which is the impetus to develop health systems capable of treating surgical disease. Still, it has been estimated that 9 out of 10 people in low and lower-middle income countries cannot access safe, timely, and affordable essential surgical care.[2,3] A once commonly held belief was that surgery is too complicated, too expensive, and too ineffectively addressing a too insignificant proportion of the burden of disease to deserve priority in a setting of scarce health care resources in low- and middle-income countries (LMICs). Yet, as we shall see, essential surgical care can be as highly cost-effective as other common public health interventions, and surgical services are increasingly considered integral to the health system strengthening necessary for reaching health-related sustainable development goals.

Global Surgery could therefore be described as the research of how, in the prescient words of Dr. Mahler, we can end the "era of only the best for the few and nothing for the many".

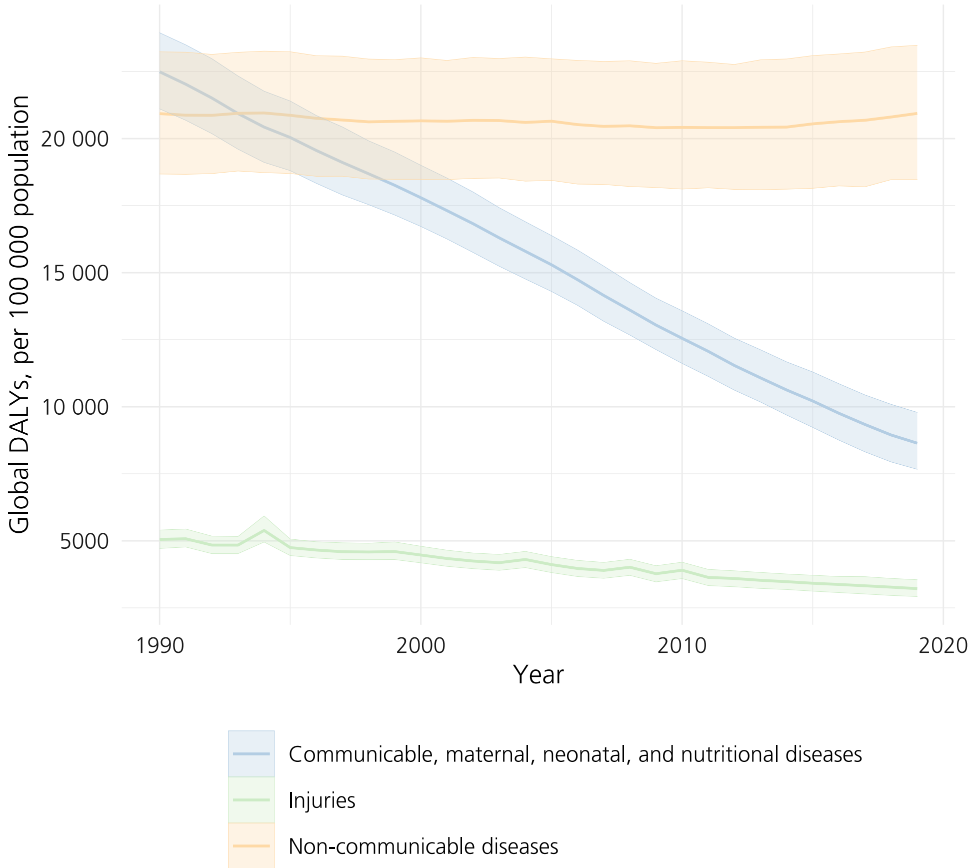


Figure 1. A demographic shift of ill-health. Global disability-adjusted life years (DALYs) lost to three groups of diseases, 1990-2019. Data from The Institute of Health Metrics and Evaluation (IHME)[4]

Surgery has famously been described as the "neglected stepchild of global health",[5] but in recent years there has been a growing interest in the emergent and multidisciplinary field of global surgery,[6] not least as evidenced by the adoption by World Health Organization (WHO) members of resolution *WHA 68.15 Strengthening emergency and essential surgical care and anaesthesia as a component of universal health coverage*,[7] and by the publication of the Lancet Commission on Global Surgery,[2] the Disease Control Priorities 3ed (DCP3): Essential Surgery,[8] and a steadily increasing number of annual publications (**Figure 2**).

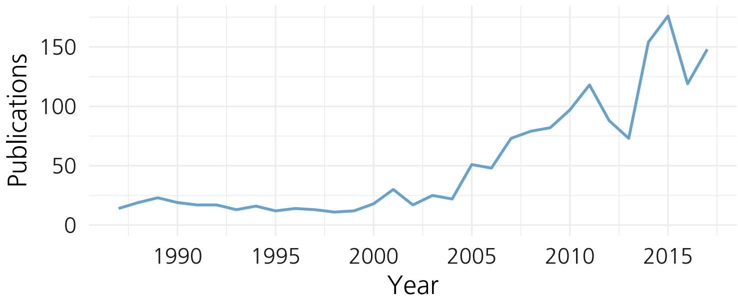


Figure 2. Annual Global Surgery publications. Data from Sgrò et al[9,a]

Table 1. Some key statistics of low income, middle income and high income countries

	Low income countries	Lower-middle income countries	Upper-middle income countries	High income countries
Proportion of the world's population[10]	9%	43%	32%	16%
GDP per capita, PPP[10]	1964	7242	18 193	50 122
Health expenditure per capita, PPP[10]	106	284	1047	6243
Life expectancy (years)[10]	64	69	76	80
Maternal mortality ratio (per 100 000 live births)[10]	453	253	41	11
Surgical specialists per 100 000 (median)[11]	0.7	3.6	23.8	67.9
Operations per capita (median)[11]	328	2445	3375	7579

[a] reproduced from World Journal of Surgery volume 43, 2019, with permission from Springer Nature CSC

Panel: Global living conditions – progress is possible

When asked, a substantial majority of people believe the world is getting worse, rather than better.[12] Yet, whilst there are undoubtedly important challenges in both high-, middle- and low-income countries, the most important metrics of human flourishing have historically improved drastically. In the words of Hans Rosling: "*Things can be bad, and getting better*".

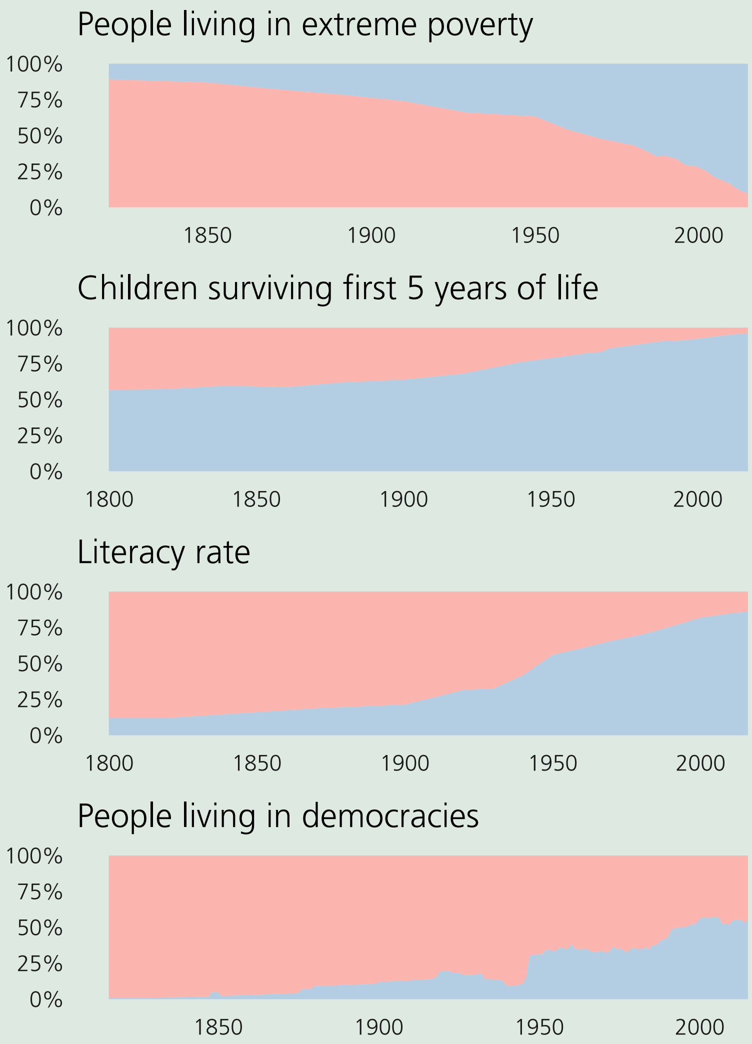


Figure 3. A short history of global living conditions in four charts. Adapted from Our World In Data[12]

Global Burden of Surgical Disease

Definitions

Surgery is an integral part of any complete health system. However, measuring the global burden of "surgical disease" is a complex issue, not least due to conceptual difficulties. Even the term "surgery" lacks a clear and uniform definition, and may be defined e.g. by broad definitions such as "interventions requiring general or neuroaxial anesthesia",[13] by lists of procedure codes, etc.

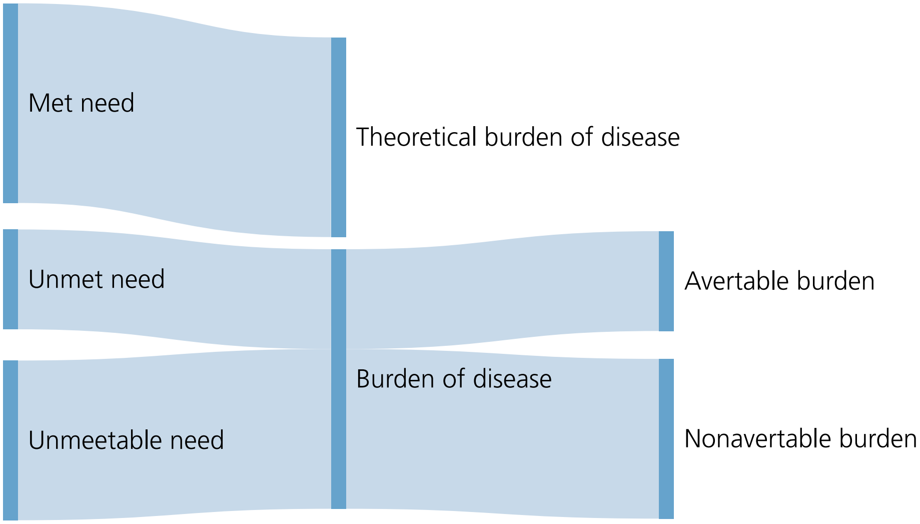


Figure 4. Burden of disease concepts

As outlined in **Figure 4**, the current total burden of disease encompasses two parts. The unmeetable need or nonavertable burden comprises burden which cannot be decreased even with the best standard of care, e.g. some prehospital trauma deaths. It should be noted that even this burden could be decreased, e.g. by decreasing the population incidence (e.g. increasing road safety) or by technological advancements. The unmet need or avertable burden comprises morbidity and mortality which could be avoided by expanding access to health services. Some authors also include the met need concept, which comprises a theoretical burden of disease which has already been avoided by the health services currently present.[14]

Estimations of surgical burden of disease

Several assessments of regional or national burden of surgical disease have been published, often utilizing survey methodology. A national population-weighed cluster randomized sample in Sierra Leone found a 25% prevalence of symptoms needing surgical consultation, and among deaths of family members in the past year, 25-33% were associated with potentially surgical conditions.[15,16] A national study in Uganda found an 11% prevalence of surgical symptoms, and a 34% incidence of surgical symptoms in the immediate period before death of deceased family members.[17] In Rwanda, the prevalence of surgical symptoms was 6.4% with a 12-month prevalence of 15%, and 33% of household deaths were associated with surgical symptoms.[18] A study in Nepal found a 10% prevalence of surgical symptoms with up to 23% of deaths amenable to surgical treatment and additionally found a high concordance between results as reported by the survey and by physical examination.[19] Similar cluster randomized survey methodology has been applied to estimate the burden from specific diseases[20] or in specific populations.[21,22] Stokes et al instead estimated the met burden of surgical disease in a prospective 3-month data collection of care delivered at a district hospital in Papua New Guinea, finding that surgical care provided averted 18% of the total burden of disease.[23]

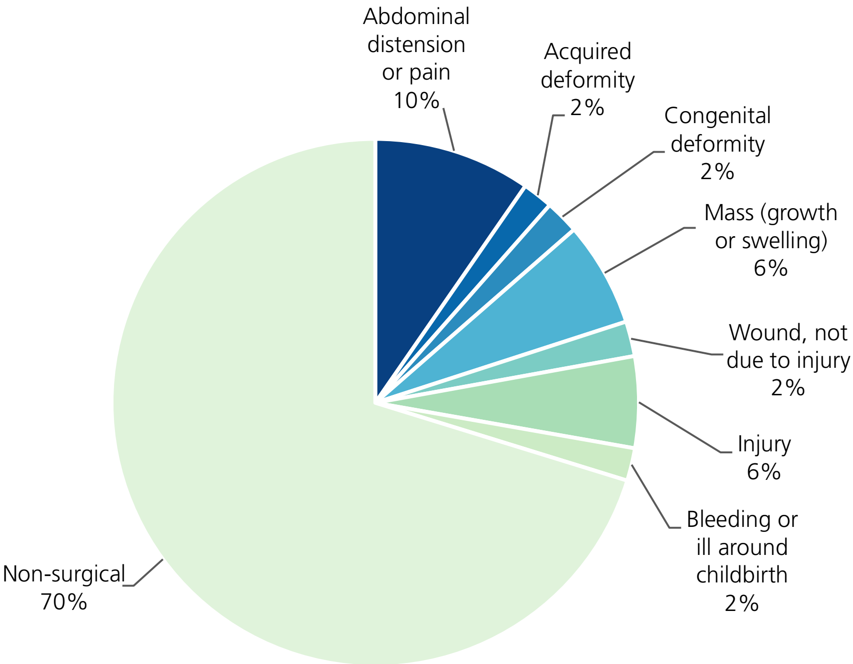


Figure 5. Deaths associated with potentially surgically treatable conditions. Average of data reported by Petroza et al,[18] Gupta et al[19] and Kwon et al[16].

Attempts have also been made to estimate the global burden of surgical disease, utilizing the Global Burden of Disease (GBD) database developed at the Institute for Health Metrics and Evaluation (IHME).[4] Stewart et al calculated the burden of disease requiring emergency surgical interventions and arrived at 2% of the global burden of disease.[24] Shrime et al, recognizing that not all surgical patients necessarily require operative intervention, instead defined surgical care as care which would benefit from a surgeon in its management, yielding an estimate of 28-32% of the global burden of disease.[25] Rose et al analyzed a representative sample of U.S. inpatient medical records and found at least one operation was performed in 29% of admissions, with a rate between 0.2% for admissions with a main diagnosis code in the “Mental and behavioral disorders” subcategory and 84% for “Musculoskeletal disorders” (**Figure 6**).[26] Specifically, operations were performed in all Global Burden of Disease subcategories, calling into question the division of diseases into surgical and non-surgical diseases and highlighting the necessity of surgical services in a comprehensive health system.

Yet another approach is taken by DCP3.[8,27-29] Here, the burden potentially addressable by a package of basic surgical care at the district hospital level and a select group of subspecialty elective interventions (detailed in **Table 3**) is calculated, finding that a total of 18% of the total burden of disease in LMICs were attributed to these diseases. The burden avertable by scaling up these select surgical services was calculated to 5.2% (**Table 2**). These estimates can be compared with the burden of other important global health priorities such as the three diseases addressed by the Global Fund (malaria, TBC, HIV/AIDS) which total 9.6% of the LMIC burden of disease, and ischemic heart disease which totals 5.8% (**Table 2**).

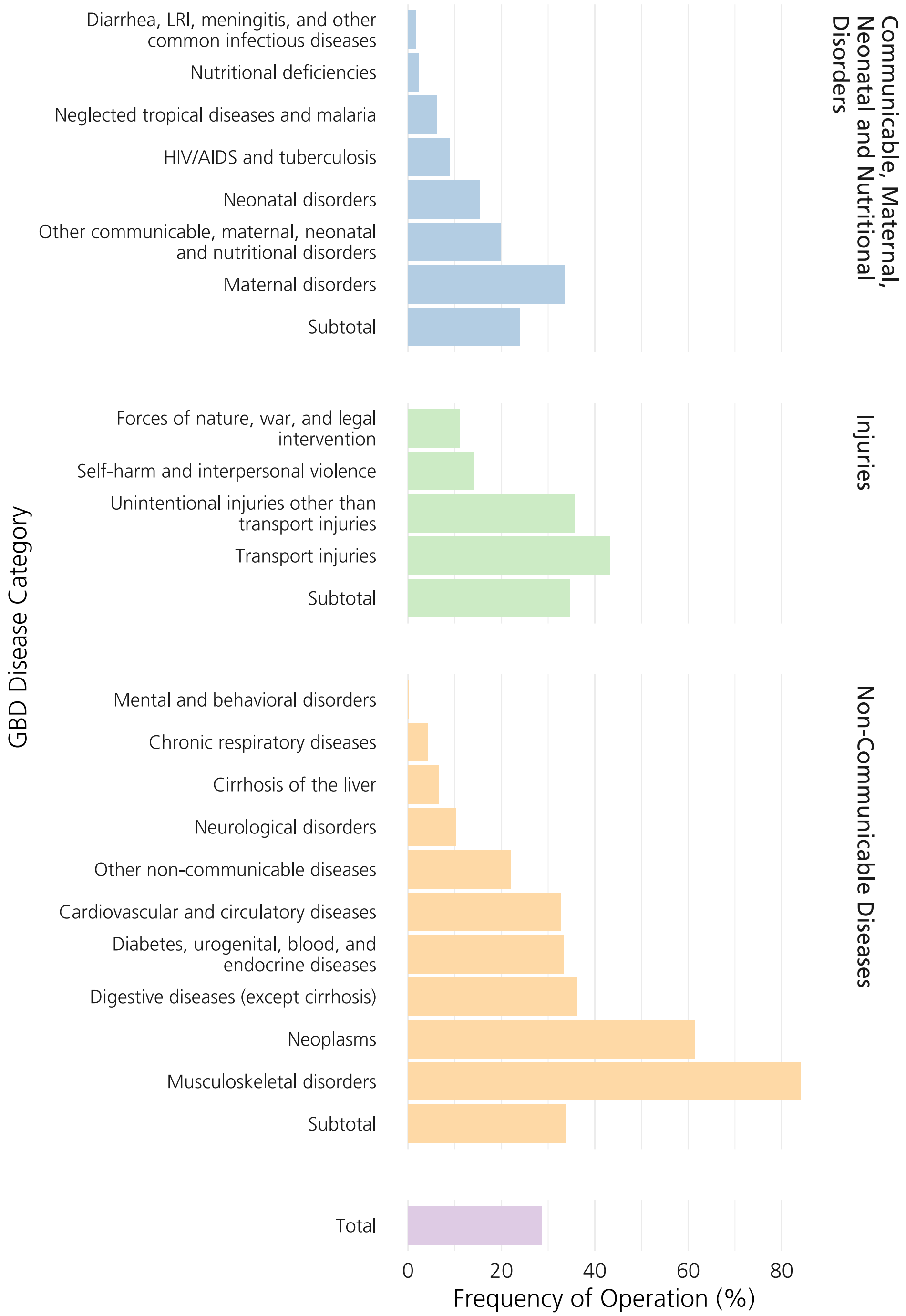


Figure 6. Percentage of inpatient admissions requiring a major surgical intervention in the US, by GBD subcategory. Adapted from Rose et al[26]

Table 2. Burden of disease treatable by a select group of surgically treatable conditions, of malaria, tuberculosis and HIV/AIDS, and of ischemic heart disease[8,b]

Disease	Million DALYs per year	Fraction of total burden of disease
Surgically treatable conditions	401	17.9%
Nonavertable burden	285	12.8%
Avertable burden	116	5.2%
Basic surgical care	316	14.2%
Select subspecialty care	85	3.8%
Malaria, Tuberculosis and HIV/AIDS	214	9.6%
Malaria	83	3.7%
Tuberculosis	49	2.2%
HIV/AIDS	81	3.6%
Ischemic heart disease	130	5.8%

[b] This is an adaptation of an original work by The World Bank. Views and opinions expressed in the adaptation are the sole responsibility of the author of the adaptation and are not endorsed by The World Bank

Table 3. List of diseases included in the basic surgical care and subspecialty surgical care packages of DCP3[8,b a]

Group	Disease
Basic surgical care package	
Injuries	Road and transport injury
	Falls
	Drowning
	Fire, heat, and hot substances
	Poisoning
	Exposure to mechanical forces
	Adverse effects of medical treatment
	Animal contact (venomous & nonvenomous)
	Unintentional injuries not classified elsewhere
	Self-harm
	Interpersonal violence
	Exposure to forces of nature
Maternal-neonatal	Maternal hemorrhage
	Obstructed labor
	Abortion
	Neonatal encephalopathy
Digestive diseases	Paralytic ileus and bowel obstruction
	Hernia
	Gall bladder and bile duct disease
	Appendicitis
Selected subspecialty surgical care package	
	Cataract
	Cleft lip and palate
	Congenital heart anomalies
	Neural tube defects
	Obstetric fistula

Global volume of surgical interventions

Total need

The annual need for surgical interventions has been estimated to 322 million operations,[13] by extrapolating New Zealand data[30] on the number of operations for 119 diseases to GBD estimates for these diseases (**Figure** 7).

Based on this data as well as an association with favorable health outcomes on a national level, the Lancet Commission on Global Surgery proposed a target level of at least 5000 annual operations per 100 000 population.[2]

Figure 7. The estimated number of surgical interventions needed per year (in millions), by Global Burden of Disease groupings. Data from Rose et al[13,c]

[c] With kind permission from the authors

Met need

The number of annual surgical interventions in 2012 was estimated to 313 million (95% CI 266 – 360).[31] For this estimation, published data from both international and national statistical agencies and from the scientific literature for 66 countries were used, and a prediction model based on health spending per capita was used to impute values for countries without data.

Utilizing similar methodology, Holmer et al estimate a total of 266 million annual operations in 2016.[11] Only 13% of these were performed in low income and lower-middle income countries, which account for 49% of the world's population.

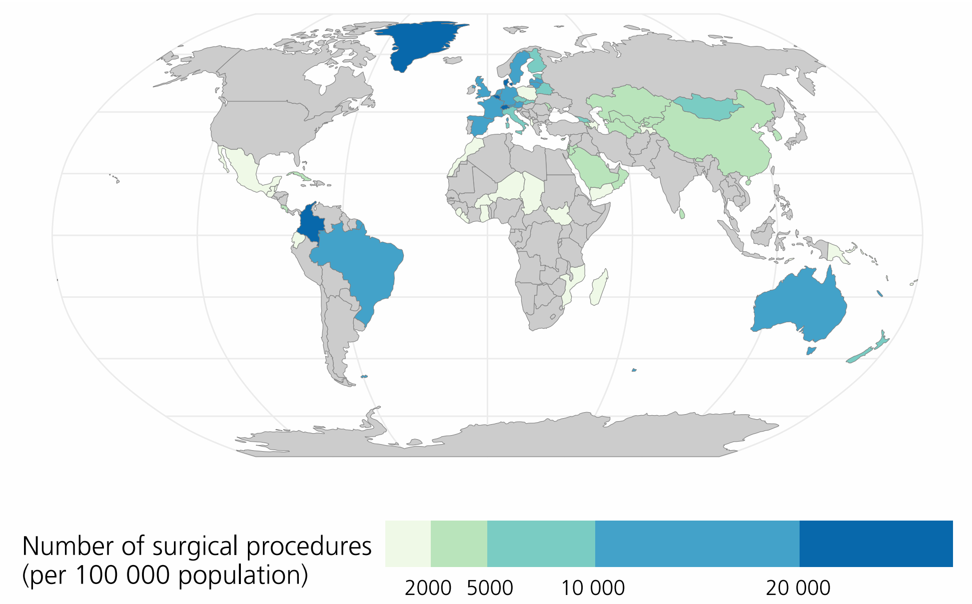


Figure 8. Primary data on the number of annual surgical procedures, latest data as reported in the WDI[10]

Unmet need

An estimated 143 million additional operations are needed annually,[2] as estimated by calculating the difference between total and met need for each of the 21 GBD regions. Note that some regions already perform on average substantially more surgery per capita than New Zealand.

Although the number of operations performed annually is increasing, only a minority of countries are projected to reach the goal of 5000 operations per 100 000 population by 2030.[32,33] However, there are promising examples of countries with a higher rate of growth which would allow the majority to reach this goal.[2,32]

Cost-effectiveness of surgical interventions

An understanding of the cost-effectiveness of different interventions is one of many crucial tools for policymakers to prioritize the scale-up of different health services in the face of constrained resources. It should be noted that other priorities besides cost-effectiveness must be taken into account, and important methodological limitations persist.[34] Analyzing the cost-effectiveness of surgery can be especially challenging. Implementation of a surgical system relies on several indispensable supporting systems (radiology, anesthesia, referral systems, pathology, etc.), but the scale up of such auxiliary systems has benefits far outside the reach of surgical care.[2] Additionally, there is a paucity of data on the long-term health effects of non-provision of surgical care (i.e. the natural course of surgical diseases) and associated disability weights necessary for DALY calculation.[35] It should be noted that similar limitations apply to nonsurgical interventions as well.

Several attempts have been made to summarize the cost-effectiveness of a broad set of surgical interventions, both for individual diseases and for entire care systems.[8,35-38] The findings of two systematic reviews are presented in **Figure 9**, and several surgical interventions have favorable cost-effectiveness profiles as compared to other important and widely implemented public health interventions.

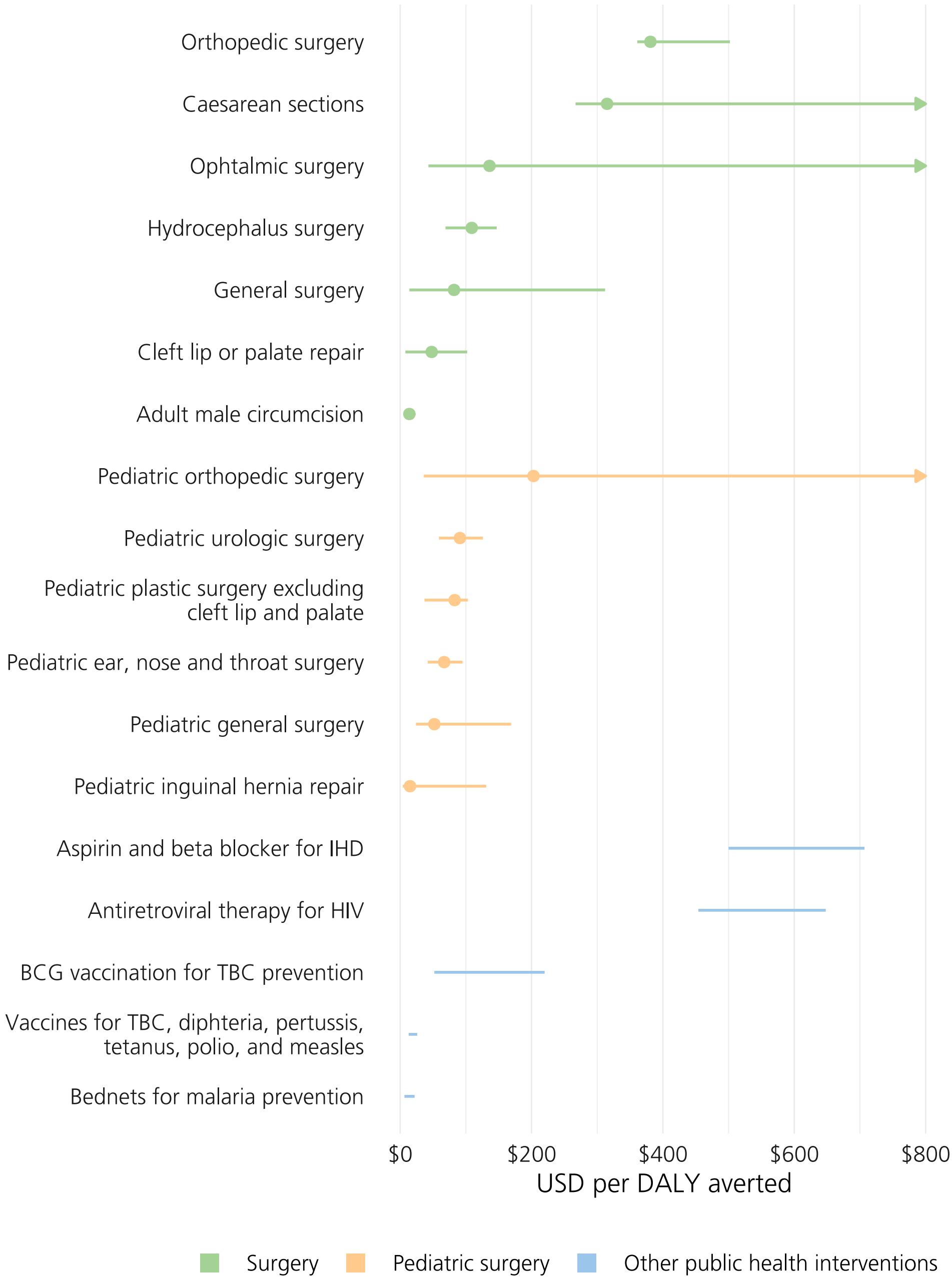


Figure 9. Cost-effectiveness of surgical and nonsurgical interventions. The bars represent range, and the dots represent median values. Adapted from Chao et al[37] and Saxton et al[38]

Measurement and indicators

The Lancet Commission on Global Surgery (LCoGS) suggested a set of 6 core indicators (**Table 4**, **Figure 10**) to be used to track the provision of surgical care, in order to facilitate international comparison, development over time, and prioritization in national health planning.[2] The stated goal is to have these indicators included in the World Bank Development Indicators (WDI) database.[39] Efforts have been made to collect data for these indicators on both a national,[40-42] regional,[43] and global scale.[11,39] A key issue hampering the utility and comparability of these indicators has been a variability of definitions used in the reporting of data. Recently, efforts have been made to standardize definitions through a collaborative, international consensus process.[44]

Table 4. Lancet Commission on Global Surgery Indicators.

Indicator	Definition[2,11,44]	LCoGS Target by 2030[2]	Number of datapoints in WDI[d] (% of countries)[10] Presenting figure
Group 1: Preparedness for surgical care			
Geographic access to surgical facilities	Proportion within 2 hours of a facility capable of providing care for the Bellwether procedures (cesarean section, laparotomy, and surgical management of open long bone fracture)	80% of the population	Not included in WDI
Specialist surgical workforce density	Number of specialist surgical, anesthetic, and obstetric physicians, per 100 000 population	20 surgical, anesthetic, and obstetric physicians per 100 000 population	168 (74%) **Figure 17**, p43

[d] Between 2012-2021

Table 4 – cont.

Group 2: Delivery of surgical care			
Surgical volume	Surgical procedures done in an operating theatre under any form of anesthesia, per 100 000 population per year	5000 procedures per 100 000 100% of countries tracking surgical volume	81 (37%) **Figure 8**, p29
Perioperative mortality	All-cause death rate (%) before discharge in patients (up to 30 days) who have had a surgical procedure in an operating theatre	80% of countries by 2020 and 100% of countries by 2030 tracking perioperative mortality, with targets being set as more data are collected	Not included in WDI
Group 3: Financial effects of surgical care			
Protection against impoverishing expenditure	Proportion of households protected from out-of-pocket expenditures pushing the households below the poverty level	100% protection	134 (62%)
Protection against catastrophic expenditure	Proportion of households protected from out-of-pocket expenditures above 10% of household income	100% protection	134 (62%) **Figure 21**, p51

Limitations and pitfalls

Owing to the highly incomplete nature of reporting on these global surgery indicators, interpretation on a global or supranational scale is difficult. This problem is compounded by the fact that non-reporting of data is correlated with health system indicators, leading to severe bias unless proper adjustments are made.

Any set of health indicators must adhere to a few guiding principles to maximize their utility and to minimize both the cost and the risk of misleading data.[45] The indicators should have clear definitions and should be easy to collect, so as not to diverge crucial resources away from the provision of care. They should be widely applicable in different geographical contexts and be interpretable to both clinicians and policymakers. They should be responsive, such that important advancements in the provision of care are indeed reflected in the gathered metrics, and vice versa. Lastly, they should be constructed in such a way as to minimize the risk of negative unintended consequences resulting from prioritizing actions believed to improve the statistic above actions believed to benefit patients, often referred to as *gaming* the indicator.

Table 5. The SMART framework[46] is meant to help evaluate goals and targets such as those made by e.g. Millennium development goals (MDGs), Sustainable Development Goals (SDGs) or LCoGS. Originally devised as Specific, Measurable, Assignable, Realistic and Time-Related, many variations of this mnemonic have been proposed.

Specific	The goal targets a specific area for improvement
Measurable	The goal is quantifiable
Attainable	The goal can realistically be achieved, given available resources
Relevant	The goal is of importance to the population affected
Timely	The goal specifies when the result(s) can or should be achieved

There is perhaps also a lack of understanding within the global health community about the limitations of international health statistics,[47] especially in the face of abundant, detailed, and seemingly precise tables and visualizations made available from such sources as the IHME, the United Nations, the World Bank, and the WHO. It should be noted that even some of the most important health metrics on which considerable resources have been spent to acquire data, such as maternal and child mortality, are to some extent based on modeling.[48] Additional complications arise from the incredibly complex nature of some of the models we now rely on, which need considerable technical expertise and time investment to understand. Calls have been made suggesting policymaking should to a larger extent rely on fewer but simpler and perhaps more robust measurements, accepting that data will not be available to such a high degree of spatial and temporal resolution.[47,49] This is not to say that modeled data are not useful or indeed sometimes necessary, but merely that considerable caution is needed in their interpretation.

Concerns have also been raised regarding the coupling of additional funding to measures of historical health improvement, introducing perverse incentives in the reporting of health statistics and in some cases calling into question the validity of such data.[50]

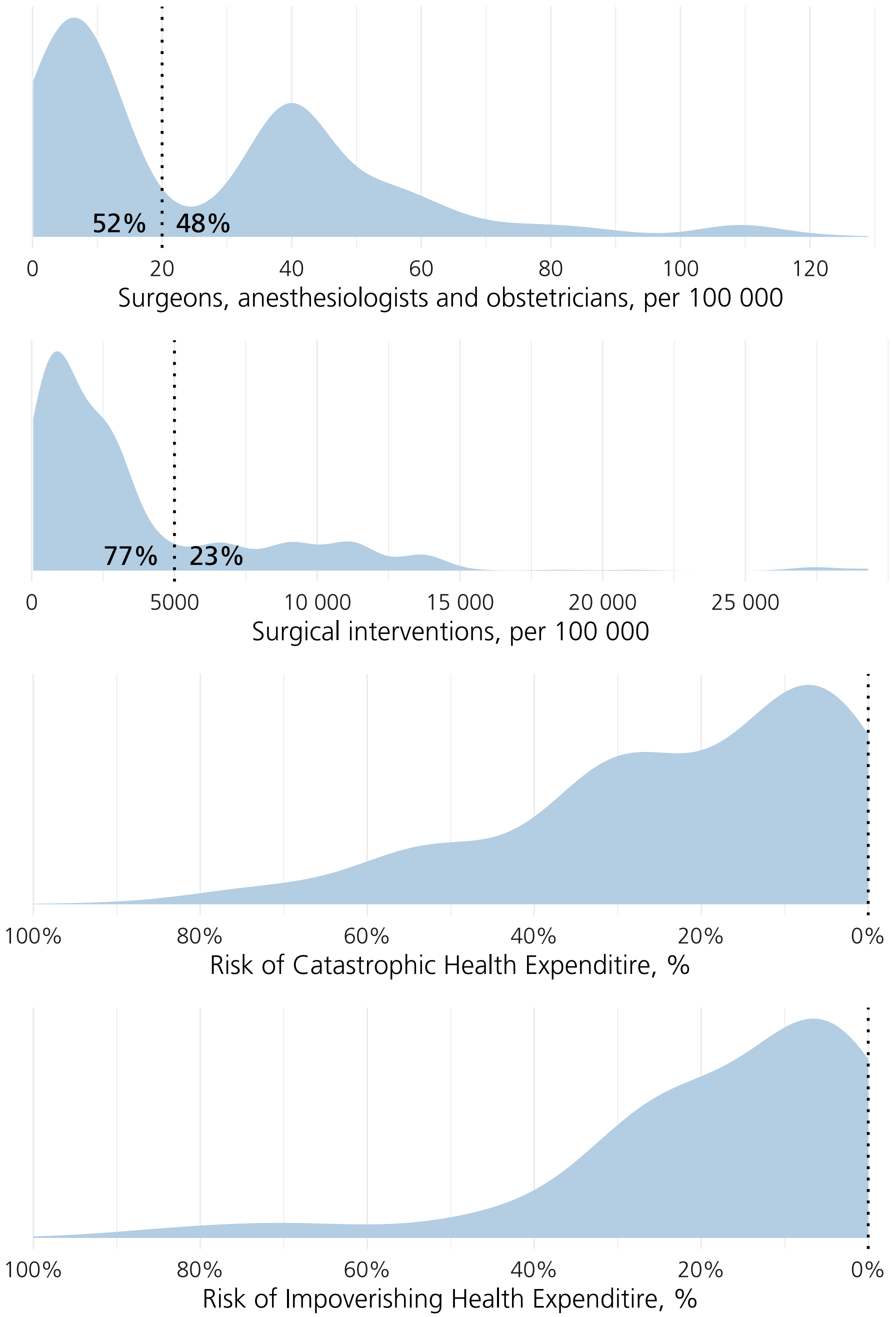


Figure 10.Global population-weighted density plots of the Lancet indicators. Dashed lines represent the LCoGS targets, e.g. 23% of the global population live in countries that perform at least 5000 surgical interventions per 100 000 population annually[10,11,51]

The four axes of access

As part of the Lancet Commission on Global Surgery, a working definition of access to surgical care was proposed:

> *For a patient to access surgical and anaesthesia care, a delivery system (including trained personnel and physical resources) should first exist. The patient should then be able to reach this system in a timely manner. For the patient to benefit, the care should be safe and effective. Finally, the costs of surgical and anaesthesia services should not act as a barrier to uptake, or result in financial catastrophe for patients and their families*[2]

Under this framework then, there are (at least) four aspects which must be fulfilled for an individual to have full access to surgical care if needed:

I. Timeliness
II. Capacity, i.e. availability of staff, equipment, and procedures
III. Safety
IV. Affordability

Utilizing this framework, it was estimated that 4.8 billion people, or roughly 70% of the world's then around 7 billion people, lacked access to surgery.[2,3]

Previous estimates had focused solely on the existence of operating theaters and estimated around 2.2 billion people lacked access to surgery.[52] There are obvious shortcomings of such an approach; the existence of an operating theatre is insufficient if patients are unable to reach the facility in time (especially so in emergency settings), if the care delivered does not hold adequate levels of quality and safety, or if the entire household is cast into poverty as a result of paying for care.

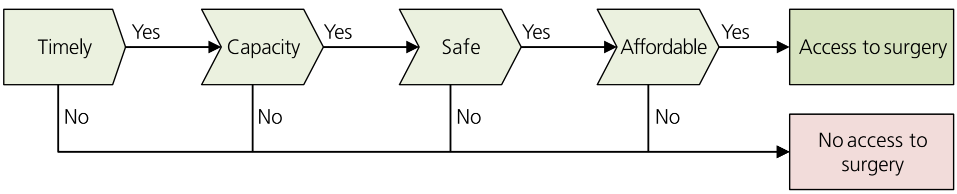


Figure 11. A framework for conceptualizing access to surgical care, adapted from Alkire et al[2,3]

While the overall global accessibility to surgical care was estimated as part of the Lancet Commission on Global Surgery, the relative contribution of the four axes had not previously been assessed.

Panel: Aim of study VII
To quantify the relative contribution of timeliness, capacity, safety, and affordability to the global lack of access to surgical care

Timeliness

For many surgical conditions there is a critical window of time between onset of symptoms and receiving treatment after which poor outcomes are much more likely, and a large proportion of the world's population lives more than a day from a center capable of common urgent and life-saving operations.

The time between onset of symptoms and receiving care can be divided into three periods using the three delays framework.[53]

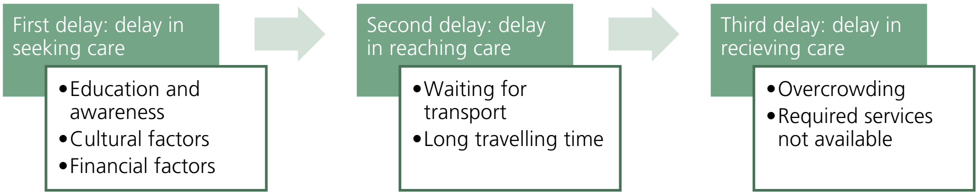


Figure 12. The three delays framework[53] and some examples of reasons for delay

The first delay – seeking care

The first delay starts at the onset of symptoms requiring surgical care. Several factors can influence the length of this delay, with examples including realizing a consultation is necessary, gathering funds for travel and healthcare, having to get permission from family members, negative expectations or experience of healthcare, utilizing traditional medicine providers first, etc.[53,54] There has been comparatively little research on ways to mitigate the first delay,[55,56] although examples include travel vouchers to overcome the need to finance travel costs,[57,58] and community outreach programs.[55]

The second delay – reaching care

The second delay covers the travel time, and examples influencing this delay include having to wait for a means of transport, long distances to the nearest capable facility, road conditions, etc.

The second delay can be readily assessed using Geographical Information Systems (GIS), and so has received considerably more attention in the scientific literature. A more detailed description of the GIS methodology as applied in this thesis can be found under *Methods* (p. 66), but in short studies on geographical access rely on three inputs:

I. A set of coordinates of facilities known to perform the healthcare intervention of interest
II. A travel time surface, consisting of information on the speed with which it is possible to travel, i.e. roads and their respective speeds, rivers and other hindrances to movement, etc. Using information from I and II, it is possible to calculate how long it would take to travel to the nearest capable facility from each point on a map
III. A map of population density. The sum of people living within for example a 2-hour radius from a capable facility can then be divided by the total population to yield a percentage

Using this methodology the 2-hour access to district hospitals in sub-Saharan Africa has been estimated to be between 71% and 92%.[59,60] However, one study of hospitals providing surgical care in seven LMICs, found only 34% of studied hospitals met criteria for consistently delivering basic surgical services.[61] In these countries a median of 77% of the population could reach any study hospital, but only a median of 52% could reach one meeting the criteria. Of 103 hospitals identified as providing surgical care in Zambia, only 17% met WHO minimum standards of surgical safety, with 2-hour access to any surgical facility estimated to 85%, but only 34% to a facility meeting standards.[62] Another study of 2-hour access to any hospital with a surgeon on staff found a per-country median access of 43% (range 17 – 84%).[63] A 2018 review was only able to identify 19 countries for which data was available on hospitals providing all of the bellwether procedures[e] with just seven of these being LMICs, although 2-hour access was generally high within the included countries.[11] In summary, 2-hour access to any district hospital is reasonably high across studied countries and continents, but data on which hospitals can provide surgical care is lacking, and in the few

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[e] Caesarean section, laparotomy and initial treatment of open fractures, see p. 41 for further discussion

countries where data exists only a minority can consistently provide essential surgical care.

Beyond merely benchmarking 2-hour access, GIS methods can also be used for health system planning. For example, a study of hospitals in Ghana found 11 sites with a high capacity for essential surgical care and was able then able to identify 5 additional strategic candidate hospitals. If surgical care was strengthened at each of these candidate hospitals, 1-hour access would double from roughly 30 to 60%.[64] Other studies have analyzed the potential effect of expanding the use of motorized transport to emergency obstetric care,[65] evaluated the effect of centralization of obstetric care in a high-income setting,[66] analyzed the uptake or outcomes of care as a function of distance,[67-69] and proposed more efficient geographic allocation of care.[70,71]

However, a concern regarding GIS travel time methods has been that they may underestimate actual travel times in LMIC contexts. Validations against patient travel times were available from high-income contexts,[72,73] but data were scarce from LMICs,[74-76] and no studies were found validating similar assumptions as made in the global surgery GIS literature referenced above, motivating study I.

Panel: Aim of study I

To validate geographical information system (GIS) methods for calculation of geographical access, by comparing patient-reported travel times to those derived by computational methods for patients travelling to a district hospital in rural Rwanda for emergency obstetric care

The third delay – receiving care

The third delay consists of delay in receiving adequate care once at the facility, for example resulting from shortages in staff, equipment, or other resources, and is covered under the capacity chapter of this thesis.

Capacity

Measuring capacity at the facility level

Several tools have been proposed for assessing the surgical capacity at the hospital level, including the WHO Situational Assessment Tool,[77] the revised PGSSC-WHO Surgical Assessment Tool (Program in Global Surgery and Social Change),[78,79] the Surgeon OverSeas Personnel, Infrastructure, Procedures, Equipment and Supplies (PIPES) tool,[15,80] and the Surgical Preparedness Index.[81]

The WHO tools in particular have been extensively used, with data collected from over 1500 hospitals worldwide over the 20 year period since the publication of the tool,[82] although updates to the data gathered are sparse and currently not centrally indexed. This tool has also been adapted to facilitate collection of the Lancet Indicators[79] and adapted to national contexts as part of surgical scale-up plans.[83]

The Surgical Preparedness Index was developed by a Delphi process to gauge surgical system preparedness against external stressors (exemplified by the Covid-19 pandemic). Results were obtained from 1632 hospitals, with a mean score of 67 in low-income countries, 82 in middle-income countries, and 89 in high-income countries (lowest possible score 23, highest possible score 115).[81]

Panel: The 4S framework

The capacity of a health system to deliver high-quality care depends on having sufficient resources, and these can be conceptualized as belonging to one of four categories; staff, stuff, space and systems.[84,85]

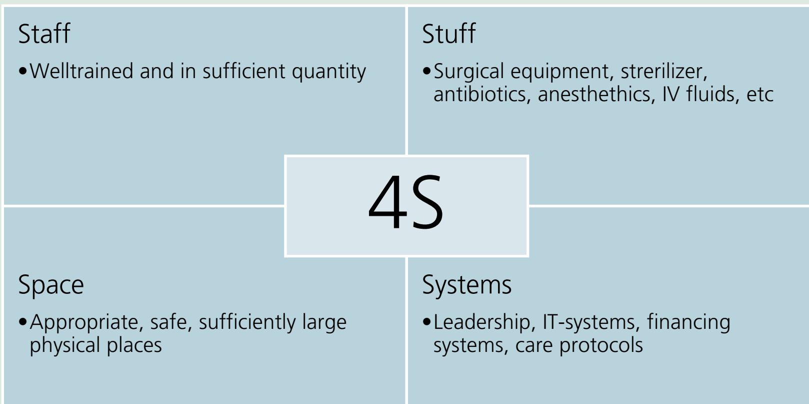


Figure 13. The 4S framework of healthcare resources

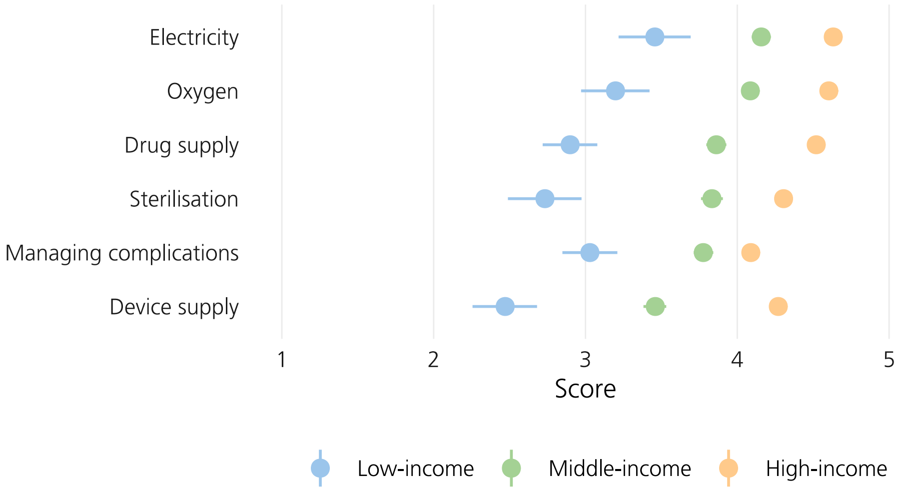


Figure 14. Stuff: mean scores across selected domains of the Surgical Preparedness Index, by income group. Mean and 95% CI. Adapted from NIHR and CovidSurg[81]

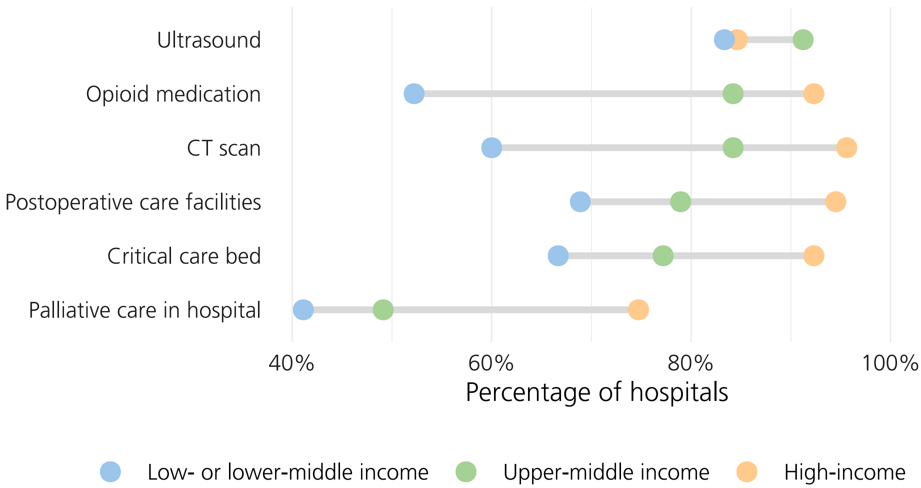


Figure 15. Stuff & staff: availability of a selected range of resources among centers performing cancer surgery, by income group. Data from GlobalSurg Collective[86]

As an alternative to the more extensive data collection suggested by the above facility assessment tools, proxy measures for surgical capacity have been developed. The *Bellwether* procedures (cesarean section, laparotomy, initial treatment of open fractures) were developed to predict availability of a majority of emergency and essential surgical procedures.[87] This simplified method of collecting data on facilities which can provide surgical care (3 questions, as opposed to the >100 questions in more comprehensive facility assessment tools) can be especially suited to gathering statistics on the national or international level. Care must be taken however to interpret the bellwether procedure list correctly, i.e. as proxy indicators of broader surgical capacity rather than as specific procedures to expand access to. Attempts have also been made to identify a broader basket of surgical procedures to assess capacity and volume, with a clearer connection to the International Classification of Disease (ICD) system.[88,89]

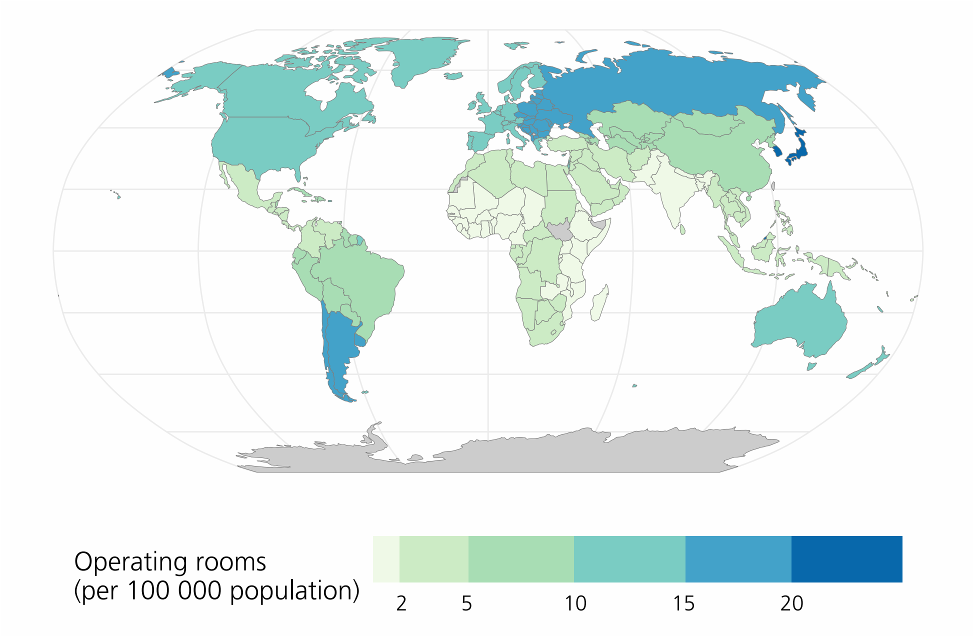


Figure 16. Space: estimated operating rooms per 100 000 population. Reported by IHME region. Source: author calculations, based on methodology described by Funk et al,[52] updated with the latest available hospital bed data as reported in the WDI[10]

The surgical workforce

Perhaps no other resource of the health system is as important as its human resources; there can be no healthcare without a workforce.[90,91]

There are primary data from 164 countries on the surgical specialist density,[10] more than any other surgical indicator, although some problems with differing definitions between countries persist.[11] An imputation approach has been used to extrapolate data necessary for global estimates.[11,92]

Globally, there are an estimated 104 million health workers, of which 13 million are physicians[93] and 2 million are surgeons, anesthesiologists or obstetricians.[11] There is a shortage of around 6 million physicians globally, the vast majority of which would be needed in south or east Asia and sub-Saharan Africa,[93] and there are over 30 times as many surgeons, obstetricians, and anesthesiologists per 100 000 population in Europe as there are in Africa.[11] Importantly, there are also stark intranational inequities in the distribution of the surgical workforce, with a vast majority residing in capitals and other major urban areas.[94,95]

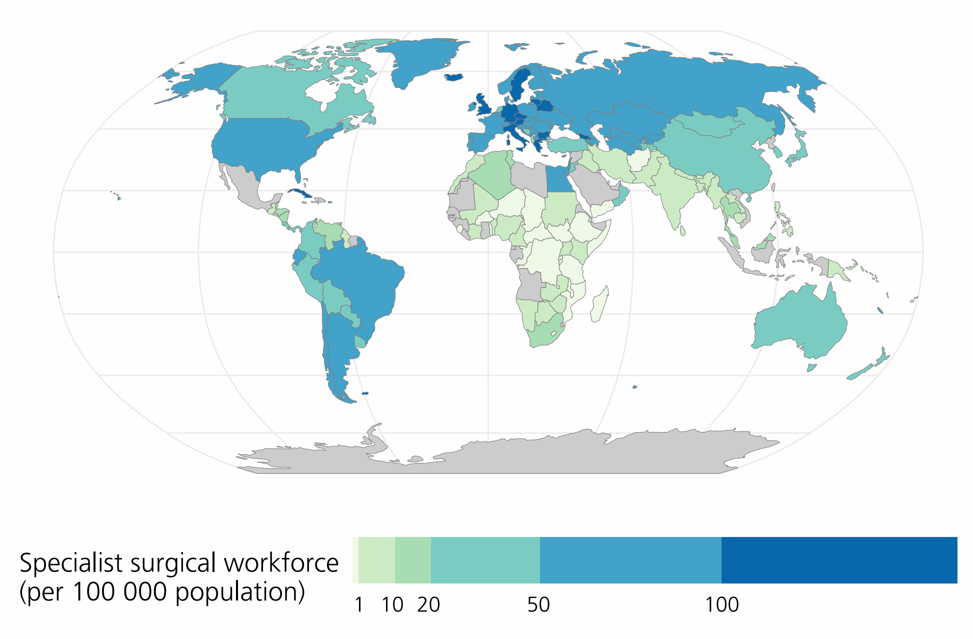


Figure 17. Staff: surgeons, anesthesiologists, and obstetricians per 100 000. Latest data reported in the WDI[10]

Panel: Workforce numbers in context

Burundi, a country with a population slightly larger than Sweden, has 19 surgeons.[95] Sweden has 8070.[11]

Tanzania has 6 anesthesiologists for 46 million inhabitants, Spain 11 000.[11]

The WHO African regions with its 500 neurosurgeons, has a slightly larger annual need for neurosurgical interventions than the European region, with its 11 000 neurosurgeons.[96]

Diagnosis is crucial for treatment. Yet, there are more radiologists working on Longwood Avenue in Boston than in the entire West African region.[97]

Many countries have explicit human resources for health strategies, and are actively working to expand medical education and institute workforce retention programs.[98] There are also initiatives to further the development of surgical education and accreditation, for example by the College of Surgeons of East, Central and Southern Africa (COSECSA),[99,100] the West African College of Surgeons (WACS), and the Pan-African Association of Christian Surgeons (PAACS).[101] Particular problems in recruiting medical students into surgical training programs include the length of training and difficult working conditions. Many are instead drawn to positions with international organizations, which often focus on infectious diseases.[94,102] Task-shifting surgical care to non-physicians represents another avenue for overcoming workforce shortages, often with excellent clinical results and workforce retention.[99,102-104]

Physician migration

One particular obstacle to the scale-up of the health workforce has been the migration of physicians and other health personnel from poorer to richer countries, sometimes known as “brain drain”.[105,106] Reasons for migration can include for example higher remuneration, opportunities for working in better-resourced facilities, career development opportunities, school systems, etc.[107,108] In the last years, the issue of physician migration has garnered significant international attention, and attempts have been made to draft and uphold ethical standards of international recruitment, including a WHO Code of Practice.[109-112]

A seminal 2005 paper on migration to just four high-income countries (the USA, Canada, the UK, Australia), found a particularly high emigration from sub-Saharan Africa and the Indian subcontinent, with 14% and 11% of physicians from said regions having emigrated to one of these four destination countries.[113] Later analyses have confirmed these numbers.[114] Similarly, at least 33 000 surgical specialists have emigrated from LMICs to HICs, representing

13% of surgical specialists educated in the WHO African region and 12% in the South East Asian region.[115]

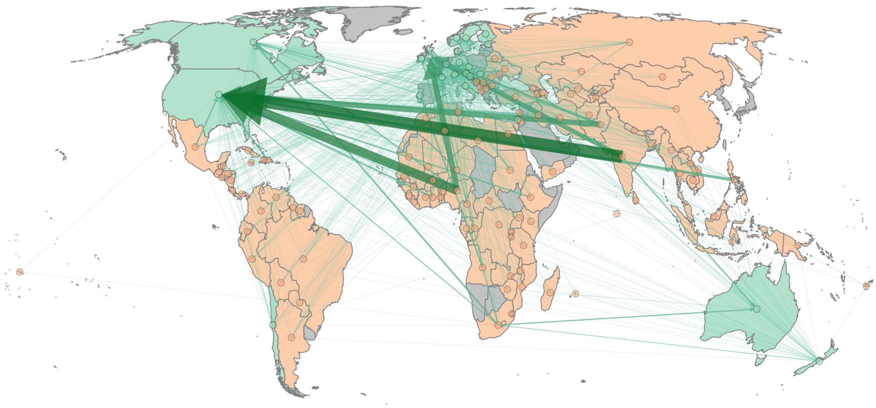


Figure 18. Economic effects of migration of physicians from LMICs to HICs, expressed in economic terms using a value of lost welfare approach. Figure from Saluja & Rudolfson et al.[116] Similarly, approaches utilizing cost of education data have found large economic benefits to HICs at the cost of LMICs[117,118]

South Africa has been described as an African hub for physician migration, as an established exporter of highly trained physicians to high-income countries and as a recipient from other African countries.[106,110,119,120] However, for surgical specialists neither the emigration from nor immigration to South Africa had been previously described.

Panel: Aim of study II

To quantify the migration of surgical specialists to South Africa from other low- and middle-income countries, and from South Africa to high-income countries. Further, to estimate the proportion relative to the total surgical workforce from the perspective of both sending and receiving countries.

Safety

The Lancet Global Health Commission on High-Quality Health Systems estimated 40% of the amenable mortality in LMICs is lost due to non-utilization of care, while 60% is lost due to inadequate quality of care.[121,122] In a wide range of countries and across the disease spectrum, deficiencies were found in diagnostic accuracy, prevention efforts, adherence to clinical guidelines, continuity and coordination, and not least patient experience (in turn affecting utilization).[121,123]

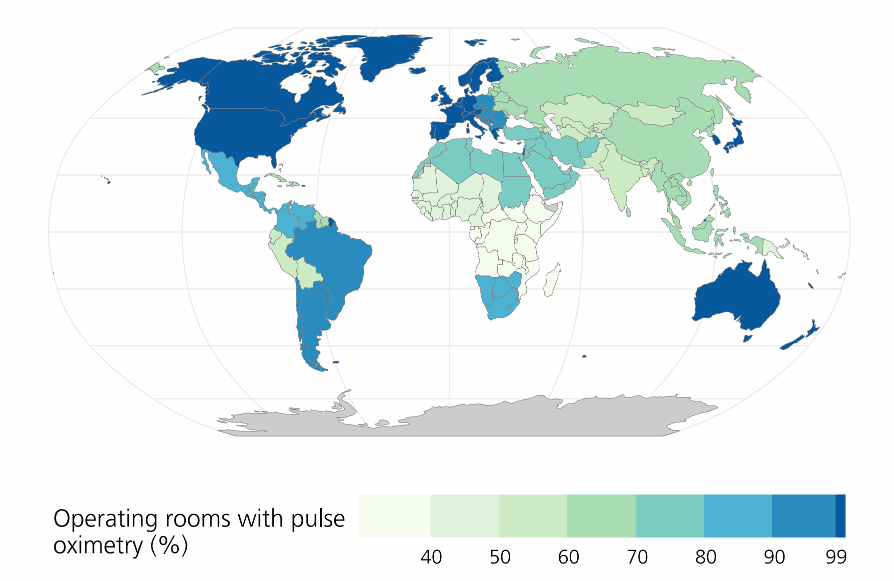


Figure 19. Estimated percentage of operating rooms with access to pulse oximeters. Estimates for 2010 from Funk et al.[f,52] Newer global estimates are not available, though data from 2021 suggest penetrance of pulse oximetry may have improved[124]

[f] Figure based on data from The Lancet, Vol 376, Funk et al, *Global operating theatre distribution and pulse oximetry supply: an estimation from reported data*, 1055-61, Copyright Elsevier (2010). With kind permission from Elsevier.

Panel: Safety, capacity, and timeliness

Of course, the close relationship between the quality of care, capacity, and timeliness must be reflected upon, and indeed are sometimes impossible to fully untangle. If a patient seeks care, but receives suboptimal care as a direct result of there being much too few surgical specialists available, shall we call it a safety or a capacity issue? If they experience a prolonged delay, is it a quality or a timeliness issue? If the perioperative outcomes are poor due to a lack of equipment, is it a safety or a capacity issue?

Despite these conceptual issues, focusing on quality and safety highlights the importance of not solely concentrating efforts on the increased uptake and availability of care. For example, a large Indian program incentivized delivery at a health facility, but despite a large increase in this proportion had no detectable effect on maternal or neonatal mortality.[125] A cluster-randomized quality improvement trial of 160 000 delivering mothers increased uptake of several practices a priori thought to be critical to quality, but had no effect on mortality.[126] Indeed, while lacking quality can be a result of inadequate resources, it can just as well result from misuse or overuse of healthcare resources.[127] Conversely, quality improvement efforts have proved effective in areas as diverse as child health, chronic condition management, health system productivity, and many more.[128]

Perioperative mortality

It has been estimated that at least 7.7% of all global deaths occur within 30 days of a surgical procedure,[129] meaning efforts to reduce perioperative mortality potentially can have a sizeable effect on population health.

A prospective, multicenter, observational study found an overall 30-day perioperative mortality rate (POMR) after emergency abdominal surgery of 5.4%, ranging from 4.5% in high human development index countries (HDI) to 6.0% in middle-HDI countries and 8.6% in low-HDI countries. Significant differences with odds ratios in the 2-3 range persisted after adjustments for patient characteristics, although it should be noted that complete adjustment for patient factors across such a wide range of diagnoses and settings is not possible.[130]

The African Surgical Outcomes Study assessed complications arising from all types of surgical procedures across 25 countries and found an overall in-hospital POMR of 2.1%, 94% of which died more than 24 hours after surgery. The observed risk profile of patients differed from that of a high-income setting: patients were younger (mean 39 years), and of lower ASA class (median 1), but had a high rate of HIV (11%) and a high rate of emergency indication for surgery (57%).[131]

An analysis of cesarean sections in the African Surgical Outcomes study found a maternal mortality rate of 0.5%, 50 times higher than in high-income countries, with peripartum hemorrhage and anesthesia complications found to be related to mortality. Neonatal mortality after cesarean section was 4.4%.[132] Consistent with these results, a systematic review of cesarean sections in LMICs found a pooled maternal mortality rate of 0.76%.[133]

A systematic review of perioperative mortality in low- and middle-income countries included 985 studies across 83 countries. Unsurprisingly, the POMR varied widely depending on the type of operation, from around 0% for appendectomy and cholecystectomy to over 20% for typhoid intestinal perforation and intracranial hemorrhage. Additionally, the definition of POMR with regard to time differed, and was often not reported at all. Patient-level risk factors were not reported in a majority of studies.[134] Likewise, a systematic review of POMR after emergency abdominal surgery found only a minority of studies reported on the definition of POMR or risk factors.[135]

Nationwide POMR are available from 28 countries (13 HICs and 15 LMICs), of which 9 report in-hospital mortality, 7 report 30-day mortality and 12 do not define the time period.[11] However, even if a higher number of countries were reporting data, comparability remains limited due to the differing case mixes between socioeconomic contexts. Approaches using a standardized basket of operations with more consistent indications and risk profiles have been suggested,[11,88,89] although with very granular data problems of imprecision with wide confidence intervals can arise even with national data.[136]

Surgical site infection

Surgical site infections (SSIs) are among the most common postoperative complications in both high-, middle- and low-income contexts, and are additionally related to both increased morbidity and mortality.[131,132,137-139]

The GlobalSurg2 study focused on SSIs, and found an overall incidence of 12%, which varied from 9.4% in high-HDI countries, 14% in middle-HDI countries and 23% in low-HDI countries, with patients in low-HDI countries suffering an increased risk of SSI even after adjustment for known risk factors (adjusted OR 1.6, 95% CI 1.1-2.4).[140] In the African Surgical Outcomes Study, the incidence of any SSI was 10%, of which 29% were deep SSIs. Mortality in the SSI group was markedly higher than for the entire cohort, regardless of elective or emergent indication.[131] Systematic reviews of SSIs in LMICs have found rates of 6-12%, as compared to 1-5% in HICs.[138,139]

Cesarean sections have been the focus of several evaluations, owing to the large proportion of all operations which are cesarean sections in many LMICs. Estimates of SSI rates after cesarean section include 15.6% from a literature review of sub-Saharan Africa,[141] 7.3% in a prospective observational study at four

Médecins Sans Frontières hospitals,[142] 3.7% in the African Surgical Outcomes Study,[132] and 10.9% in a prospective study in Rwanda.[143]

Several approaches have been suggested to increase quality and safety with regards to SSI; a systematic review of quality improvement efforts in sub-Saharan Africa found a quarter of the included articles had the goal of reducing SSI burden, second only to WHO Safe Surgery Checklist usage.[144] For example, a multi-center before-after implementation study in four African hospitals of a multimodal infection reduction program including a basket of SSI-combatting activities found a decreased SSI incidence from 8.0% to 3.9%.[145] After the introduction of an infection reduction program at five referral hospitals in Ethiopia, SSI incidence fell from 7.4 to 5.8%, with a relative risk of 0.65 (95% CI 0.43 – 0.99) in the preplanned multivariable regression analysis.[146] Several authors have highlighted the importance of tailoring quality improvement interventions to the local context and to the available resources.[147-149]

Yet another approach for decreasing the SSI burden is to improve early diagnosis. Particularly in resource-poor and rural settings, barriers for follow-up care[54,150] pose a risk of delayed diagnosis and progressive disease, especially since the majority of SSIs develop after hospital discharge. Community Health Worker (CHW) based follow-up has been piloted and found to be an acceptable and feasible way to conduct early at-home SSI diagnosis.[151-153] Many unknowns remain however, including uncertainty regarding the diagnostic accuracy under both the current standard of care and with community health workers, and regarding the health and financial effects under different scenarios.

Panel: Aim of study III

To assess the feasibility of task-shifting postoperative wound care to community health workers, analyzing under which conditions this could be beneficial

Affordability

Healthcare expenses are one of the leading causes of impoverishment, wreaking havoc upon entire households, and each year millions of people face catastrophic health expenditure[g] (CHE) as a result of seeking surgical- and non-surgical care. Consequently, financial risk protection is a crucial part of universal health coverage (UHC) and is prioritized by the UN as an SDG, measured by SDG indicator 3.8.2.

Modeling studies have estimated the annual incidence of CHE from surgery to be 33 million from direct medical costs alone, with an additional 49 million suffering CHE when indirect costs such as for transport are included.[2,154] Patients living in countries with lower health spending have a higher risk of CHE, and within countries there is a stark correlation between poverty quintile and CHE.[51]

Panel: Universal Health Coverage

Universal Health Coverage (UHC) can be defined as the "*desired outcome of health system performance whereby all people who need health services (promotion, prevention, treatment, rehabilitation, and palliation) receive them, without undue financial hardship*."[155]

Three questions need answering when evaluating how close a country is to universal health coverage: *What* is covered? *Who* is covered? *How much* is covered?

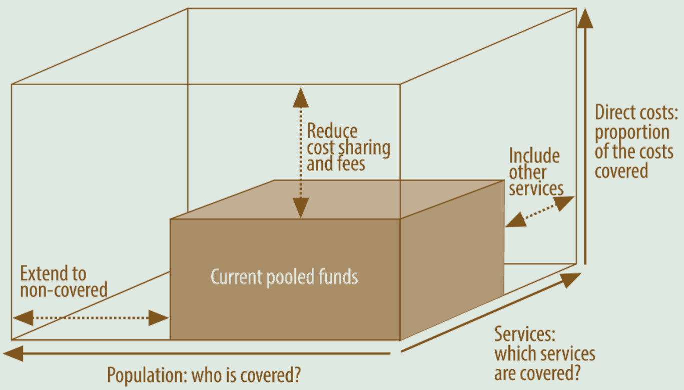


Figure 20. The dimensions of UHC. Adapted from Boerma et al[155]

[g] Catastrophic health expenditure can be defined in various ways, a discussion of which is found under *Patient-level financial outcome measures,* p. 64.

Affordability of care can also directly affect health in two ways. Firstly, expenditures which are catastrophic or even impoverishing can cast entire households into a dire situation in which future spending on healthcare, food or education is compromised, in turn affecting health.[156] Secondly, the prospect of catastrophic expenditures can act as a deterrent to seeking care in the first place, especially among the poorest.[157-159] For example, a household survey in Rwanda showed 55% of respondents lacked resources to fund transport to the nearest facility offering basic surgical services,[18] and an insurance scheme for the poor in India had a measurable impact on mortality.[160]

It should be noted that catastrophic expenditure can occur even when care is ostensibly free-of-charge, for example from having to purchase out-of-stock items or consumables, from informal payments,[161] or from associated and necessary costs such as transport expenditure, increased food expenditure, and lost income. For example, healthcare in Uganda is free, but in one study 31% of surgical patients still faced CHE, 53% had to borrow money and 21% had to sell assets.[162] Consequently, efforts to stave off CHE often need to go beyond solely decreasing the out-of-pocket proportion of healthcare spending. Examples include outreach services, travel vouchers, and negative healthcare payments.[159,160,163]

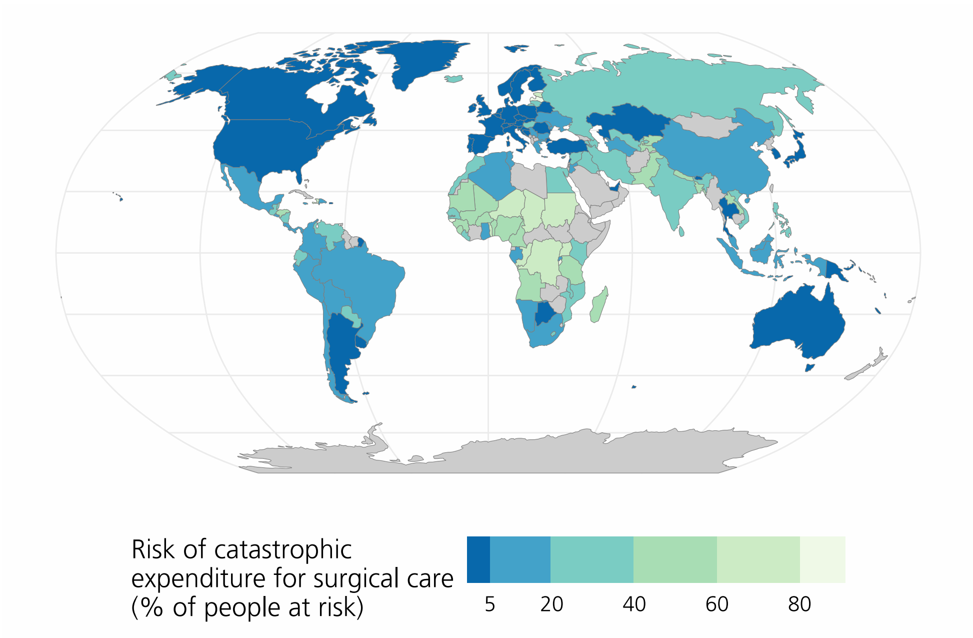


Figure 21. Risk of catastrophic health expenditure from surgical care, latest data as reported in the WDI[10]

While modeling studies can give an overall estimation of the risk of CHE, primary data collection from observational or interventional studies are needed to validate and/or calibrate the mathematical models, to more precisely measure CHE in a specific location, and to understand the cost drivers and correlations of CHE.[158,162,164-166] Consequently, study IV measures CHE from cesarean sections at a rural hospital in Rwanda, specifically in the context of the Rwandan community-based health insurance system.

Panel: Aim of study IV
To estimate the burden of out-of-pocket payments for cesarean sections in the context of community-based health insurance and determine if having it reduces catastrophic health expenditure

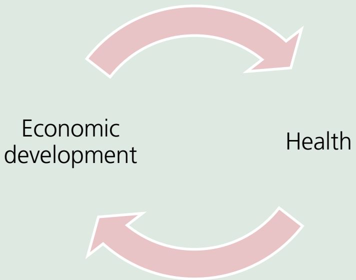
Further, early results from the mathematical model of study III and from on-the-ground observations suggested the incidence of CHE could be substantially higher when post-discharge costs were accounted for, and no studies were found accounting for these costs.

Panel: Aim of study V
To expand measurement of catastrophic health expenditure to the postoperative period, comparing incidence at discharge to postoperative day 30

Panel: Community-based health insurance in Rwanda[167,168]
Rwanda instituted a community-based health insurance system known locally as Mutuelles de Santé in 1999, which now covers a large majority of the population. Citizens are divided into four wealth categories (*Ubudehe*), with patients in category 1 including the poorest patients and category 4 the richest. Patients in category 1 pay neither an annual fee nor any charges at the point of care, while patients in the other categories pay a fixed annual fee based on their Ubudehe category as well as 10% of hospital medical costs.

Surgery and wider societal effects

Panel: Health and wealth



As a result of the bidirectional relationship between health and wealth, countries can enter virtuous or vicious health-income spirals[169]

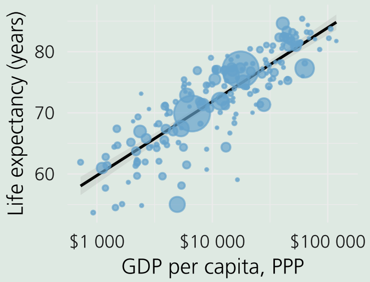


Figure 22. The relationship between GDP per capita and life expectancy. Data from WDI.[10] Point size represents country population

Access to surgery and the lack thereof not only profoundly affect patients and their families, but also has broader societal implications. Economical, technological, and institutional development has been a prerequisite for the emergence of advanced and life-saving surgical care where such care is available and will continue to be so in the scale-up of surgical care to the uncovered global population. But increased access to surgical care can conversely have positive spin-off effects on the larger economy.

While there undoubtedly exists a relationship between health and wealth (**Figure 22**), the exact causality and directionality of this relationship is more difficult to untangle. There are numerous ways in which increased wealth can affect health, mediated through e.g. increased healthcare expenditure, better education with secondary health effects, increased spending on environmental prevention efforts (e.g. road safety, pollution), etc. In the other direction, health can affect economic development through increased labor market participation and productivity (through effects on mortality and disability), increased opportunities and incentives for education, and a number of other mechanisms,[169-177] for example as shown in **Figure 23**. Additionally, increased access to universal health coverage with financial protection protects individuals from impoverishing and catastrophic expenditures. These in turn decrease productivity, especially if patients are forced to sell productive assets.[173]

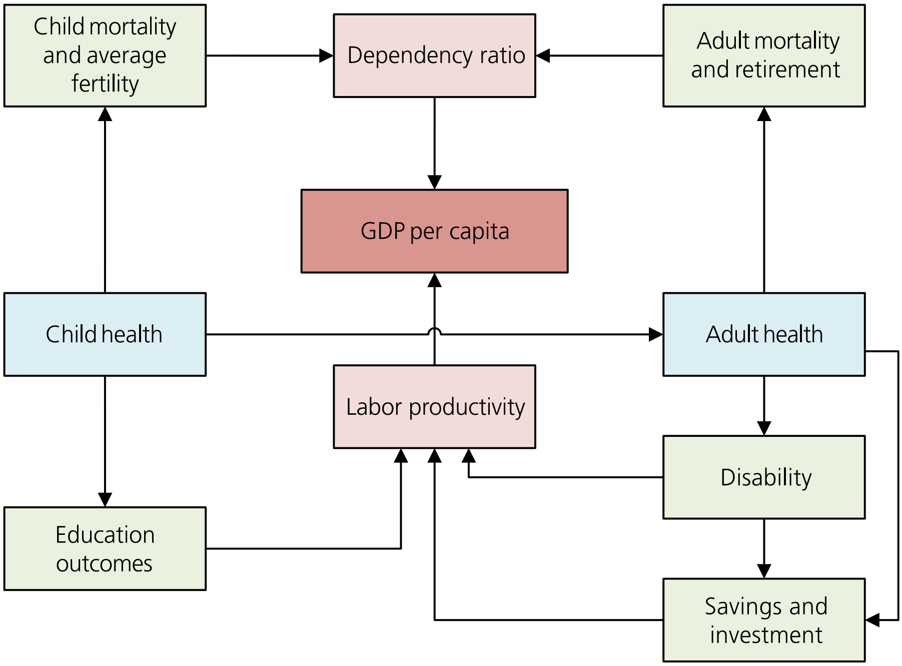


Figure 23. Links between health and income. The diagram depicts some, but not all, ways in which health can affect per capita income. The dependency ratio is the ratio of active participants in the workforce to the entire population. Adapted from WHO[h,178]

Notably, measuring the effect of health on GDP output may not fully capture the economic value of increased health. Many authors have argued the intrinsic value of health must be included in measurements of development, e.g. utilizing a so-called *full-income approach*, in which a compound measure of economic output and health is created[i,176,179].

Panel: Criticism of and alternatives to GDP and GNI[j]
While the income of countries correlates to many other desirable measures, and indeed is used extensively throughout this thesis, it is not without controversy as a

[h] With kind permission from WHO: The World health report 1999: Making a difference, p. 11

[i] A discussion of the value of welfare and value of a statistical life concepts used in the full-income approach is found under *Macroeconomic models - Value of lost welfare*, p. 68.

[j] GDP and GNI both measure economic productivity. The main difference lies in how productivity is assigned to countries. GDP is based on where economic output is produced, while GNI instead is based on citizenship/residency.

measure of human development. In the words of Robert F. Kennedy, "*The gross national product does not allow for the health of our children, the quality of their education or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage, neither our wisdom nor our learning […] it measures everything in short, except that which makes life worthwhile*"[180]

The *World Bank Lending Group* classification divides countries into low-income ($1085 or less), lower middle-income ($1086 to $4255), upper middle-income ($4256 to $13 205) and high-income ($13 206 and above). It is based solely on GNI per capita.

The *Human Development Index* was proposed by Pakistani economist Mahbub ul Haq and is reported by the United Nations Development Programme. It consists of a geometric mean of scaled indices of life expectancy, education, and income.[181]

The *Sustainable Development Goal Index* is a composite index consisting of more than 100 indicators, which are summarized to a score between 0 and 100, measuring the attainment across the UN SDGs.[182]

The *full income* is a sum of both the economic output and the intrinsic value of life and health expressed in economic terms.[176,183]

Several studies have attempted to capture the broader effects of disease on economic development. Studies on individual diseases have examined the effects of e.g. cleft lip and palate,[184] obstructed labor[185] and hydrocephalus,[186] while other studies have examined broader categories such as NCDs,[170] chronic disease in LMIC,[187,188] and disease amenable to high-quality care.[189] In particular, the Lancet Commission on Global Surgery estimated $12.3 trillion USD of GDP output would be lost to a group of surgical diseases between 2015 and 2030.[2,190] However, the economic effects of neurosurgical disease remained poorly understood.

Panel: Aim of study VI

To estimate the economic consequences of neurosurgical disease in low- and middle-income countries

Summary of thesis aims

Little is known on the upstream determinants of access and of the downstream effects of insufficient surgical health systems. The overall purpose of this thesis is therefore to expand knowledge on public access to surgical care along the axes of timeliness, capacity, safety, and affordability.

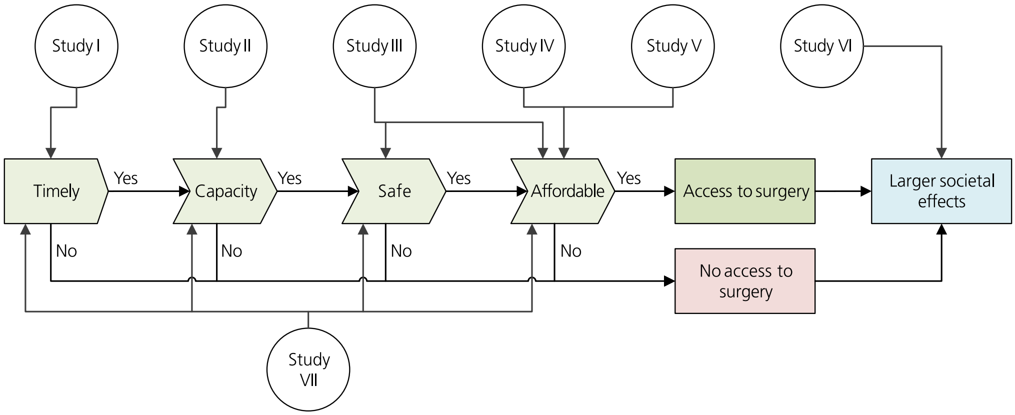


Figure 24. Study aims, and their relationship with the access framework. Modified from Alkire et al[3]

I	To validate geographical information system (GIS) methods for calculation of geographical access, by comparing patient-reported travel times to those derived by computational methods for patients travelling to a district hospital in rural Rwanda for emergency obstetric care
II	To quantify the migration of surgical specialists to South Africa from other low- and middle-income countries, and from South Africa to high-income countries. Further, to estimate the proportion relative to the total surgical workforce from the perspective of both sending and receiving countries.
III	To assess the feasibility of task-shifting postoperative wound care and SSI surveillance to community health workers, analyzing under which conditions this could be beneficial
IV	To estimate the burden of out-of-pocket payments for cesarean sections in the context of community-based health insurance and determine if having it reduces catastrophic health expenditure
V	To expand measurement of catastrophic health expenditure to the postoperative period, comparing incidence at discharge to postoperative day 30
VI	To estimate the economic consequences of neurosurgical disease in low- and middle-income countries
VII	To quantify the relative contribution of timeliness, capacity, safety, and affordability to the global lack of access to surgical care

”Emergencies occur everywhere, and each day they consume resources regardless of whether there are systems capable of achieving good outcomes”

– Olive Kobysingye et al, 2005

“Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise”

– John Tukey, 1962

Methods

Study design

	Design	Data collection	Study site	Subjects and sample size	Primary outcome
I	Comparative GIS study	Prospective patient questionnaire and GIS modelling	Rwanda	664 patients	Time to hospital, patient-reported vs GIS estimated
II	Cross-sectional observational study	National registries of surgical providers	South Africa and Global	6670 SAO providers in South Africa, and 1295 SAO providers in HICs	SAO providers from LMICs in South Africa, and SAO providers from South Africa in HICs
III	State transition modelling study	Various, including patient questionnaires, literature estimates, billing data	Rwanda	50 million simulations	QALY and catastrophic health expenditure after cesarean section
IV	Prospective observational study	Patient questionnaire, hospital billing data	Rwanda	340 patients	Catastrophic health expenditure by discharge
V	Prospective observational study	Patient questionnaire, hospital billing data	Rwanda	479 patients	Catastrophic health expenditure by postoperative day 30
VI	Macroeconomic modelling study	Country-level datasets on health and economic parameters	Global	127 countries	$USD, trillions. Value of lost output and value of lost welfare
VII	Decision tree modeling study	Country-level health systems indicators	Global	180 countries	Proportion of the global population without access to surgical care due to timeliness, capacity, safety and/or affordability

Data sources

Patient questionnaires and expense data

For study I, III, IV and V, data was collected at the Kirehe District Hospital, a rural district hospital in eastern Rwanda. The hospital is run by the Ministry of Health, with support provided by the American non-governmental organization (NGO) Partners in Health/Inshuti mu Buzima. The hospital has a catchment area of around 350 thousand patients for basic first-level hospital care. Primary care is delivered at one of 16 health centers in the district, which can refer to Kirehe District Hospital when needed.

Data were collected by trained data collectors using REDCap,[191] with several rounds of data collection between June 2017 and February 2020. The financial portions of the questionnaire were adapted from the Program in Global Surgery and Social Change Financial Risk Protection Survey,[162,192] and expenses verified from the hospital billing system (OpenMRS).

GIS data sources

Data on the road network and hindrances to movement were obtained from OpenStreetMap.[193] The geographic boundaries of village districts were obtained from the Global Administrative Areas database,[194] with village names gathered from the National Institute of Statistics Rwanda.[195] Data on health provider coordinates were obtained from Partners in Health/Inshuti mu Buzima.

Data on surgeons, anesthesiologists, and obstetricians

Workforce data were used for study II.

The number of SAO providers in South Africa, as well as data on their country of origin, was obtained from the Health Professions Council of South Africa through the iRegister database.

Data on immigrated SAO providers in high-income countries were from the national registries of 14 high-income countries.[196]

The number of SAO providers in LMICs were obtained from the 2016 update of the WHO surgical workforce database by Holmer et al[11], with the underlying data coming from (in order of preference) governmental sources, professional bodies, WHO/OECD/Eurostat databases, scientific publications, and other reports.

QALY weights

A literature review was performed to identify quality-adjusted life years (QALY) weights for surgical site infections used in study III. QALY weights for ongoing surgical site infections requiring outpatient or inpatient treatment were obtained from a cost-effectiveness study on breast surgery,[197] with similar values found in a systematic review of QALY weights associated with surgical site infection.[198] The QALY weight for recovery after surgical site infection was obtained from a cost-effectiveness study on surgical site infection prevention among cesarean section patients.[199]

Country-level statistics

Data from the WDI were utilized in study II, VI and VII, and included data on GNI per capita in purchasing power parity (PPP), World Bank lending group (i.e. LMIC status), population and capital depreciation.[10]

Data from the WHO were utilized in study II, VI and VII, and included region classification, ambulance coverage, healthcare expenditures and inputs to the EPIC model (detailed under *Value of lost output*, p. 68), including population projections.[200] Additional data for the EPIC model were provided by the International Futures modelling system,[201] Penn World Tables,[202] the International Labor Organization,[203] and the WDI.[10]

Life expectancy figures from the UN population division were utilized in study III.[204]

Burden of disease data

Data on burden of disease were obtained from the IHME.[4] These were then used in calculations of the neurosurgical burden as detailed in study VI. The IHME assigns burden by the cause of injury rather than the type of injury (i.e. car accident rather than traumatic brain injury). The proportions of injury deaths broken down by cause and by age group were calculated from US Center for Disease Control data, and these proportions were then applied to the IHME data. For other disease categories, i.e. stroke, not all cases require the involvement of a neurosurgeon. To account for this, the results of a survey which asked neurosurgeons in low-, middle-, and high-income countries to estimate the proportion of selected diseases which required at least neurosurgical consultation was used, with the proportions multiplied by IHME estimates.

Study settings

Table 6. Some key statistics of the study countries Rwanda and South Africa. Data from Sweden for comparison, see also averages by World Bank lending group in **Table 1**, p. 20.

	Rwanda	South Africa	Sweden
World Bank lending group	Low-income	Upper middle-income	High-income
Population (million)[10]	13.5	59.4	10.4
GDP per capita, PPP[10]	2239	13 312	53 613
Health expenditure per capita, PPP[10]	146	1187	6223
Life expectancy (years)[10]	67	65	82
Maternal mortality ratio (per 100 000 live births)[10]	248	119	4
Surgical specialists (per 100 000)[11]	0.7	11.4	113.1

Outcomes and definitions

Travel time

The travel time in study I was defined as the time spent on the road, as this is the time modeled by GIS methodology, and the time spent waiting for an ambulance or other means of transport was not included.

Surgeons, anesthesiologists, and obstetricians (SAO providers)

Physicians licensed to practice in the following specialties were considered *SAO providers*: general surgery, pediatric surgery, ophthalmology, plastic and reconstructive surgery, orthopedics, otorhinolaryngology, urology, neurosurgery, cardiothoracic surgery, anesthesiology, and obstetrics & gynecology.

The country of origin was defined according to the country of medical school graduation.

Patient-level financial outcome measures

Impoverishing health expenditure is defined as an expenditure which pushes the household below a poverty limit, in this thesis as defined by the World Bank as either 1.90 or 3.20 international dollars per person per day.

Catastrophic health expenditure (CHE) can be defined in two ways. In a seminal 2003 paper, Xu et al suggested a CHE threshold of 40% of annual household expenditure after subsistence needs have been met, i.e. after deduction of food expenditures.[205] Most recent studies have instead defined CHE as expenditures exceeding 10% of total annual household expenditure.[206] CHE has also been adopted as one of the official UN SDG indicators; SDG indicator 3.8.2 utilizes the total annual household expenditure definition, with two sub-indicators defined at the 10% and 25% levels.

Studies in this thesis (III, IV, V, VII) all define CHE as an expenditure on health that is at least 10% of total annual household expenditure.

Further, expenditures can be divided into medical and non-medical costs, and into direct and indirect costs. Direct medical costs are defined as out-of-pocket expenditures for healthcare. Direct non-medical costs are defined as out-of-pocket expenditures not for healthcare, but which are a direct result of having to seek care, e.g. transportation costs. Indirect costs are defined as opportunity costs, e.g. lost income, which result from the care episode. CHE can therefore be defined in relation to either of these three expenditure categories: direct medical costs, direct medical and non-medical costs, or direct and indirect costs.

Health outcome measures

Health outcomes can be measured in a number of ways, for example, number of deaths, years of life lost, disability-adjusted life years (DALY) and quality-adjusted life years (QALY).[207-209] DALYs and QALYs share the common property of measuring morbidity in addition to mortality, although there are practical and philosophical differences.

The QALY reflects the health *gained* from enjoying quality of life, with 1 = perfect health and 0 = death. Since the quality of life can be perceived differently depending on the cultural and socioeconomic context, they should ideally be adapted to the study context. For example, paraplegia may lead to a smaller decrease in the quality of life in a context of ample community adaptions for disability. In difference to this, DALYs reflect the disability and death *lost* to disease, with 0 = no disability and 1 = death. DALYs can additionally be age-weighted and/or time discounted.

Study III utilizes QALYs. The vast majority of health utility values found during an initial literature review of health utility values associated with SSI were QALYs, necessitating the usage of this metric for the analysis. Study IV utilized DALYs, which are endorsed by the WHO and thus used by the IHME burden of disease data used for calculations in study IV. DALYs were both age-weighted and time discounted in study VI.

Macroeconomic outcome measures

Two macroeconomic approaches were used to quantify the effect of disease on society.

The *value of lost output* (VLO) is defined as the decrease in GDP output which results from the negative effects of disease on an economy. In study VI, the VLO resulting from deaths in the period 2015-2030 is calculated.

The *value of lost welfare* (VLW) is conceptually different in that it measures the economic value assigned to the inherent value of good health by a population. In study VI, the VLW resulting from morbidity and mortality in 2015 is calculated.

Further details are found under *Macroeconomic models* (p. 68).

Access to surgical care

The term *surgical care* includes care provided by both surgeons, anesthesiologists, and obstetricians, and refers both to care delivered in an operating room as well as non-operative care. A person is considered to have full *access to surgical care* if all four of the following parameters are adequate: timeliness, capacity, affordability, and safety.

Travel time calculations by GIS

For study II, a travel time model was constructed. The region was discretized into cells (pixels) of approximately 100x100 m. Each cell was then assigned a travel speed, according to the presence and type of road. In order to be consistent with the global surgery travel time literature the study aimed to asses[59,61,62], roads were classified as either primary, secondary or tertiary, and assigned a travel speed of 100 km/h, 50 km/h, and 30 km/h respectively. Cells without a road were assigned a walking speed of 5 km/h, and rivers were taken as barriers to movement.

Each patient's journey was assumed to start in their home village; geometrical centroids for each of the 612 villages were calculated as journey starting points. Village was collected as a free text field. A combination of automatic (string distance calculations) and manual procedures were used to match the answers given by patients to the list of official village names.

Two travel time models were constructed. In the first model, patients were assumed to directly travel via the shortest route possible to the district hospital, replicating essentially all literature on the timeliness of surgical care. In the second model, patients were instead assumed to travel first to their local health center, replicating the actual path traveled by the vast majority of patients from the study.

For visual comparison, a map representing the travel time surface derived using the method above was contrasted with one derived from patient data (**Figure** 27). In order to produce a full map from discrete patient data, an interpolation technique is necessary; this study used inverse distance weighting.[210]

Stochastic state transition model

Study III models a theoretical cohort of patients after cesarean section. The cohort is initialized so as to reflect the observed patient characteristics of study IV, i.e. patients are sampled with replacement from the primary data of study IV. The model then simulates the next 200 days, with patients moving through a set of possible health states (**Figure 25**).

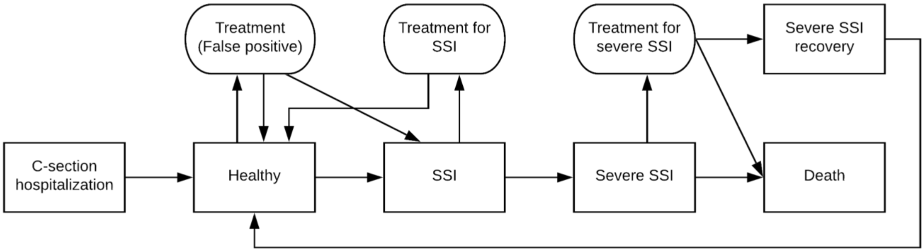


Figure 25. A diagram of the state transition model used in study III.

The movement of patients between each state is probabilistic, derived where possible from observed data at the district hospital of study IV, and elsewhere using estimates from the literature. An example of a state transition probability function is shown in **Figure 26**.

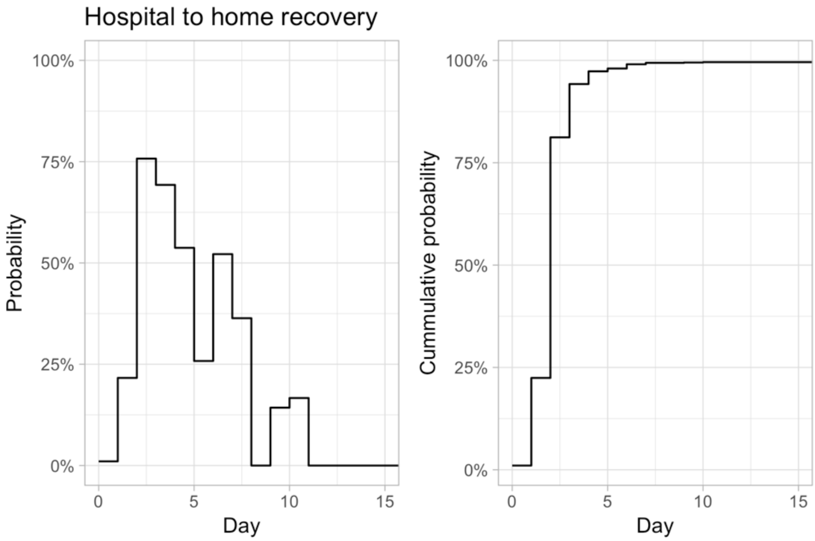


Figure 26. An example of a probabilistic state change function

At the conclusion of the 200 days, both QALYs and out-of-pocket expenses are summed on a per-patient basis, with the latter used to calculate CHE.

Since the primary question related to the effect of varying sensitivity and specificity for SSI diagnosis, as well as the mode of follow-up (via community health worker or at the health center), the model is run for each combination of a set of possible parameters, varying sensitivity and specificity between 70 – 100%.

Macroeconomic models

Value of lost output

To calculate the impact of neurosurgical disease on the economic output of LMICs, the WHO tool *Projecting the Economic Cost of Ill-health* (EPIC) is used.[188] The model assumes the economic output of a country is a monotonically increasing, concave function with respect to labor- and capital supply, and is additionally influenced by economic productivity as well as time- and country-specific factors. The Cobb-Douglas production function[211] is used:

$$Y_{i,t} = A_{i,t}K_{i,t}^{\alpha}L_{i,t}^{\beta}$$

Where Y is GDP output, i is country, t is year, K is the physical capital input (i.e. machinery, infrastructure, etc.), L is the labor input, α and β are elasticities, and A is the total factor productivity. The total factor productivity relates to the economic productivity and technological development, and is defined as the change in GDP not explained by changes in K or L.

The labor supply and average experience (L) is in turn a function of time-, country-, sex-, and age-specific mortality estimates. A counterfactual scenario with no neurosurgical mortality can then be constructed, and the increased economic output related to the increased labor supply can be calculated.[190]

Value of lost welfare

The VLW method does not measure the economic output of the labor supply, but rather the value placed by the population on health, expressed in economic terms. To achieve this, a concept known as the value of a statistical life is used.

Panel: Value of a Statistical Life (VSL)[212-219]

The VSL is a measure of the amount an individual would be willing to pay to reduce their risk of death by a small amount. Implicit choices regarding the trade-off between health and finances are constantly made both by individuals (e.g. choice of line of work) and government (e.g. investments in safer roads or pollution-lowering regulations).

If, for example, an individual would be willing to lower their annual salary by $500 for an occupation with a one in ten thousand lower annual risk of death, an implicit VSL of $5 million is revealed:

$$VSL = \frac{\Delta wage}{\Delta mortality\ risk} = \frac{\$500}{0.0001} = \$5\ 000\ 000$$

Having an estimate of the VSL is a prerequisite for performing cost-benefit analyses which include health effects, which can then be used to inform government policy in areas such as health, environment, and transportation.

The VSL in a population can be calculated using revealed preference methods, often based on wage differentials. The VSL can also be derived using stated preference methods, where panels of representative samples of the population answer questions on the willingness-to-pay for small reductions in their mortality risks.

It should be noted that VSL estimates are affected by several factors, only some of which studies can adjust for practically, while other factors deliberately are not adjusted on philosophical grounds. The VSL in an obvious way related to the respondent's income and national-level wealth, but estimates are only adjusted on a national level, not by individual income. Other factors include age, the cause of the mortality risk, the latency, and the size of the mortality risk. Specifically, VSL estimates are generally not considered valid when the risk size approaches 1, i.e. when an identifiable person's life is evaluated.

Some examples of recommendations regarding the VSL include $7.4 million (GNI per capita $47 300) from the US Environmental Protection Agency, $3.0 (GNI per capita $30 600) from the OECD, and $9.6 million (GNI per capita $57 900) from the US Department of Transportation.

The VSL can be adjusted to the differing income levels of a country (i) according to the following formula[220]

$$VSL_i = VSL_{Base} * \left(\frac{GNI\ PPP_i}{GNI\ PPP_{Base}}\right)^{IE\ VSL}$$

Crucial to this calculation is the income elasticity (IE VSL), with a value of 1 yielding VSLs which are linearly proportional to GNI, while values >1 yield VSL estimates which are smaller as a proportion of GNI the lower the GNI of the country, and vice versa. Study VI uses an income elasticity of 1.0. There is some uncertainty regarding which income elasticity should be utilized. While values around 0.5 have often been used for transfers between high-income studies, newer studies on transferring VSL to lower-income countries suggest higher values in the range of 1 to 1.5.[217,220-223]

The VSL can also be converted into the *value of a statistical life year* (VSLY).[213] To achieve this, an age-specific estimate of the VSL is treated as the present value of an annuity consisting of the VSLY, yielding country- and age-specific estimates of the VSLY. These VSLY can then be multiplied by DALYs lost to disease, yielding an economic valuation of both morbidity and mortality. Further details can be found in the appendix of study VI.

Decision tree model

Study VII utilizes a decision tree model, following the methodology used by Alkire et al.[190] The decision tree used is presented in **Figure 11** (p. 36). A decision tree model is created for each of the included 180 countries which had the necessary data available for the construction of the model. Timeliness was estimated from ambulance availability,[224] capacity from the proportion of necessary operations currently performed,[13,225] safety from the proportion of operating rooms with pulse oximetry[52] and affordability from the risk of catastrophic health expenditure.[154]

To quantify the contribution of each of these factors, the model is specified using every possible joint probability, i.e. p(*Timeliness*), p(*Timeliness* ∩ *Capacity*), p(*Timeliness* ∩ *Safety*)[k] and so on. Each of the 15 possible combinations is visualized in an area-proportional Euler diagram.[l,226].

Statistical analysis

Inferential statistical tests

Associations between continuous variables are assessed by linear regression (studies I and II). Associations with a binary outcome variable are assessed in the case of multiple predictors by multivariable logistic regression (study V), and in the case of a single categorical predictor by the Chi-squared test (studies IV and

[k] The notation p(*Timeliness* ∩ *Safety*) refers to the proportion *p* considered to have access, when considering the joint probability of timeliness and safety.

[l] Euler diagrams are conceptually similar to Venn diagrams but show only the intersections observed in the data rather than all possible combinations.

V). Lastly, the Wilcoxon rank sum test is used to compare continuous values by group (study V).

Confidence intervals for proportions are calculated using the Wilson method. Throughout, p-values below 0.05 are considered statistically significant. Adjustments for multiple comparisons are not made.

Modeling approaches

Specific mathematical models used in the thesis are detailed under their respective chapters; *Travel time calculations by GIS*, *Stochastic state transition model*, *Macroeconomic models*, and *Decision tree model*.

Study IV utilizes a Monte Carlo approach to estimate the effect of different insurance strategies on the incidence of CHE. Five different strategies are modeled, whereby the out-of-pocket proportion paid by patients is varied. For a subset of the poorest patients, data on out-of-pocket were all 0 as they were covered by a more generous insurance policy than richer patients. Due to this correlation between poverty and missingness, excluding them from the analysis would have biased calculations. Therefore, healthcare costs for this group were bootstrapped (sampled with replacement) from the group with known healthcare costs. The process was repeated 10 000 times, and average parameter estimates are then calculated.

Missing data

The proportion of missing data was generally low in the included studies of this thesis – therefore an assumption of MCAR (missing completely at random) is made for the majority of calculations, with an exception as detailed under *Modeling approaches*.

Ethical considerations

Studies I, III, IV and V were based to some extent on patient data gathered in Rwanda. All women were enrolled after providing written informed consent. Voluntary assent was obtained from individuals less than 18 years, with signed consent from their parents or guardians. All data used for the thesis projects were deidentified. For those patients needing to return to the hospital for assessment as part of the study, travel vouchers were provided so as not to subject the patients to additional financial stress. Before the start of the data collection, approvals were obtained from the Rwandan Ministry of Health as well as from the Partners In Health/Inshuti Mu Buzima (PIH/IMB) Research Committee. Data collection for study I, III and IV had ethical approval from Rwanda National Ethics Committee (Kigali, Rwanda; no. 848/RNEC/2016) and Partners Human Research Committee (Boston, Massachusetts, USA; no.

2016P001943/MGH). Seven months into data collection, an interim approval to continue data collection was granted by a Data and Safety Monitoring Board. Data collection for study V had ethical approval granted by Rwanda National Ethics Committee (Kigali, Rwanda, No.326/RNEC/2019) and Harvard Medical School (IRB18-1033).

Study II was deemed exempt from full ethical review by the institutional review board at Boston Children's Hospital (IRB-P00024135). While no full ethical review was deemed necessary for the purposes of carrying out the study, the topic of migration presents a complex ethical dilemma, examined at some length in the discussion section of study II.

Study VI utilized only national-level statistics, and thus no ethical approval was necessary.

Software

R[227] is used for the majority of calculations in the thesis; Excel[228], and Stata[229] are used for a subset of calculations. The author wishes to thank the creators of the many free and useful R packages written both inside and outside of academia. A non-comprehensive list of packages used in the thesis include, in no particular order; for general data processing - tidyverse[230], summarytools[231], naniar[232], fuzzyjoin[233], lubridate[234], tidylog[235], readxl[236], and broom[237]; for visualization and presentation of data – eulerr[226], knitr[238], kableExtra[239], sjPlot[240], huxtable[241], tableone[242], patchwork[243], and ggrepel[244]; for GIS - raster[245], sf[246], sp[247], mapview[248], and tmap[249]; some generally useful tools - here[250], countrycode[251], magrittr[252], and progress[253]; and for statistical methods - binom[254] and kknn[255].

The WHO tool AccessMod is used for travel time modelling.[256] REDCap was used for data collection.[191] The WHO tool EPIC was used for macroeconomic modelling.[188]

Results

I

The study included 664 patients. Most patients either used public transportation (72%) or walked (28%) to get from home to the health center. From the health center to the hospital, most used an ambulance (70%) or walked (24%), although notably, all patients who walked did so from the health center on the hospital grounds.

The mean patient-reported travel time of 88 minutes was considerably longer than the 48 minutes yielded by the standard GIS model, with a linear regression coefficient between the two of 1.49 (95% CI 1.40 – 1.57).

In the modified GIS model, where the health center detour was taken into account, the mean estimated time of 62 minutes (β = 1.11, 95% CI 1.04 – 1.19) was closer to that reported by patients.

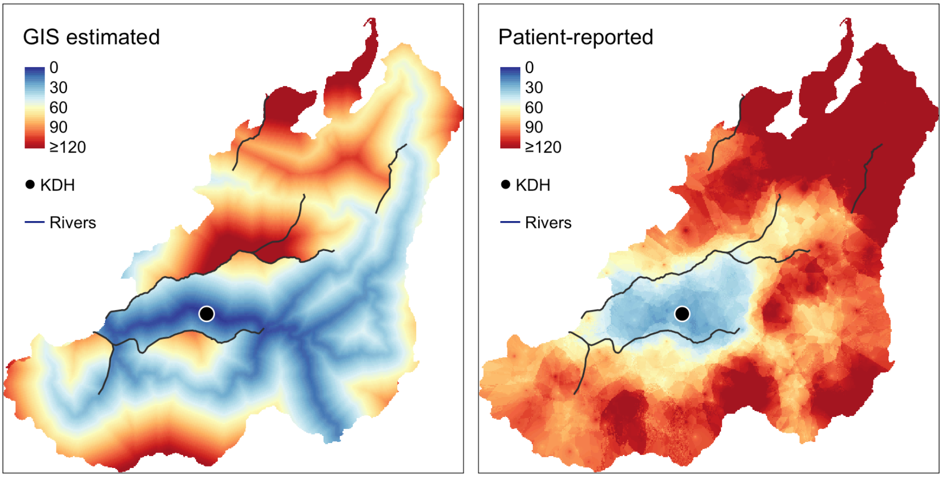


Figure 27. Map comparison of GIS estimated and patient-reported travel times. KDH: Kirehe District Hospital. Time in minutes.

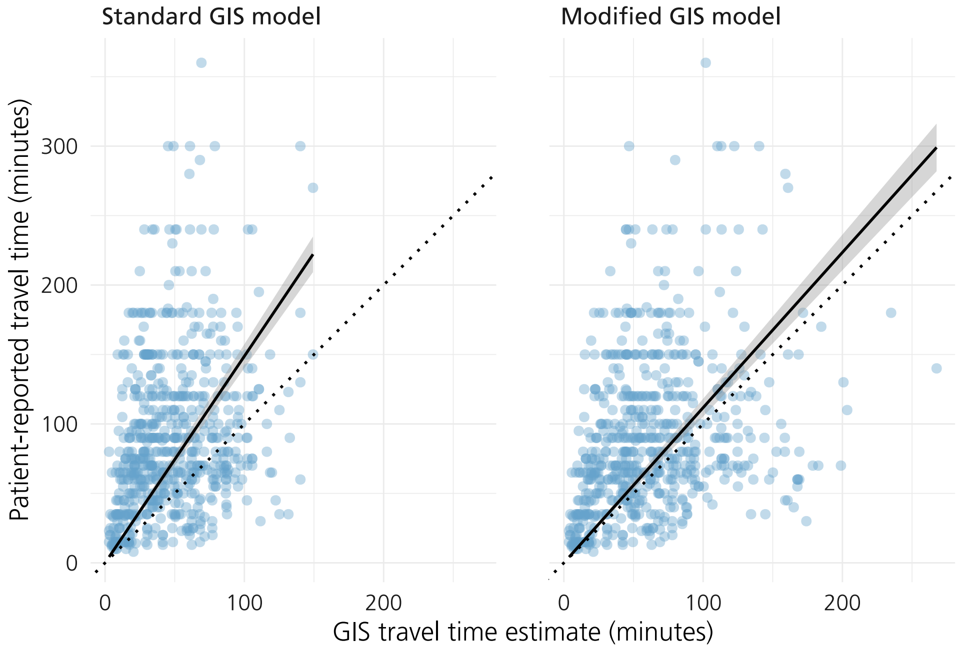


Figure 28. Relationship between patient-reported and GIS estimated travel times. The dashed line represents equality between the two estimates, and the solid line linear regression. The standard model assumes patients travel directly from their home to the hospital, and the modified model assumes they travel via a health center.

II

A total of 65 301 records were included. Among these, 6670 surgeons, anesthesiologists and obstetricians were identified, leading to an estimated 12.1 specialist surgical providers per 100 000 population. These were comprised of 3685 surgeons, 1749 anesthesiologists, and 1236 obstetricians.

Additionally, 1295 specialist surgical providers originating from South Africa were identified in any of the 14 assessed high-income countries.

Seven hundred and thirteen of the registered specialist surgical providers in South Africa were foreign medical graduates, of which 396 were from an LMIC, corresponding to a total of 5.9% of the South African workforce.

Low-income countries had the highest proportion of emigrated specialist surgical providers. Almost one in ten had emigrated, 6.1% to any of the 14 high-income countries, and 2.1% to South Africa. Some countries had a particularly high proportion of specialist surgical providers abroad (**Figure 30**).

Additionally, in regression analysis, the fewer specialist surgical providers a country had or the lower the GNI per capita, the higher was the proportion that had emigrated to South Africa.

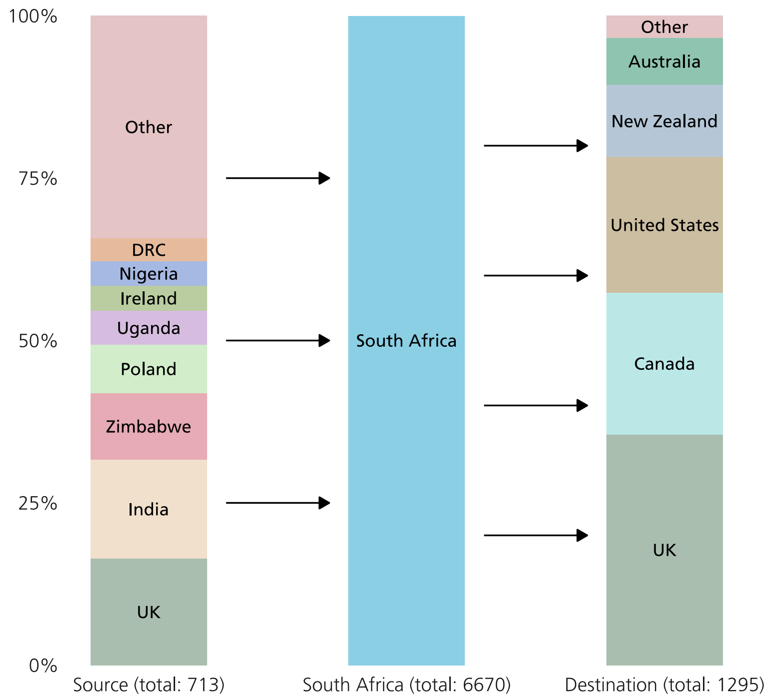


Figure 29. The leading source and destination countries for surgery, anesthesia, and obstetric specialists who have migrated in and out of South Africa.

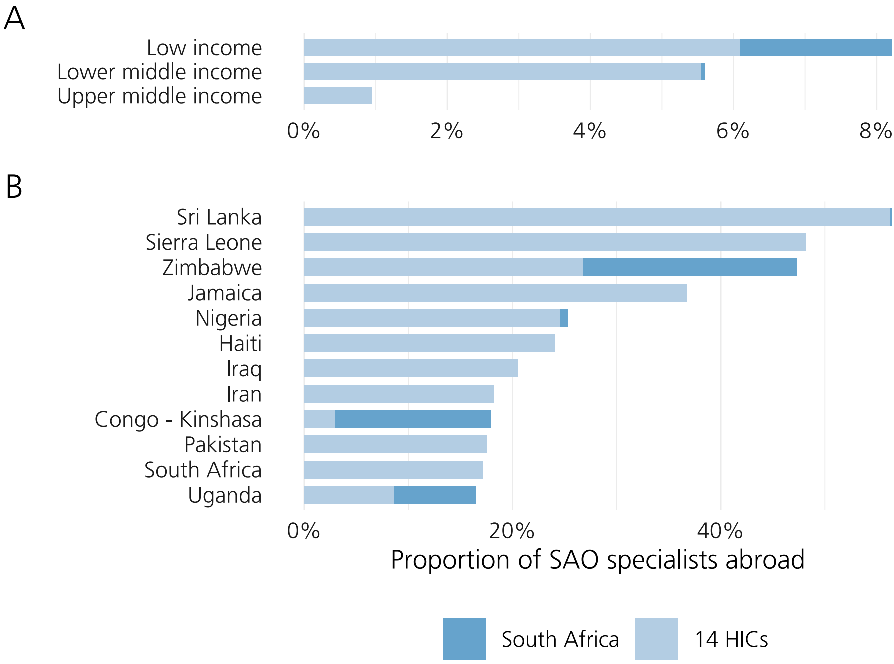


Figure 30. The proportion of specialist surgical providers abroad, by World Bank income group and by country (listing the top 12 countries).

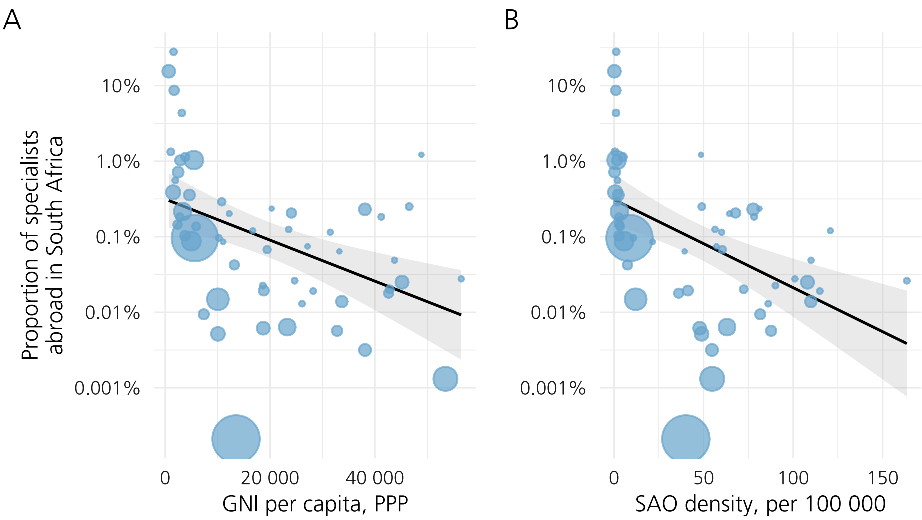


Figure 31. Correlation between the proportion of specialist surgical providers abroad and (A) GNI per capita, PPP, and (B) SAO density per 100 000 population.

III

Fifty million patients were simulated under each scenario, with a median age of 27 [IQR: 23 - 32], and a median total household expenditure of $417 [IQR: 254 – 570]. A large majority (95%) had community-based health insurance.

In the scenario without any scheduled follow-up, the model estimated 100 QALYs per 10 000 patients would be lost to SSI. In the baseline "status quo" scenario with health center based follow-up, the model estimated 75 QALYs lost to SSI per 10 000 patients. Sixteen different scenarios with CHW-led follow-up were simulated, with combinations of sensitivity and specificity ranging from 70 – 100%. The incremental QALYs under each of these scenarios, as compared to the baseline health center scenario, are presented in **Figure 32A**.

In the baseline health center scenario, 34% of patients were estimated to incur catastrophic health expenditure. **Figure 32B** presents the incremental incidence of catastrophic health expenditure under each of the sixteen scenarios for CHW diagnostic performance.

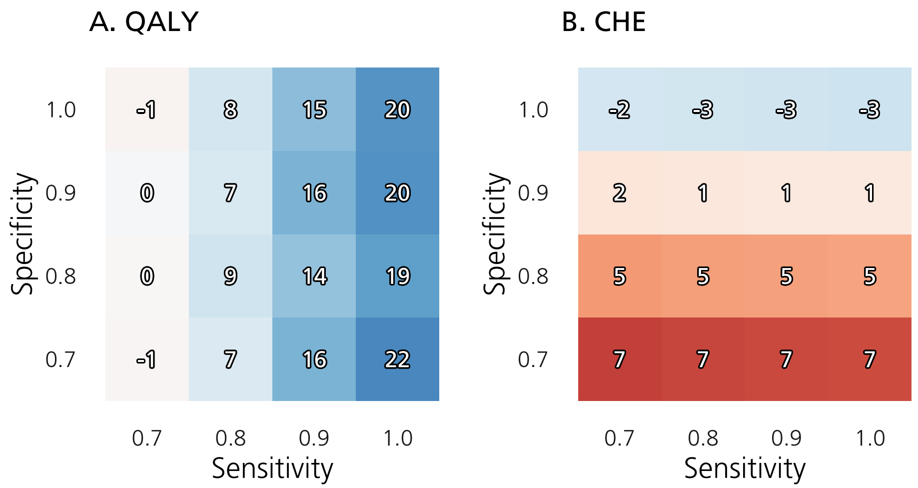


Figure 32. Incremental QALYs gained/lost (per 10 000 patients) and catastrophic health expenditure incidence (%) with CHW based follow-up versus the status quo of follow-up at the health center, under different scenarios of sensitivity and specificity

A sensitivity analysis was performed in which patients were assumed to travel to their health center on the same schedule as proposed for the CHW intervention, i.e. on POD 6, 10 and 13 instead of POD 10, and the sensitivity and specificity is varied are the same manner as for CHWs. In this way, the effect of CHW- vs. health center-based diagnosis can be isolated, since all other factors are held equal. The mean results of this analysis are presented in **Figure 33**.

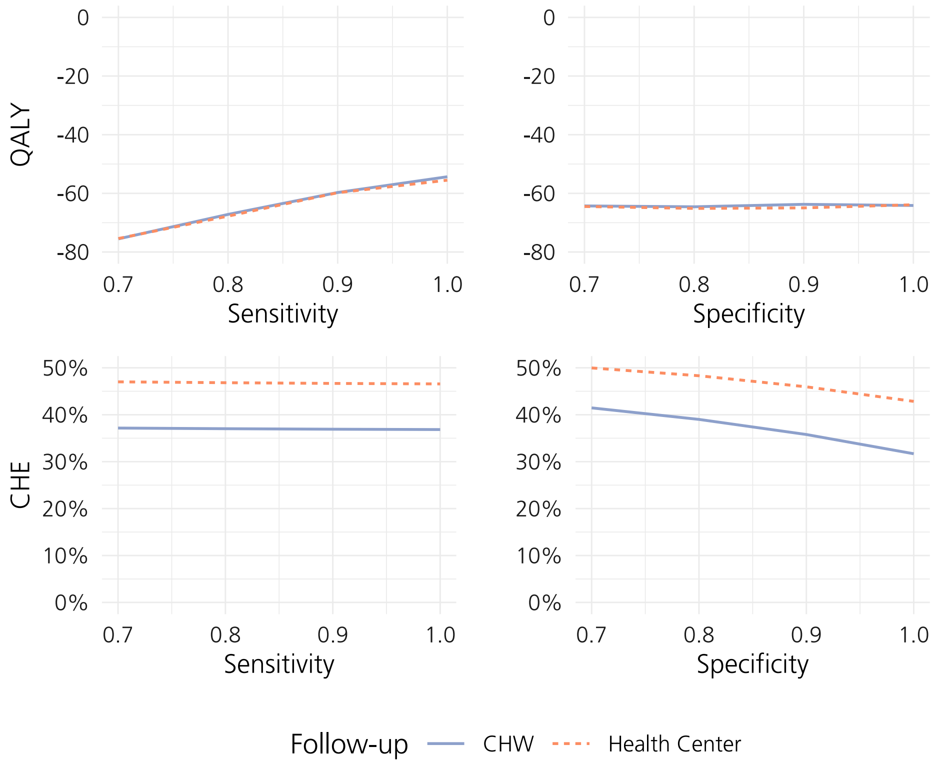


Figure 33. The individual effects of sensitivity, specificity, and mode of follow-up on the incidence of CHE (%) and on QALYs lost to SSI (per 10 000 patients), all else being equal.

IV

A total of 340 patients were included. The vast majority (330, 97%) had some form of insurance, with community-based health insurance being the most common type (310, 91%). A majority were farmers (234, 69%), and most households were classified by World Bank standards as either poor (18, 5%) or extremely poor (316, 93%). Median out-of-pocket expenditures were $9.36 for direct medical expenses, $19.29 for total direct expenses, and $29.78 for total direct and indirect expenses.

Almost half of the included patients (164, 48%) had to borrow money to afford care, and 43 (13%) had to sell possessions.

The rate of catastrophic health expenditure was 5.3% when accounting for only direct medical costs but rose to 15.4% when all direct costs were accounted for and 22.6% when both direct and indirect costs were included. The patients who qualified for Ubudehe 1 had substantially lower rates of catastrophic health expenditure (**Figure 34**), which was also reflected in the lower rate of having to borrow money in this group (**Figure 35**).

Figure 36 displays the rates of catastrophic health expenditure under different insurance schemes. When accounting for total direct costs, 95% would suffer catastrophic health expenditure without insurance, 56% if the coverage was 64% (as is the mean in sub-Saharan LMICs), 17% if the coverage was 90%, and 4% if the coverage was 100%.

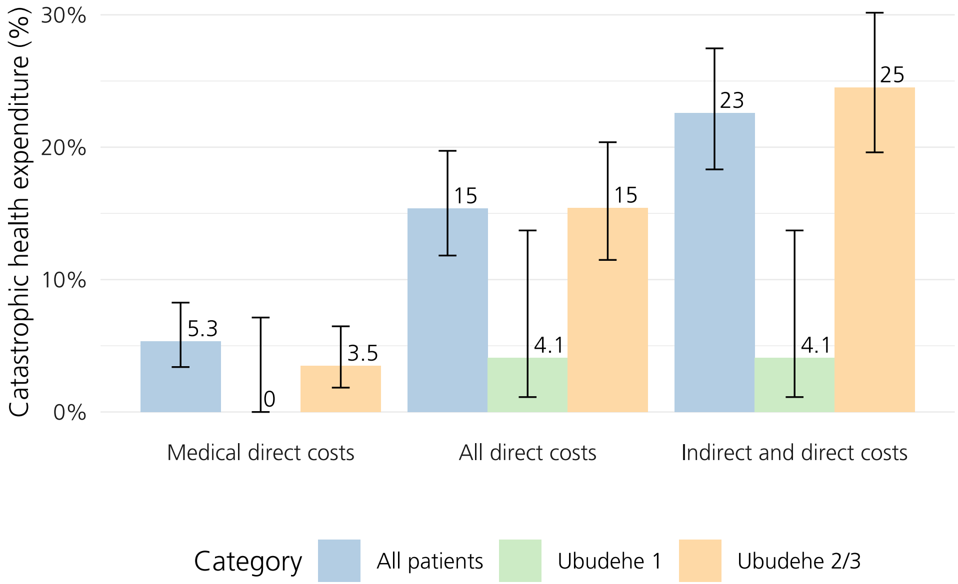


Figure 34. Rate of catastrophic health expenditure by insurance group

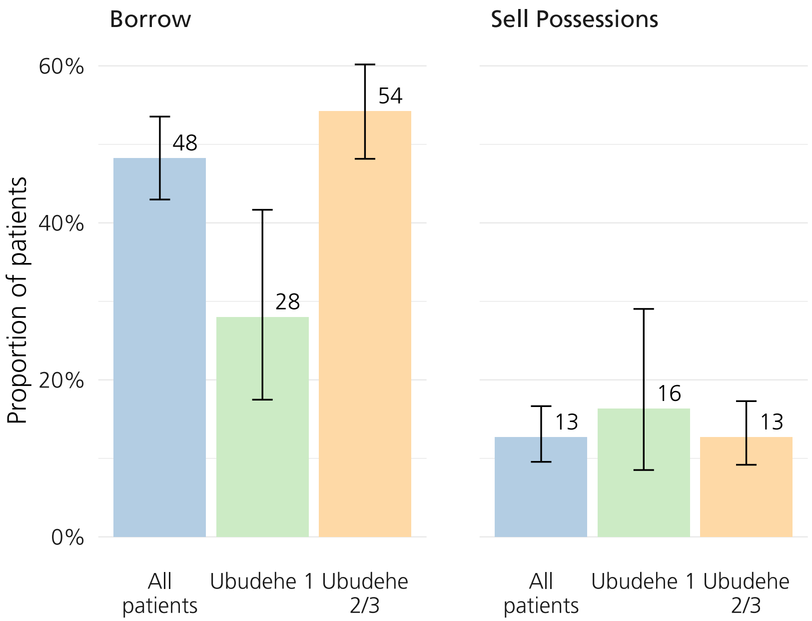


Figure 35. Proportion of patients who borrowed money or sold possessions to pay for care, by insurance group

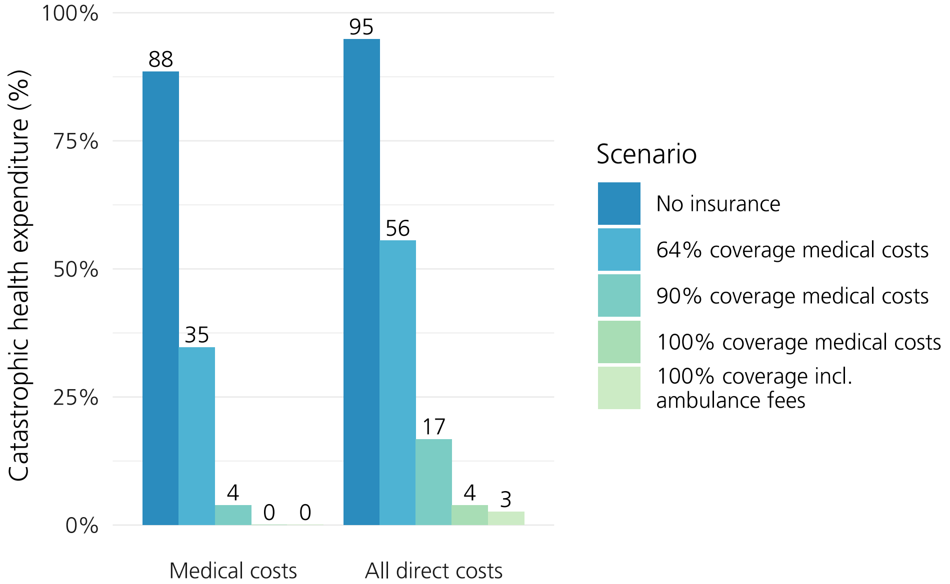


Figure 36. Rate of catastrophic health expenditure by insurance coverage model

V

A total of 479 patients were included in the study. All had insurance, the vast majority (454, 95%) community-based health insurance. A large proportion, 90%, lived below the international poverty line.

Up until hospital discharge, the median total direct expenditure was $15.00 and the median total direct and indirect expenditure was $40.04. Up until post-operative day 30, this rose to a median of $122.16.

The incidence of catastrophic health expenditure was 3% when accounting only for direct medical costs, 27% when accounting for direct and indirect costs up until hospital discharge, and 77% by post-operative day 30.

In multivariable analysis, catastrophic health expenditure at post-operative day 30 was associated with occupation as a farmer (OR 2.25, 95% CI 1.00 – 3.03), primary school education (OR 2.35, 95% CI 1.19 – 4.66) and community-based health insurance as compared to private insurance (OR 3.40, 95% CI 1.21 – 9.60).

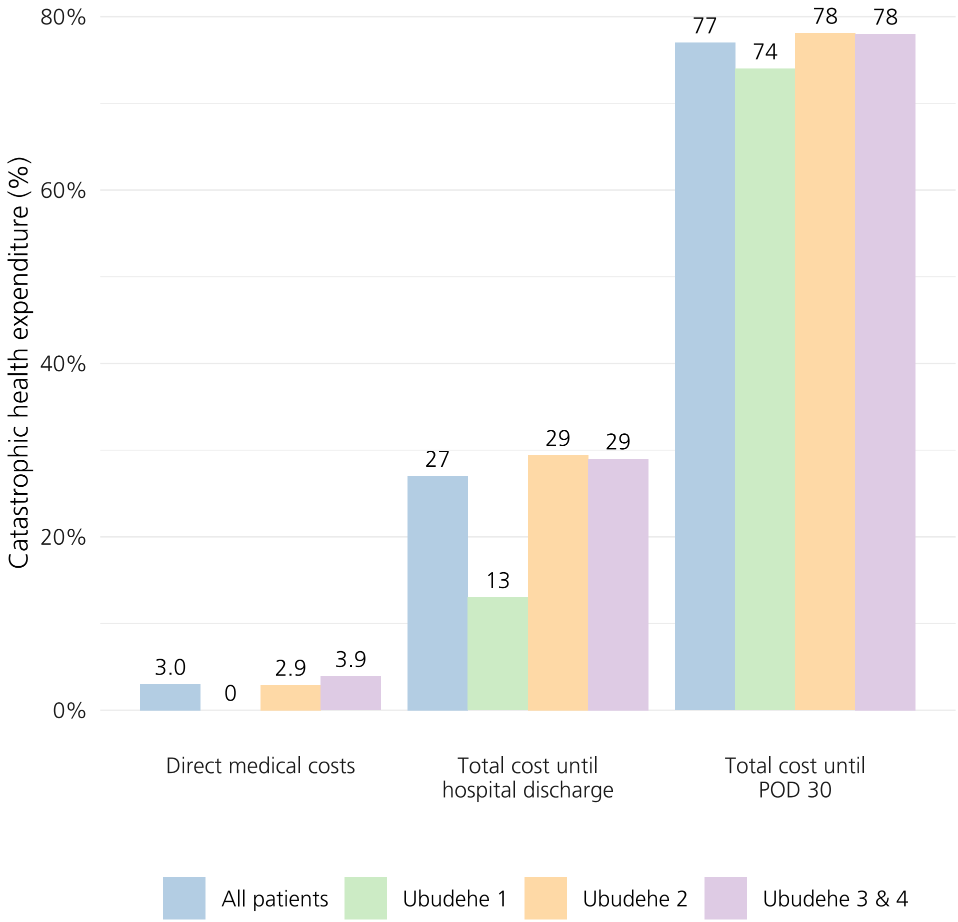


Figure 37. Incidence of catastrophic health expenditure, by definition and insurance group

VI

The Value of Lost Output model evaluated 90 LMICs and estimated a cumulative total of $4.4 trillion in GDP (2013 USD PPP) would be lost during 2015 – 2030, with the projected annual GDP loss growing steadily during the study period (**Figure 38**).

The effect was proportionally larger in the low-income and lower-middle-income groups, which by 2030 were projected to lose 0.60% and 0.54% of total GDP (**Figure 39**).

The Value of Lost Welfare model assessed 127 LMICs, with an estimated $3 trillion of economic welfare losses in 2015. Stroke and traumatic brain injury (TBI) contributed 90% of these losses. As a proportion of GDP, CNS infections disproportionally affected low- and lower-middle-income countries (**Figure 40**)

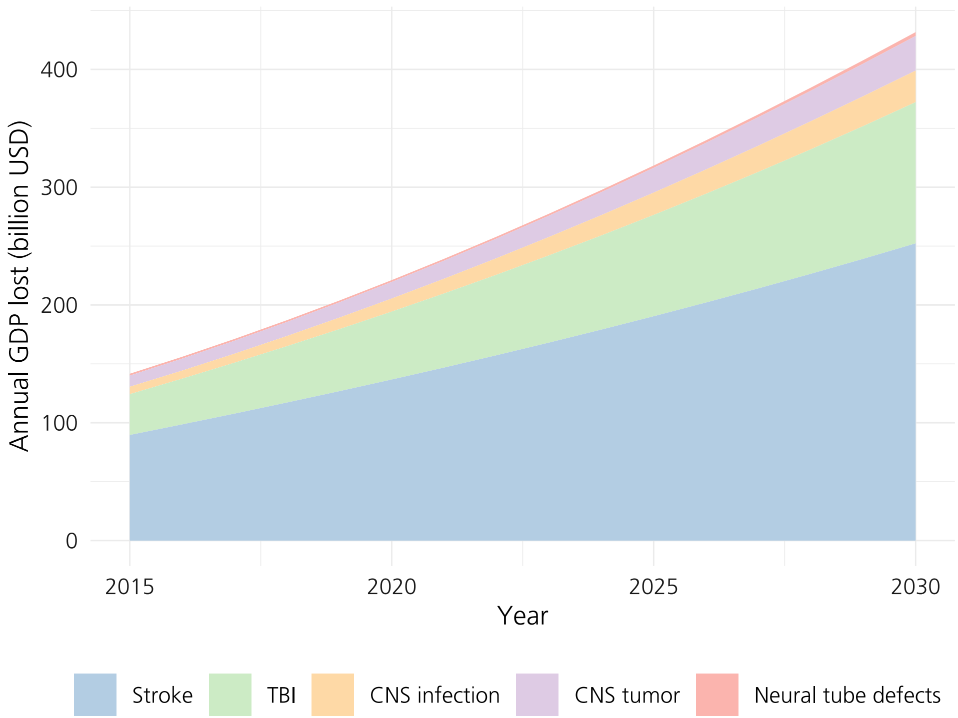


Figure 38. Projected annual GDP lost secondary to neurosurgical disease in LMICs between 2015 and 2030. [m]

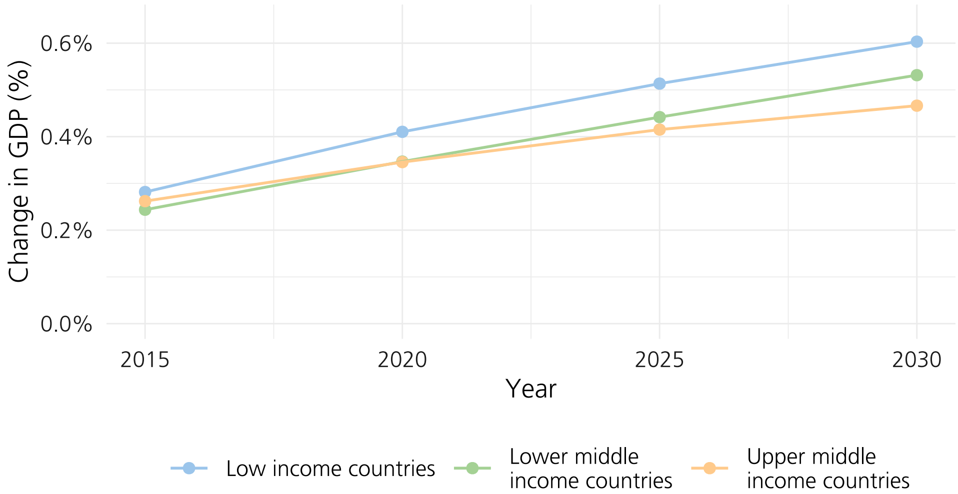


Figure 39. Projected annual value of lost economic output as a percentage of GDP, stratified by World Bank income classification. [m]

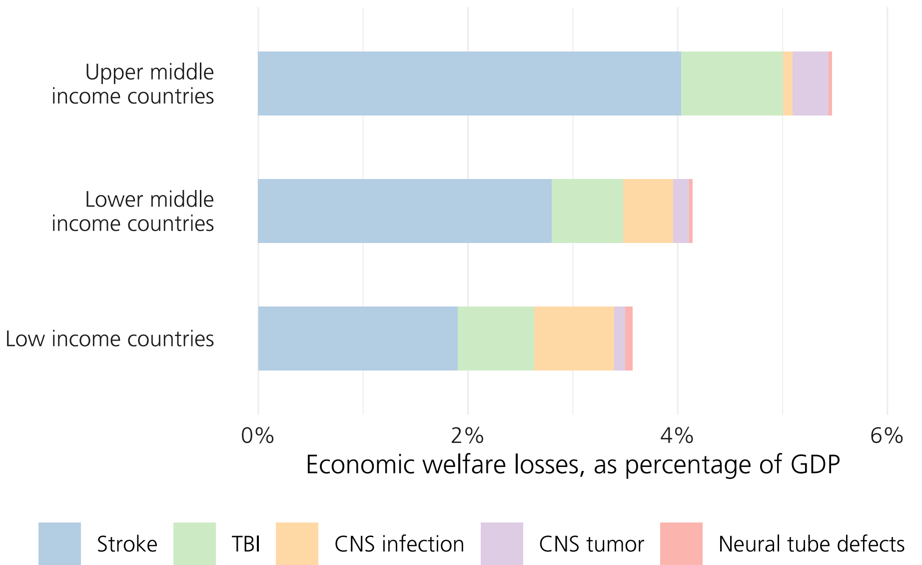


Figure 40. Total economic welfare losses resulting from neurosurgical disease in 2015, expressed as equivalent percentages of GDP, stratified by World Bank income classification and disease category.[m]

[m] Figures modified from Rudolfson et al, *The economic consequences of neurosurgical disease in low- and middle-income countries. J Neurosurg 2018*, with kind permission from the publisher

VII

The model evaluates a population of 7 billion people, 4.8 of which are estimated to lack access to surgical care. Individually, 3.8 billion people are estimated to lack access due to unaffordability, 2.4 billion due to inadequate safety, 1.9 billion due to lack of capacity and 1.5 billion due to issues with timeliness. Of those who lack access, 60% do so due to a lack of 2 or more factors, 27% due to a lack of 3 or more factors, and 13% due to all four.

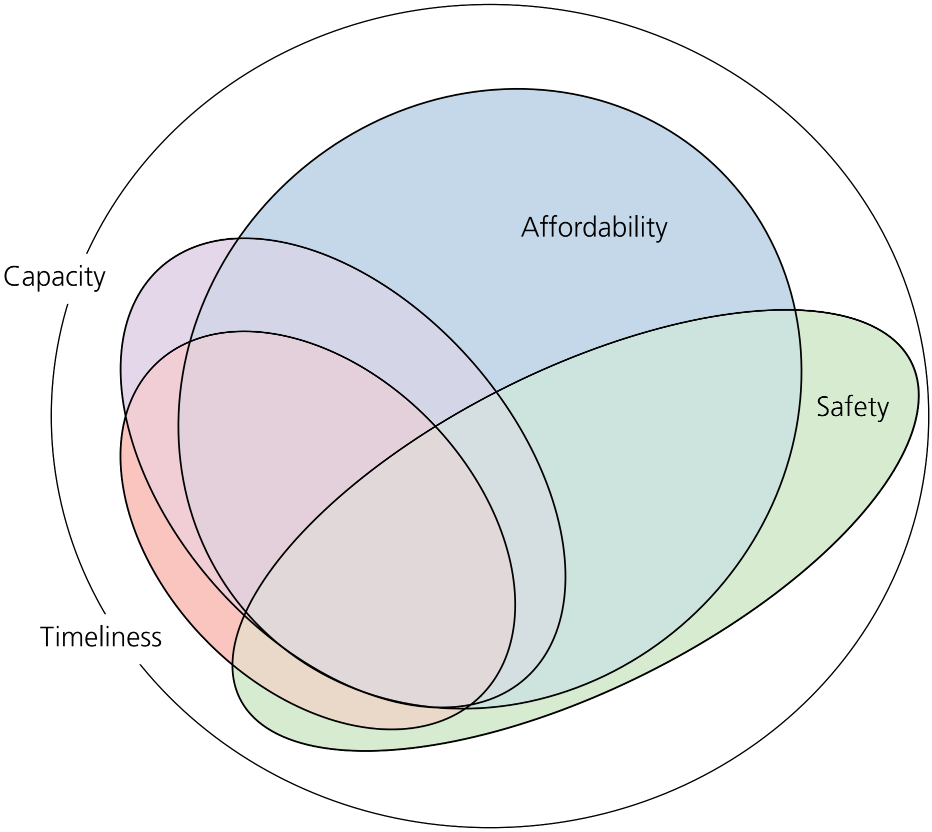


Figure 41. Area-proportional Euler diagram of the lack of access to surgery. The large circle represents the total global population, and the smaller ellipses represent those who don't have, due to each factor, access to surgical care.

Table 7. The estimated number of people globally that lack access to surgery due to issues with timeliness (T), capacity (C), affordability (A), safety (S), and the combinations thereof. Global population used in these calculations: 7 billion.

Factor	Million people
T	1500
C	1900
S	2400
A	3800
$T \cup C$	2200
$T \cup S$	3200
$T \cup A$	4100
$C \cup S$	3400
$C \cup A$	4100
$S \cup A$	4500
$T \cup C \cup S$	3600
$T \cup C \cup A$	4300
$T \cup S \cup A$	4700
$C \cup S \cup A$	4700
$T \cup C \cup S \cup A$	4800

Discussion

Main findings

This thesis has explored factors related to public access to surgical care. In particular, current methods utilized to measure timeliness to surgical care were shown to be overly optimistic in at least one context (I). South Africa acts as a regional hub for migration of surgical specialists, representing an important destination for sub-Saharan emigrating surgical specialists, whilst itself acting as an even larger exporter of surgical specialists to high-income countries (II). SSI diagnosis at home via CHWs represents a potential way to reduce SSI burden, both in terms of morbidity and undue financial hardship (III). Indeed, even with robust health insurance, cesarean section patients are at high risk of catastrophic health expenditure, and often need to borrow money or sell assets in order to afford care (IV). When the postoperative follow-up after discharge is accounted for, the incidence of financial catastrophe is even larger (V). The previously unaccounted burden of neurosurgical disease will lead to profound global macroeconomic losses in the coming decades (VI). Insufficient access to surgical care is highly multidimensional, and the majority of the billions of people who lack access to surgical care do so due to a combination of 2 or more factors (VII).

Interpretation and implications

Timeliness

As discussed under *Background: The second delay – reaching care*, 2-hour access to district hospitals (potentially providing surgical care) has been estimated to 71-92%,[59,60] with high levels of estimated 2-hour access to surgical care also found in a review by Holmer et al of 19 countries with available data.[11]

The results obtained from study I, however, imply a potential for systematic overestimation in the literature of timely access to surgical care. If the results obtained from this district of Rwanda are generalizable to other rural locations in sub-Saharan Africa, or indeed to other rural locations more broadly, GIS models used for estimation of timeliness and planning of surgical scale-up will need to be revised.

Indeed, several studies in different contexts comparing GIS model estimates to patient-reported data have been published since study I. A study comparing the same GIS model as study I to self-reported travel times to care in Kenya in urban- and semi-urban contexts found self-reported times around 1.5 – 2 times greater than modeled times, even when accounting for mode-of-transport.[257] A study among injury patients in Malawi compared a GIS model with much slower assumed travel speeds, and still found patient-reported times were 1.3-2.1 times greater.[258] A study in Lagos, Nigeria benchmarking against prospectively replicated journeys found even larger discrepancies, up to an order of magnitude, although a different GIS model was assessed. This was likely explained by traffic congestion, highlighting the importance of accounting for the differing conditions in urban and rural contexts. Interestingly, the commercial Google Maps algorithm was found to be fairly accurate.[259] Lastly, a study in Sierra Leone evaluating the same GIS model as in study I found patient-reported travel times were several times larger than GIS estimates.[260] In summary, the results of study I combined with subsequently published literature show previous 2-hour evaluations are highly likely overestimating geographical access. Luckily, more recent studies seem to start to account for this overestimation.[261,262]

There are two fundamental mechanisms for deviations between GIS models and real-world travel times; either patients do not follow the fastest route, or they are traveling at slower than assumed speeds (or a combination thereof). In study I, the majority of the bias could be explained by the first reason – patients always had to travel via their assigned health center. When accounting for this detour, results were fairly accurate. It must be noted, however, that this is an artificially optimistic result. The vast majority of patients traveled onward from the health center with an ambulance. Ambulances travel at high speeds, with the trade-off of having to wait for their arrival. In study I, however, waiting times for ambulances were not included. Additionally, ambulance coverage is significantly lower in many other low- and lower-middle-income countries.[224]

Care must also be taken when interpreting the results of travel time studies, even in the presence of accurate and unbiased GIS models. Specifically, they can only evaluate the second delay of the three delay framework, as outlined in **Table 8**.

Table 8. Assumptions made when taking GIS model output at face value as timeliness. The assumptions in green are evaluated by study I. Adapted from Rudolfson et al[263]

Delay	Assumption	Strength of assumption	Ideal method of measurement	Difficulties in measurement	Example of unaccounted delay
1	When need arises, patient can start their travel right away	Weak	Patient interviews	Highly context and patient specific	Ambulance arrival, not allowed to travel until permission of husband, have to sell assets before affording travel cost etc.
2	Patients can travel at declared speed	Unknown	Patient interviews or replicated journeys	Context-specific	Poor road conditions, using slower modes of transport
2	Patients choose the fastest route	Unknown	Patient interviews	Depends on setting, referral system	Travels another route, e.g. via lower tier hospital
3	Upon arrival, there is capacity to take care of patient	Unknown	Many, e.g. chart review	Costly, may vary depending on time of day	No surgeon on site, overfilled ER etc.

Capacity

Study II found 16% of all surgical specialists originating from South Africa were registered in one of the assessed HICs, while 6% of the surgical specialists registered in South Africa originated from another LMIC.

The topic of "brain drain" has been extensively debated both with regard to surgical specialists and other highly trained individuals (physicians, nurses, engineers, etc.). Indeed, for some countries e.g. Sri Lanka, Zimbabwe, and Nigeria (**Figure 30**), a very large proportion of surgical specialists have emigrated, and including South Africa as a destination country paints a more accurate picture. Particularly among low-income countries, the emigrated proportion rises from 6% to 8% as a result of including South Africa as a destination country, while it plays a much more marginal role as a destination among middle-income countries.

For emigration from South Africa, the results of study II show a fairly sizeable proportion of its surgical specialists have emigrated to high-income countries (16%), several-fold above the proportion of other upper-middle-income countries (1%), and 11th highest among LMICs.

The results of study II imply we need to include South Africa as a destination country if we are to fully understand the impact of surgical specialist migration, in addition to the other 14 countries for which data were previously available. Additionally, there very well may be other countries with a sizable influx of specialists which have yet to be quantified. For policymakers, the results of all the available evidence imply training program sizes may need to be slightly over-dimensioned to account for migration. The impact of the emigration of surgical specialists should not be overstated however; if 10% leave, this also means 90% stay, and so the concept of "brain drain" must not deter from investment in surgical education. A high degree of emigration can also serve as a signal to improve working conditions. Additionally, there are several potential positive effects of emigration, which are summarized in **Table 9** and discussed at length in study II.

Table 9. A summary of the effects of physician migration on sending and receiving countries. Adapted from Aluttis et al[105] and Stewart et al[264]

	Sending countries	Receiving countries
Costs	• Shortages in domestic healthcare service capacity • Financial loss in investment of training and educating the workforce • Undermining institution building and development as a whole • Financial loss of consumption and tax receipts	• Administrative costs
Benefits	• Remittances received from people working abroad • Improvements in skills of returnees • Collaborative partnership between diaspora and local professionals	• Relief of supply shortages • Improved quality of healthcare • Tax receipts from foreign workers

Safety

Study III evaluated different methods of post-discharge follow-up and SSI diagnosis, using a stochastic state transition model. Under the assumptions of the model, several broad conclusions can be drawn.

Effect of individual factors

Ceteris paribus (all else being equal), the sensitivity of the diagnostician seems to primarily affect health outcomes, while specificity seems to primarily affect CHE. Meanwhile, ceteris paribus, follow-up via CHW versus at the health center lowers CHE, but does not affect health outcomes. We can intuitively understand these results if we consider the mechanisms by which health and financial outcomes are affected by the diagnostic process.

Health outcomes are driven primarily by correct and prompt treatment of SSI before more advanced disease or complications have time to develop. For treatment to start, a true positive diagnosis needs to occur, a direct effect of the sensitivity. Lower specificity leads to more false positives and more unnecessary, but not necessarily harmful, treatment.

Catastrophic expenditure is driven by patient costs for follow-up and delivered care – if the specificity is low, more false positive treatments will occur, and be paid for by patients. The effect of sensitivity on CHE is more complicated. On one hand, higher sensitivity will lead to more treatment which must be paid for, but on the other hand, early correct diagnosis and treatment can save costs down the line. In this model, the effect of sensitivity on CHE turns out to be negligible. Lastly, follow-up at home is cheaper for the patient than having to travel to the health center, which explains why the incidence of CHE is lower with CHW follow-up, ceteris paribus.

Feasibility of CHW-led SSI monitoring

The diagnostic accuracy of CHW-based SSI diagnosis is largely unknown and varies depending on training, diagnostic decision algorithm and/or technical aides. Several possibilities exist; best guess of the CHW, scoring systems based on appearance and/or symptoms, telemedical evaluation i.e. evaluation of photos by physicians at the local hospital, AI algorithms on photos, thermal imaging cameras, or a combination of any of the above.

Additionally, with either of these methods, setting the cut-off value for positive diagnosis entails a trade-off between sensitivity and specificity (i.e. moving along the ROC curve[n]).

An understanding of the potential effects of varying levels of sensitivity and specificity of CHWs can therefore facilitate the interpretation and design of

[n] Receiver operating characteristics

future research into diagnostic methods. Specifically, in the baseline scenario, the repeated visits of CHWs as compared to the status quo of one visit at the health center seems to be able to compensate for a lower sensitivity to around the 70-80% level. Conversely, the added number of visits mean specificity needs to be around 90-100% to avoid creating additional instances of CHE.

Affordability

Studies IV and V show a significant proportion of households incur catastrophic and impoverishing expenditures despite the very high uptake of community-based health insurance. In both studies, the incidence of CHE was low when only direct medical expenses were accounted for, but substantially higher when other necessary costs around the delivery of care were included. These results imply the design of the health insurance system is sufficient for covering direct medical expenses, but additional subsidies for direct non-medical expenses (such as transport vouchers) and/or coverage for lost wages need to be considered if the incidence of CHE is to be decreased.

Previous literature on CHE from surgical care has not included post-discharge costs, likely due to the practicality of gathering data at the time of discharge. However, many patients may be right on the cusp of CHE after paying for hospital care, and so even small post-discharge expenditures could be highly detrimental. Indeed, studies IV and V find 23-27% of patients incur CHE from direct and indirect costs up until the day of hospital discharge, while 77% do so by post-operative day 30. From the perspective of the patient, it matters little whether costs are incurred before, during or after hospitalization as the effect will be the same, and so measures of CHE need to take post-discharge costs into account. It should be noted that these figures include opportunity costs due to lost wages which also accounted for the majority of post-discharge costs, and there is a lack of agreement in the literature as to whether these indirect costs should count towards CHE.

Local measurement of CHE can be informative and useful in several ways. First, it can allow a more granular patient-level analysis of drivers of CHE, and aid in understanding which patients are at risk, and why. For example, the very poorest patients in studies IV and V qualify for a more generous health insurance with a zero percent out-of-pocket proportion for medical expenses, and indeed have a lower risk of CHE than do the richer patients.

Local studies can also serve to inform the choice of CHE threshold, by finding the level which correlates to negative financial outcomes. As discussed under *Patient-level financial outcome measures* (p. 64), different thresholds have been suggested, and currently, both CHE at the 10% and 25% levels are reported by the UN. Additionally, patients in richer countries are arguably less likely to suffer substantial negative consequences as a result of having to pay a fixed percentage of their annual income on healthcare than patients in poorer countries. In study IV, a comparison between CHE and having to borrow money or sell assets is made, while other studies have gone further and for example combined measurement of CHE with qualitative interview data[166,265] or measures of perceived financial burden[266].

Lastly, local measurement can serve to validate and/or calibrate national, regional, or global modeling studies. For example, a previous modeled estimate for CHE in Rwanda from direct expenditures was 59%,[51] substantially higher than the measurements in studies IV and V. This modeled estimate was based on a mean out-of-pocket proportion of 21% however, much larger than the 10% patients are expected to pay under the community-based health insurance system, and potentially therefore reflecting outdated input data. Additionally, several local measurements from differing contexts are needed to evaluate potential bias of global modeled estimates.

Societal effects

Study VI estimated the macroeconomic effects of neurosurgical disease. The model estimated a total of $4.4 trillion USD of GDP output would be lost between 2015 and 2030 in the 90 included LMICs. Losses as a share of GDP were particularly high in low-income countries. The value of lost welfare lost was much greater - $3 trillion USD in 2015 alone, equivalent to 5% of GDP, emphasizing the large value placed on health and life.

Although not all of these economic losses would be avertable even with a comprehensive neurosurgical package, large differences both in incidence and case fatality rates between HICs and LMICs suggest a significant proportion of this economic burden could be averted with increased efforts in both prevention and treatment. These results complement the previously estimated $12.3 trillion USD of GDP predicted lost to surgical disease,[190] although they cannot be directly summed due to a potential for overlap of trauma cases.

These results highlight the consequences of a lack of healthcare for society and need to be interpreted together with studies on disease burden, cost-effectiveness, and projected cost of scale-up, to make the economic case for investment in neurosurgical care.

Global access to surgical care

Study VII estimates the proportion of the global population with and without access to surgical care due to issues of timeliness, capacity, safety, and affordability. From the data and accompanying Euler diagram, the multifactorial nature of the problem is highlighted. Solutions aimed at tackling the problem will consequently need to be equally multifactorial. In particular, solely addressing capacity issues will not suffice if substantial progress is to be made.

Crucially, we can also improve upon our understanding of the concepts of access and universal health coverage, moving from a dichotomy to a continuum.

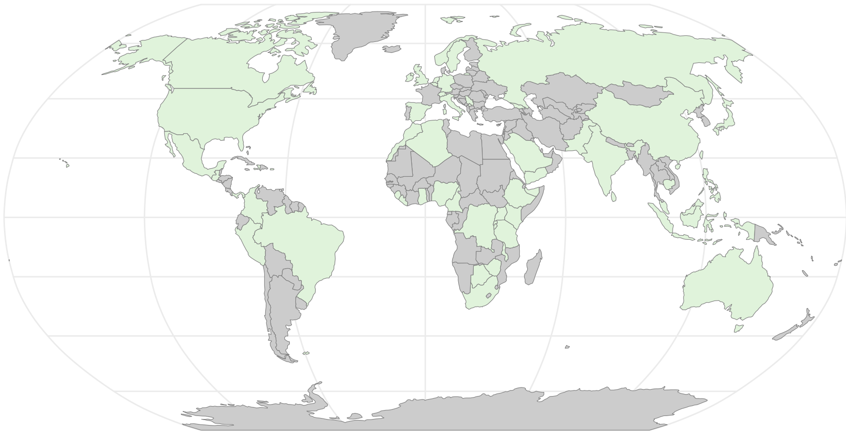


Figure 42. A global research field. Author affiliation countries of research articles citing any of the thesis studies. Countries with at least one citing author are shown in green.

Strengths, limitations, and methodological considerations

To be a researcher in global surgery is to handle uncertainty, and to attempt insight from data which are often incomplete, inconsistent, and imprecise. We must be balanced in our desire for certainty and exactness, and not let perfect be the enemy of good. Any attempt at understanding the current scientific literature of the global surgery movement would be incomplete without acknowledgment and appreciation of this fact; nevertheless, we cannot become complacent in our efforts to achieve methodological excellence and increased reliability of our scientific results.

Surgery is a multidisciplinary affair, reliant not only on a multitude of different specialists and subspecialists, but also on a wide array of other services such as ambulances, referral systems, sterilization, financing mechanisms, oxygen delivery, blood banks, equipment repair, and countless others. Likewise, an array of different perspectives and methodologies are necessary to understand the global delivery of surgical care. In this thesis, a host of different approaches and study designs are used, including e.g. patient questionaries, macroeconomic models, GIS travel times estimations, state transition modeling, etc.

Panel: Nobody knows how to make a pencil
An oft-used analogy to understand the complexities of the modern economy is that of the ordinary pencil. In his 1958 essay *I, pencil*, Leonard Read points out that no one person knows how to make a pencil. Countless people are involved in its creation if we consider all the materials and machinery necessary for its production, and then the manufacture of those machines, and so on.

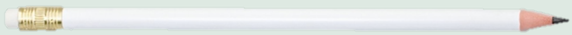


Figure 43. *A pencil. The result of tractor drivers, rubber chemists, metal miners, shipping vessel crew members, chainsaw spare part manufacturers, and many others.*

Perhaps this analogy can teach some humility. No one person understands the complete process of surgical care. We cannot plan fully for its scale-up, and are fully reliant on countless people, each doing their part.

Utility and pitfalls of mathematical modeling in global surgery research

Without the usage of mathematical and statistical modeling, many important questions in global surgery would remain wholly unexplored. Yet, our understanding of the world is incomplete at best, and we cannot model that which we do not understand. Perhaps the most pertinent measure we can take to ensure the usefulness of modeling is to aim for clarity of reporting, with a transparent account of key assumptions and the consequences if said assumptions do not hold.

For study I, some key examples of GIS assumptions are discussed in **Table 8**. More broadly, study I is an example of the perils involved in taking the results of unvalidated methodologies at face value and highlights the importance of grounding models in the local context to which they are applied.

Study III uses a stochastic state transition model to understand the potential effects of task-shifting SSI surveillance to community health workers. To do so, several assumptions need to be made regarding the progression of infections. Of course, no definitive prediction of health effects can be made from such a model – only a carefully designed randomized controlled trial can definitively answer this question. What it can do, is assess the feasibility of the intervention before patients are recruited and inform the design of both intervention and study design.

Study VI uses two macroeconomic models. The meaning of the value of lost welfare model must not be interpreted as actual GDP lost, but as a combined measure of economic productivity and the inherent value of good health. It should also be noted that the counterfactual scenario for both models is the absence of neurosurgical disease. Even with the highest quality neurosurgical care, only a proportion of morbidity and mortality is avoidable. Lastly, prediction and extrapolation into the future based on past trends in inherently precarious, not least due to the possibility of major geopolitical events disrupting past trends. The Covid-19 pandemic serves as a valuable reminder of this lesson.

Generalization issues

Careful judgment is needed when attempting generalization of study results. Specifically, studies I, III, IV and V all use data from one rural district in Rwanda and are likely applicable to varying degrees in other locations. Some aspects of socioeconomic factors and healthcare characteristics are likely similar to other rural African locations, but there are also distinctive qualities, such as the very high uptake of community-based health insurance. Data are also restricted to one surgical procedure, cesarean sections, although it should be noted that a large proportion of all surgeries are cesarean sections, especially in low-income settings.

As discussed under *Interpretation and implications - Timeliness* (p. 89), similar results as those from study I have since been reported in several independent studies.

Study IV utilizes a Monte Carlo technique to infer counterfactual results under other insurance systems, thereby aiding in the interpretation and generalizability of the study results.

For the VLW method used in study VI, VSL estimates for each country are needed, but few studies on the VSL have been performed in LMICs, mandating the usage of conversion techniques to adapt estimates from HICs (see *Value of lost welfare*, p. 68). If the income elasticity of the VSL is higher than assumed, as is indeed suggested by at least some newer albeit conflicting evidence on the topic, this would result in an overestimation of the economic effects.

Missing data

Missing data was a relatively minor issue for studies I, III, IV and VII, which all had missingness well below 5%. In study II, country of medical qualification was missing for 14% of surgical specialists of foreign origin in South Africa, and in study V, data were available for 84% at postoperative day 30. For both these studies, a missing completely at random assumption was (implicitly) made, analyzing data on a complete case basis. If there were systematic differences between study subjects with missingness, results could suffer bias.

Misclassification issues

Studies I, III, IV and V utilize patient questionaries, and so are subject to potential recall bias and rounding errors. For household incomes and expenditures, data were gathered in multiple ways (monthly total averages, sum of individual components), and although there were differences, these were deemed not to have a substantial effect on overall study results.

For study II, it is not mandatory to deregister from the medical council upon emigration in many countries, and in effect, one person could be counted as practicing in several countries in the study. Temporal data were also not available, precluding the evaluation of policies on migration patterns, as well as an analysis of the career timing for migration of the included physicians.

The lack of a gold standard for SSI diagnosis complicates the analysis in study III. All measurements of SSI incidence and the incidence of complications within the group which develop SSIs are affected by subjective judgment by diagnosticians.

Survey data are used in study VI to estimate the proportion of e.g. stroke cases which need neurosurgical consultation. A systematic bias of these survey results would in turn lead to a bias of the macroeconomic estimates.

Global data availability

Studies in global surgery are also hampered by the incompleteness of national statistics, especially for studies which aim to make global estimates. For study VI, data necessary for the calculation of the VLO method were available for 90 LMICs, and for the VLW method, data were available for 127 countries. In study II, data on the immigration of South African surgical specialists were only available from 14 HICs. As a general reflection however, the larger the country, the higher the probability of data availability, and therefore a large proportion of the global population can be included in studies even if numerically the number of countries is relatively lower.

Future directions

Improving measures of access to surgical care

Future studies should focus both on improving the accuracy of the proportion of the global population which has access to surgical care and on increasing the utility of this data.

The best currently available data on the proportion of the world's population which can access surgery, around 70%, is based on several proxy measures for which data are available on a global scale.[2,3]

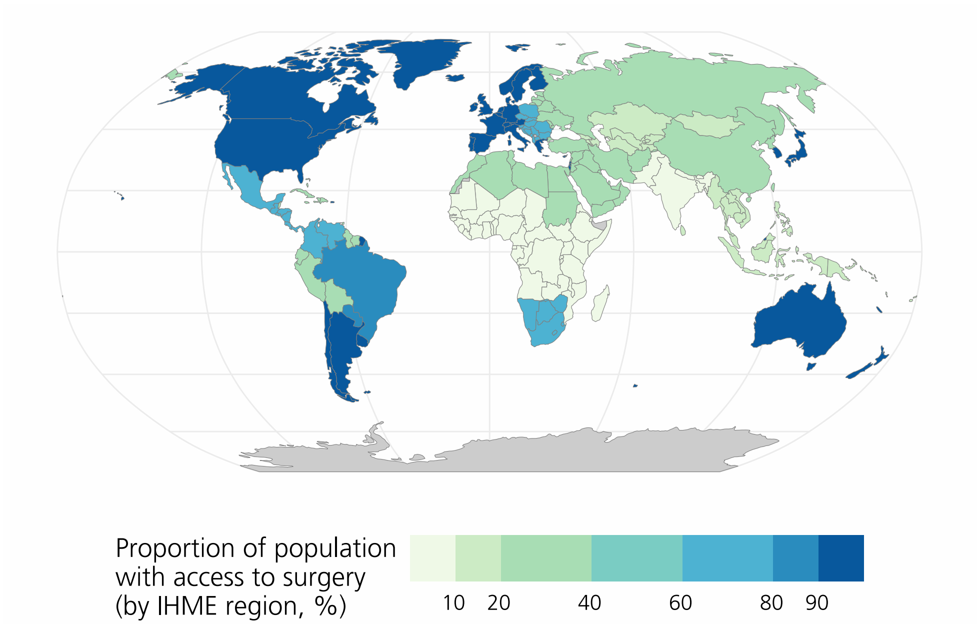


Figure 44. The estimated proportion of the population with access to surgical care. Adapted from Alkire et al[3]

For timeliness, the proportion of seriously injured patients transported by ambulance is used. This data is reported by the WHO,[224] but unfortunately the data in turn is based on expert solicitation rather than registry data for a large proportion of countries. Additionally, even with better raw data for ambulance transports, the density of surgically capable hospitals and the state of the road network would not be taken into account. A preferable approach therefore would be to utilize GIS modeling. Although computationally intensive, such models are highly feasible even on a global scale.[267,268] As discussed under *Interpretation and implications - Timeliness* (p. 89), travel speed models need to be adjusted for local conditions, an increasingly realistic prospect. The major hindrance is a lack of data on the locations of surgically capable hospitals worldwide. There are projects to map healthcare facilities on a regional or worldwide basis,[59,268,269] but data on which hospitals offer surgical services are much scarcer, and substantial effort will be needed if global estimates are to be produced using this methodology. An interim solution would be to interpolate estimates for countries without such data, for example using a simple regression approach. This could yield plausible and unbiased global estimates but would limit applicability of results at the national level. Additionally, while the 2-hour cutoff for timely access is reasonable for some emergency diseases, longer travel times would be acceptable for many elective cases. This introduces conceptual complexity, where patients no longer binarily either have or haven't timely access to surgical care, but where this instead varies by disease. A pragmatic solution might be to set different time targets for emergency and elective surgical care, and then to perform two calculations using these targets and combine them according to the proportion of needed surgical care which is elective.

For capacity, the proportion of current estimated annual operations divided by the estimated needed annual operations is calculated. A discussion of the origin and assumptions of these estimates can be found under *Global volume of surgical interventions* (p. 28). While the underlying methodology is sound in this author's opinion, the estimates are now quite old.

For safety, the proportion of operating rooms with a pulse oximeter is used as a proxy. Different standards for surgical quality have been proposed,[270] which may improve conceptually on the one-dimensional application of pulse oximetry, but data availability remains a major concern. Another approach would be to utilize outcomes rather than process measures, for example the perioperative mortality rate, although standardization of measurement and risk stratification remain unsolved matters. Regardless of method of measurement, dividing surgical care into safe/not safe presents difficult philosophical issues.

For affordability, the proportion at risk of CHE is used. This data in turn is modeled using cesarean sections as a proxy for all surgical procedures[51,154] and uses modeled estimates of population income distributions. By contrast, for overall healthcare spending, microdata have been successfully utilized to more directly measure the incidence of CHE.[206] While it may not be feasible to gather surgery-specific healthcare expenditure microdata on a global scale, additional local or national measurements of the risk of CHE can serve to inform and improve on global modeling efforts, as exemplified by studies IV and V.

To improve the utility of these global estimates of access to surgical care, they need to be reported in a transparent manner, highlighting the assumptions, definitions, and implications of the calculations. Additionally, periodic updates to the estimate can serve to track developments and to highlight need for additional efforts. Data are not temporally granular enough to permit annual updates, but meaningful differences may be detected if data were updated every 5 or 10 years.

Converting knowledge to action

To stay relevant to academics, policymakers, and most importantly to patients, global surgery as a research field needs to graduate from *describing* inequity to *reducing* inequity.

This is not to say all future research in the field must be interventional, nor that advocacy or policy development are more important than research, merely that increased attention to research projects which will improve patient access and outcomes will increase the utility of this research field. Indeed, a thorough and reliable description of the current situation is a prerequisite for effective advocacy for the surgical patient.

There are therefore numerous ways in which academia can contribute to improved access, including research, policy, advocacy and capacity building.[271] One specific example of how academia can interact with broader society includes contributing to the creation of so-called National Surgical, Obstetric and Anesthesia Plans (NSOAP).[272,273] Surgery is scarcely mentioned in existing overall national health plans,[274] and implementation of an NSOAP is meant to provide institutional and governmental leadership and buy-in.

Table 10. Some examples of research questions which would serve to improve upon the current lack of access to surgical care

Describing the status quo	Changing the status quo
Measuring 2-hour access	Utilizing GIS methodology to optimize the placement of new facilities
Measuring CHE incidence	Designing new insurance coverage systems specifically designed around current weaknesses, and measuring the effect of their implementation on CHE and utilization
Comparing perioperative mortality rates	RCT of interventions meant to reduce morbidity and mortality, specifically in an LMIC context

”Life is short,
art long,
opportunity fleeting,
experience treacherous,
judgement difficult”

– Hippocrates, ca 4th century BC

”There is only one thing for it then — to learn. Learn why the world wags and what wags it. This is the only thing which the mind can never exhaust, never alienate, never be tortured by, never fear or distrust, and never dream of regretting”

– T.H. White, 1958

Populärvetenskaplig sammanfattning

Under de senaste decennierna har det skett en remarkabel utveckling av den globala folkhälsan, med stora förbättringar vad gäller till exempel barnadödlighet, mödradödlighet, och infektionssjukdomar såsom HIV, tuberkulos och malaria. Världen går nu in i en era där icke-smittsamma sjukdomar (t.ex. hjärtsjukdom, diabetes, blindtarmsinflammation, bilolyckor, etc.) är den dominerande orsaken till ohälsa inte bara i rika länder såsom Sverige, utan också på ett globalt plan. Detta innebär att sjukvården i många länder behöver skalas upp för att tackla de utmaningar som behandling av dessa sjukdomar innebär.

Vetenskapen om hur folkhälsan på ett globalt plan påverkas av sjukdom och sjukvård kallas global hälsa, och utifrån detta har det nu snabbt växande forskningsfältet *global kirurgi* uppkommit. I detta begrepp innefattas all kirurgisk vård, alltså t.ex. allmänkirurgi (operationer främst i matsmältningsorgan), obstetrik (vård i samband med barnafödsel), urologi (operationer i urinvägarna), neurokirurgi (operationer i nervsystemet), anestesi (sövning och smärtlindring i samband med vård) och flera andra. Under lång tid har det ansetts att kirurgisk vård är för dyrt, för komplext, och inte tillräckligt viktigt för folkhälsan, för att förtjäna någon större uppmärksamhet inom det globala hälsoarbetet. Delvis som ett resultat av det saknar så mycket som 70% av världens befolkning fullgod tillgång till kirurgisk vård, och uppemot 90% i låg- och medelinkomstländer. Nyare forskning har dock visat att flertalet kirurgiska operationer kan vara höggradigt kostnadseffektiva, eftersom de med en kortare insats kan innebära att ett livslångt lidande eller till och med död kan undvikas. Det gäller exempelvis behandling av brutna ben som förhindrar livslång funktionsnedsättning, kejsarsnitt som kan rädda liv på både barn och moder, operation av grå starr som tar ca 15 min och ger synen tillbaka, operation vid blindtarmsinflammation som kan rädda liv, och många fler.

Ett sätt att definiera fullgod tillgång till kirurgisk vård är att (1) patienten måste ha möjlighet att komma till vård i tid, (2) det finns kapacitet och möjlighet att erbjuda rätt sorts vård, (3) vården håller en tillräckligt god säkerhet och kvalitet, samt (4) patienten försätts inte i fattigdom som ett resultat av att behöva vård.

Tidsaspekter

För många kirurgiska sjukdomar finns det ett tidsfönster inom vilket behandling måste påbörjas för att undvika död och/eller komplikationer, t.ex. vid bilolyckor eller blödning efter förlossning. I många länder har en stor del av befolkningen långa avstånd till närmsta sjukhus, och få möjligheter till snabb transporter med t.ex. ambulans. För att utvärdera hur den geografiska tillgången till kirurgisk vård ser ut och hur den kan förbättras används ofta datormodeller, s.k. geografiska informationssystem (GIS). Utifrån sådana studier har man beräknat att en förvånansvärt hög andel av befolkningen (70–90% inom Afrika söder om Sahara) kan ta sig till sjukhuset inom de första två kritiska timmarna. En svaghet med tidigare studier har dock varit att datormodellerna inte jämförts med data från verkligheten. I **studie I** konstruerades en GIS-modell, och resultaten jämfördes med hur lång tid patienter på ett sjukhus i Rwanda uppgav att det tagit dem att komma till sjukhuset. Resultatet visade en avvikelse på ca 50%. Flera andra forskargrupper har sedermera utfört liknande studier, och resultaten visar samstämmigt att tidigare GIS-modeller haft orealistiska antaganden gällande hur snabbt patienter kan ta sig till ett sjukhus.

Kapacitet

Cirka 300 miljoner kirurgiska ingrepp utförs årligen, men bara 13% av dessa utförs i låg- eller lägre medel-inkomstländer där ungefär hälften av världens befolkning bor. Ytterligare ca 150 miljoner operationer behövs årligen. Det finns ungefär 30 gånger fler kirurger, obstetriker och narkosläkare per 100 000 invånare i europeiska länder än i afrikanska länder. Denna obalans förstärks av att vårdpersonal från fattigare länder flyttar till rikare länder, vilket tidigare uppmäts i bl.a. europeiska och nordamerikanska databaser över kirurgisk personal. **Studie II** mäter migrationen av kirurgisk personal in och ut från Sydafrika, vilket tidigare inte studerats. Ungefär 16% av kirurgiska specialistläkare från Sydafrika har flyttat till rika, främst anglosaxiska, länder. Det har i sin tur skapat ett underskott, och 6% av kirurgiska specialistläkare i Sydafrika kommer i sin tur från andra låg- och medelinkomstländer, varför man kan beskriva Sydafrika som ett regionalt nav för migration av kirurgiska specialistläkare.

Säkerhet

Det finns stora utmaningar inte bara vad gäller att tillräckligt många människor ska få tillgång till vård, utan också att denna ska hålla tillräckligt hög kvalitet och säkerhet. Vissa forskare vill till och med göra gällande att fler människor dör som ett resultat av otillräcklig kvalitet än av otillräcklig tillgång, även om noggrann analys av detta är svår och osäker. Klart är dock att stora skillnader består. Exempelvis är dödligheten efter kejsarsnitt 50–100 gånger högre i Afrika söder om Sahara än i höginkomstländer i Västeuropa, och andelen patienter som drabbas av komplikationer efter kirurgi såsom djupa vävnadsinfektioner är betydligt högre. En svårighet är att uppföljningen efter kirurgi är eftersatt, vilket leder till försenade diagnoser. **Studie III** undersöker möjligheten att använda s.k. community health workers för att diagnosticera postoperativa infektioner, dvs lokalt anställda personer med en kortare utbildning i att utföra specifika uppgifter men ingen traditionell sjukvårdsutbildning. Mycket kunskap saknas fortfarande innan en sådan lösning kan bli möjlig, inte minst vad gäller den diagnostiska träffsäkerheten. Därför konstruerades en matematisk modell som undersöker effekten av användning av community health workers på patientutfall under ett stort antal möjliga scenarion. Denna kunskap kan sedan ligga till grund i utvecklandet av uppföljningssystem som kan prövas i verkligheten.

Privatekonomiska effekter

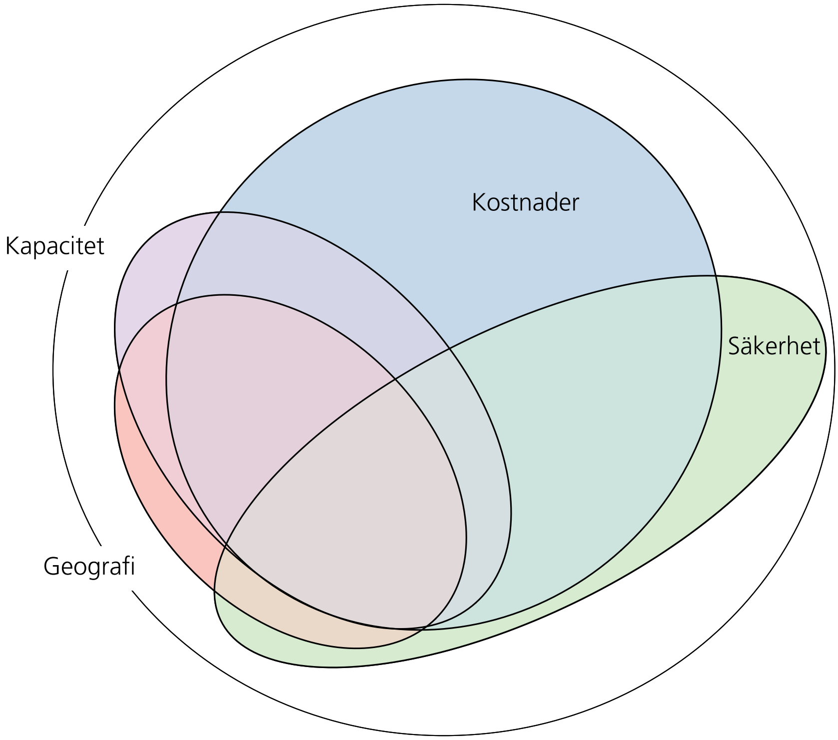
Att behöva kirurgisk vård kan få fatala ekonomiska effekter för både patient och familj, både om den nödvändiga vården är dyr, men även från runtomkringkostnader såsom transportkostnader eller om inkomstbortfall inträder. För hushåll som befinner sig nära fattigdomsgränsen med små marginaler kan även små kostnader få mycket stora konsekvenser om de leder till att man behöver sälja produktiva tillgångar såsom boskap, eller om barnen måste avsluta skolgången. FN har därför definierat begreppet *katastrofala sjukvårdsutgifter*. Matematiska modeller uppskattar att så många som 80 miljoner människor har katastrofala sjukvårdsutgifter årligen. I Rwanda, liksom i Sverige och många andra länder, skyddar man befolkningen mot sjukvårdskostnader genom försäkringssystem, men dessa täcker i regel bara själva sjukvårdskostnaderna och ej runtomkringkostnader. I **studie IV** har Rwandiska patienter tillfrågats om inkomster och utgifter i samband med kejsarsnitt. Cirka 5% av patienterna hade katastrofala sjukvårdsutgifter om man bara räknar med direkta sjukvårdskostnader, men över 20% hade det om alla runtomkringkostnader räknades in. **Studie V** räknade även med kostnader som inträffade efter sjukhusvistelsen, vilket inte tagits hänsyn till i tidigare studier, och fann att än fler patienter drabbades.

Samhällsekonomiska effekter

Kirurgiskt behandlingsbara sjukdomar drabbar inte enbart den enskilda patienten, utan kan även påverka hela samhället, genom att funktionsnedsättning och död minskar produktiviteten i ekonomin. Detta får i sin tur en rad andra negativa konsekvenser, inte minst då en brist på resurser återigen drabbar hälsan, en form av negativ återkoppling. **Studie VI** använder därför en matematisk modell för att uppskatta de makroekonomiska effekterna av neurokirurgisk sjukdom. Under perioden 2015–2030 väntas över 4 biljoner dollar av BNP förloras som ett resultat av neurokirurgisk sjukdom, och om man även värderar egenvärdet av hälsa i ekonomiska termer blir förlusterna mångdubbelt högre.

Global tillgång till kirurgisk vård

Den relativa betydelsen av de fyra aspekterna ovan för bristen på tillgång till kirurgisk vård har tidigare inte uppmätts. **Studie VII** bygger på en matematisk modell som uppskattar antalet personer i varje land som saknar tillgång till kirurgi som ett resultat av varje enskild faktor eller kombination därutav. Risken för katastrofala sjukvårdsutgifter är det enskilt största hindret räknat i antalet personer, följt utav bristande säkerhet, kapacitetsbrist och tidsaspekter. Majoriteten (60%) av de människor som har otillräcklig tillgång till kirurgisk vård påverkas dock av minst två av dessa faktorer. För att tillgången till kirurgi ska kunna förbättras behöver därför åtgärder riktas mot hela spektret av orsaker till bristande tillgång till kirurgisk vård.



Figur från studie VII. Ett Venndiagram över bristen på tillgång till kirurgi. Den stora vita cirkeln representerar världens befolkning, medan de mindre cirklarna representerar de människor som saknar tillgång till kirurgi beroende på var och en av de fyra faktorerna. Varje cirkels storlek är proportionerlig till antalet människor som saknar tillgång på grund av sagda faktor.

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References

1. Mahler H. Surgery and health for all. Address By Dr H. Mahler Director-General Of The World Health Organization To The XXII Biennial World Congress Of The International College Of Surgeons. 1980.
2. Meara JG, Leather AJM, Hagander L, et al. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *The Lancet* 2015; **386**(9993): 569 - 624.
3. Alkire BC, Raykar NP, Shrime MG, et al. Global access to surgical care: a modelling study. *Lancet Glob Health* 2015; **3**(6): e316-23.
4. Institute for Health Metrics and Evaluation. Global Burden of Disease Study 2019. Global Health Data Exchange. Seattle, WA.
5. Farmer PE, Kim JY. Surgery and Global Health: A View from Beyond the OR. *World J Surg* 2008; **32**(4): 533-6.
6. Bath M, Bashford T, Fitzgerald JE. What is 'global surgery'? Defining the multidisciplinary interface between surgery, anaesthesia and public health. *BMJ Global Health* 2019; **4**(5): e001808.
7. WHA68.15: Strengthening Emergency and Essential Surgical Care and Anaesthesia as a Component of Universal Health Coverage. The World Health Organisation; 2015.
8. Debas HT, Donkor P, Gawande AA, Jamison DT, Kruk ME, Mock C. Disease control priorities 3ed: Essential Surgery. 2015: 1 - 445.
9. Sgrò A, Al-Busaidi IS, Wells CI, et al. Global Surgery: A 30-Year Bibliometric Analysis (1987–2017). *World J Surg* 2019; **43**(11): 2689-98.
10. World Bank. World Development Indicators. Washington, DC.
11. Holmer H, Bekele A, Hagander L, et al. Evaluating the collection, comparability and findings of six global surgery indicators. *Br J Surg* 2019; **106**(2): e138-e50.
12. Roser M, Our World in Data. The short history of global living conditions and why it matters that we know it. 2020. https://ourworldindata.org/a-history-of-global-living-conditions-in-5-charts#education.
13. Rose J, Weiser TG, Hider P, Wilson L, Gruen RL, Bickler SW. Estimated need for surgery worldwide based on prevalence of diseases: a modelling strategy for the WHO Global Health Estimate. *Lancet Global Heal* 2015; **3**: S13-S20.
14. Bickler S, Ozgediz D, Gosselin R, et al. Key Concepts for Estimating the Burden of Surgical Conditions and the Unmet Need for Surgical Care. *World J Surg* 2010; **34**(3): 374-80.

15. Groen RS, Kamara TB, Dixon-Cole R, Kwon S, Kingham TP, Kushner AL. A Tool and Index to Assess Surgical Capacity in Low Income Countries: An Initial Implementation in Sierra Leone. *World J Surg* 2012; **36**(8): 1970-7.
16. Kwon S, Groen RS, Kamara TB, et al. Nationally Representative Household Survey of Surgery and Mortality in Sierra Leone. *World J Surg* 2013; **37**(8): 1829-35.
17. Tran TM, Fuller AT, Butler EK, et al. Burden of Surgical Conditions in Uganda. *Ann Surg* 2017; **266**(2): 389-99.
18. Petroze RT, Groen RS, Niyonkuru F, et al. Estimating operative disease prevalence in a low-income country: Results of a nationwide population survey in Rwanda. *Surgery* 2013; **153**(4): 457-64.
19. Gupta S, Shrestha S, Ranjit A, et al. Conditions, preventable deaths, procedures and validation of a countrywide survey of surgical care in Nepal. *Brit J Surg* 2015; **102**(6): 700-7.
20. Patel HD, Groen RS, Kamara TB, et al. An estimate of hernia prevalence in Sierra Leone from a nationwide community survey. *Hernia* 2014; **18**(2): 297-303.
21. Ademuyiwa AO, Odugbemi TO, Bode CO, et al. Prevalence of surgically correctable conditions among children in a mixed urban-rural community in Nigeria using the SOSAS survey tool: Implications for paediatric surgical capacity-building. *PLoS ONE* 2019; **14**(10): e0223423.
22. Butler EK, Tran TM, Fuller AT, et al. Quantifying the pediatric surgical need in Uganda: results of a nationwide cross-sectional, household survey. *Pediatr Surg Int* 2016; **32**(11): 1075-85.
23. Stokes MAR, Guest GD, Mamadi P, et al. Measuring the Burden of Surgical Disease Averted by Emergency and Essential Surgical Care in a District Hospital in Papua New Guinea. *World J Surg* 2017; **41**(3): 650-9.
24. Stewart B, Khanduri P, McCord C, et al. Global disease burden of conditions requiring emergency surgery. *Brit J Surg* 2014; **101**(1): e9-e22.
25. Shrime MG, Bickler SW, Alkire BC, Mock C. Global burden of surgical disease: an estimation from the provider perspective. *Lancet Global Heal* 2015; **3**: S8-S9.
26. Rose J, Chang DC, Weiser TG, Kassebaum NJ, Bickler SW. 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* 2014; **9**(2): e89693.
27. Higashi H, Barendregt JJ, Kassebaum NJ, Weiser TG, Bickler SW, Vos T. Surgically avertable burden of obstetric conditions in low- and middle-income regions: a modelled analysis. *BJOG: An International Journal of Obstetrics & Gynaecology* 2015; **122**(2): 228-36.

28. Higashi H, Barendregt JJ, Kassebaum NJ, Weiser TG, Bickler SW, Vos T. Surgically avertable burden of digestive diseases at first-level hospitals in low and middle-income regions. *Surgery* 2015; **157**(3): 411-9.

29. Higashi H, Barendregt JJ, Kassebaum NJ, Weiser TG, Bickler SW, Vos T. Burden of Injuries Avertable By a Basic Surgical Package in Low- and Middle-Income Regions: A Systematic Analysis From the Global Burden of Disease 2010 Study. *World J Surg* 2015; **39**(1): 1-9.

30. Hider P, Wilson L, Rose J, Weiser TG, Gruen R, Bickler SW. 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* 2015; **158**(1): 44-54.

31. Weiser TG, Haynes AB, Molina G, et al. Estimate of the global volume of surgery in 2012: an assessment supporting improved health outcomes. *The Lancet* 2015; **385**(S2): S11.

32. Verguet S, Alkire BC, Bickler SW, et al. Timing and cost of scaling up surgical services in low-income and middle-income countries from 2012 to 2030: a modelling study. *Lancet Global Heal* 2015; **3**: S28-S37.

33. Uribe-Leitz T, Esquivel MM, Molina G, et al. Projections for Achieving the Lancet Commission Recommended Surgical Rate of 5000 Operations per 100,000 Population by Region-Specific Surgical Rate Estimates. *World J Surg* 2015; **39**(9): 2168-72.

34. Disease Control Priorities, Third Edition (Volume 9): Improving Health and Reducing Poverty. 2017.

35. Grimes CE, Henry JA, Maraka J, Mkandawire NC, Cotton M. Cost-effectiveness of Surgery in Low- and Middle-income Countries: A Systematic Review. *World J Surg* 2014; **38**(1): 252-63.

36. Gosselin RA, Thind A, Bellardinelli A. Cost/DALY Averted in a Small Hospital in Sierra Leone: What Is the Relative Contribution of Different Services? *World J Surg* 2006; **30**(4): 505-11.

37. Chao TE, Sharma K, Mandigo M, et al. Cost-effectiveness of surgery and its policy implications for global health: a systematic review and analysis. *Lancet Glob Health* 2014; **2**(6): e334-45.

38. Saxton AT, Poenaru D, Ozgediz D, et al. Economic Analysis of Children's Surgical Care in Low- and Middle-Income Countries: A Systematic Review and Analysis. *PLoS ONE* 2016; **11**(10): e0165480 - 20.

39. Raykar NP, Ng-Kamstra JS, Bickler S, et al. New global surgical and anaesthesia indicators in the World Development Indicators dataset. *BMJ Global Health* 2017; **2**(2): e000265 - 5.

40. Hanna JS, Herrera-Almario GE, Pinilla-Roncancio M, et al. Use of the six core surgical indicators from the Lancet Commission on Global Surgery in Colombia: a situational analysis. *Lancet Global Heal* 2020; **8**(5): e699-e710.
41. Nunez JM, Nellermoe J, Davis A, et al. Establishing a baseline for surgical care in Mongolia: a situational analysis using the six indicators from the Lancet Commission on Global Surgery. *BMJ Open* 2022; **12**(7): e051838.
42. Albutt K, Punchak M, Kayima P, Namanya DB, Anderson GA, Shrime MG. Access to Safe, Timely, and Affordable Surgical Care in Uganda: A Stratified Randomized Evaluation of Nationwide Public Sector Surgical Capacity and Core Surgical Indicators. *World J Surg* 2018; **386**(Suppl): 569 - 11.
43. Guest GD, McLeod E, Perry WRG, et al. Collecting data for global surgical indicators: a collaborative approach in the Pacific Region. *BMJ Global Health* 2017; **2**(4): e000376 - 10.
44. Davies JI, Gelb AW, Gore-Booth J, et al. Global surgery, obstetric, and anaesthesia indicator definitions and reporting: An Utstein consensus report. *PLoS Med* 2021; **18**(8): e1003749.
45. Weiser TG, Makary MA, Haynes AB, et al. Standardised metrics for global surgical surveillance. *The Lancet* 2009; **374**(9695): 1113-7.
46. Doran GT. There's a S.M.A.R.T. way to write management's goals and objectives. *Management Review* 1981.
47. Boerma T, Victora C, Abouzahr C. Monitoring country progress and achievements by making global predictions: is the tail wagging the dog? *The Lancet* 2018; **392**(10147): 607-9.
48. Trends in maternal mortality: 1990 to 2015: estimates by WHO, UNICEF, UNFPA, World Bank Group and the United Nations Population Division.
49. Sridhar D. Making the SDGs useful: a Herculean task. *The Lancet* 2016; **388**(10053): 1453-4.
50. Rajkotia Y. Beware of the success cartel: a plea for rational progress in global health. *BMJ Global Health* 2018; **3**(6): e001197 - 3.
51. Shrime MG, Dare A, Alkire BC, Meara JG. A global country-level comparison of the financial burden of surgery. *Br J Surg* 2016; **103**(11): 1453 - 61.
52. Funk LM, Weiser TG, Berry WR, et al. Global operating theatre distribution and pulse oximetry supply: an estimation from reported data. *The Lancet* 2010; **376**(9746): 1055-61.
53. Thaddeus S, Maine D. Too far to walk: Maternal mortality in context. *Soc Sci Med* 1994; **38**(8): 1091-110.
54. Grimes CE, Bowman KG, Dodgion CM, Lavy CBD. Systematic Review of Barriers to Surgical Care in Low-Income and Middle-Income Countries. *World J Surg* 2011; **35**(5): 941-50.

55. Raykar N, Gillies R, Rodas E, et al. Appendix 2.1 to The Lancet Commission on Global Health: Health Delivery and Management Supplemental Core Content. *The Lancet* 2015.

56. Whitaker J, O'Donohoe N, Denning M, et al. Assessing trauma care systems in low-income and middle-income countries: a systematic review and evidence synthesis mapping the Three Delays framework to injury health system assessments. *BMJ Global Health* 2021; **6**(5): e004324.

57. Sacks E, Vail D, Austin-Evelyn K, et al. Factors influencing modes of transport and travel time for obstetric care: a mixed methods study in Zambia and Uganda. *Health Policy and Planning* 2016; **31**(3): 293 - 301.

58. Poel EVd, Flores G, Ir P, O'Donnell O, Doorslaer EV. Can vouchers deliver? An evaluation of subsidies for maternal health care in Cambodia. *Bulletin of the World Health Organization* 2014; **92**(5): 331-9.

59. Ouma PO, Maina J, Thuranira PN, et al. Access to emergency hospital care provided by the public sector in sub-Saharan Africa in 2015: a geocoded inventory and spatial analysis. *Lancet Global Heal* 2018; **6**(3): e342 - e50.

60. Juran S, Broer PN, Klug SJ, et al. Geospatial mapping of access to timely essential surgery in sub-Saharan Africa. *BMJ Global Health* 2018; **3**(4): e000875 - 10.

61. Knowlton LM, Banguti P, Chackungal S, et al. A geospatial evaluation of timely access to surgical care in seven countries. *Bulletin of the World Health Organization* 2017; **95**(6): 437 - 44.

62. Esquivel MM, Uribe-Leitz T, Makasa E, et al. Mapping Disparities in Access to Safe, Timely, and Essential Surgical Care in Zambia. *JAMA Surg* 2016; **151**(11): 1064 - 11.

63. Raykar NP, Bowder AN, Liu C, et al. Geospatial mapping to estimate timely access to surgical care in nine low-income and middle-income countries. *The Lancet* 2015; **385**: S16.

64. Stewart BT, Tansley G, Gyedu A, et al. Mapping Population-Level Spatial Access to Essential Surgical Care in Ghana Using Availability of Bellwether Procedures. *JAMA Surg* 2016; **151**(8): e161239 - 9.

65. Chen YN, Schmitz MM, Serbanescu F, Dynes MM, Maro G, Kramer MR. Geographic Access Modeling of Emergency Obstetric and Neonatal Care in Kigoma Region, Tanzania: Transportation Schemes and Programmatic Implications. *Glob Health Sci Pract* 2017; **5**(3): 430 - 45.

66. Engjom HM, Morken NH, Norheim OF, Klungsøyr K. Availability and access in modern obstetric care: a retrospective population-based study. *BJOG: An International Journal of Obstetrics & Gynaecology* 2013; **121**(3): 290 - 9.

67. Niyitegeka J, Nshimirimana G, Silverstein A, et al. Longer travel time to district hospital worsens neonatal outcomes: a retrospective cross-sectional study of the effect of delays in receiving emergency cesarean section in Rwanda. *BMC Pregnancy and Childbirth* 2017: 1 - 10.
68. Wong KLM, Benova L, Campbell OMR. A look back on how far to walk: Systematic review and meta-analysis of physical access to skilled care for childbirth in Sub-Saharan Africa. *PLoS ONE* 2017; **12**(9): e0184432 - 20.
69. Dare AJ, Ng-Kamstra JS, Patra J, et al. Deaths from acute abdominal conditions and geographical access to surgical care in India: a nationally representative spatial analysis. *Lancet Global Heal* 2015; **3**(10): e646-e53.
70. Macharia PM, Odera PA, Snow RW, Noor AM. Spatial models for the rational allocation of routinely distributed bed nets to public health facilities in Western Kenya. *Malaria Journal* 2017; **16**(1): 1 - 11.
71. Robin TA, Khan MA, Kabir N, et al. Using spatial analysis and GIS to improve planning and resource allocation in a rural district of Bangladesh. *BMJ Global Health* 2019; **4**(Suppl 5): e000832 - 9.
72. Patel AB, Waters NM, Blanchard IE, Doig CJ, Ghali WA. A validation of ground ambulance pre-hospital times modeled using geographic information systems. *Int J Health Geogr* 2012; **11**(1): 42.
73. Haynes R, Jones AP, Sauerzapf V, Zhao H. Validation of travel times to hospital estimated by GIS. *Int J Health Geogr* 2006; **5**(1): 40.
74. Davis JL, Handley MA, Haguma P, et al. Investigating Barriers to Tuberculosis Evaluation in Uganda Using Geographic Information Systems. *The American Journal of Tropical Medicine and Hygiene* 2015; **93**(4): 733 - 8.
75. Gething PW, Johnson FA, Frempong-Ainguah F, et al. Geographical access to care at birth in Ghana: a barrier to safe motherhood. *BMC Public Health* 2012; **12**(1): 1 -
76. Hirose A, Borchert M, Cox J, Alkozai AS, Filippi V. Determinants of delays in travelling to an emergency obstetric care facility in Herat, Afghanistan: an analysis of cross-sectional survey data and spatial modelling. *BMC Pregnancy and Childbirth* 2015; **15**(1): 14.
77. WHO. WHO Situational Assessment Tool. https://cdn.who.int/media/docs/default-source/integrated-health-services-(ihs)/csy/surgical-care/who_surgical_assessment_tool.pdf?sfvrsn=739788e4_7&Status=Master.
78. Program in Global Surgery and Social Change. PGSSC Surgical Assessment Tool (SAT). https://www.pgssc.org/_files/ugd/d9a674_f2b179abea9e4b0a9a103fbe93ac6479.pdf.

79. Lin Y, Raykar NP, Saluja S, et al. Identifying essential components of surgical care delivery through quality improvement: An updated surgical assessment tool. *Int J Surg* 2020; **82**: 103-7.

80. Markin A, Barbero R, Leow JJ, et al. Inter-Rater Reliability of the PIPES Tool: Validation of a Surgical Capacity Index for Use in Resource-Limited Settings. *World J Surg* 2014; **38**(9): 2195-9.

81. NIHR Global Health Unit on Global Surgery, COVIDsurg collaborative. Elective surgery system strengthening: development, measurement, and validation of the surgical preparedness index across 1632 hospitals in 119 countries. *The Lancet* 2022; **400**(10363): 1607-17.

82. WHO. WHO Surgical and Anesthesia Care Global Database. https://www.who.int/teams/integrated-health-services/clinical-services-and-systems/surgical-care/research.

83. Iverson KR, Ahearn O, Citron I, et al. Development of a surgical assessment tool for national policy monitoring & evaluation in Ethiopia: A quality improvement study. *Int J Surg* 2020; **80**: 231-40.

84. Kaji A, Koenig KL, Bey T. Surge Capacity for Healthcare Systems: A Conceptual Framework. *Acad Emerg Med* 2006; **13**(11): 1157-9.

85. PIH's Five S's: Essential Elements for Strong Health Systems. 2021. https://www.pih.org/article/pihs-five-ss-essential-elements-strong-health-systems.

86. Knight SR, Shaw CA, Pius R, et al. Effects of hospital facilities on patient outcomes after cancer surgery: an international, prospective, observational study. *Lancet Global Heal* 2022; **10**(7): e1003-e11.

87. O'Neill KM, Greenberg SLM, Cherian M, et al. Bellwether Procedures for Monitoring and Planning Essential Surgical Care in Low- and Middle-Income Countries: Caesarean Delivery, Laparotomy, and Treatment of Open Fractures. *World J Surg* 2016; **40**(11): 2611-9.

88. Odland ML, Nepogodiev D, Morton D, et al. Identifying a Basket of Surgical Procedures to Standardize Global Surgical Metrics. *Ann Surg* 2021; **274**(6): 1107-14.

89. Weiser TG. Bellwethers versus Baskets: Operative Capacity and the Metrics of Global Surgery. *World J Surg* 2020; **44**(10): 3310-1.

90. WHO. Global strategy on human resources for health: workforce 2030. Geneva, Switzerland: The World Health Organisation, 2016.

91. WHO. No Health Without a Workforce, 2014.

92. Holmer H, Lantz A, Kunjumen T, et al. Global distribution of surgeons, anaesthesiologists, and obstetricians. *Lancet Glob Health* 2015; **3 Suppl 2**(S2): S9-11.

93. GBD Human Resources for Health Collaborators, Haakenstad A, Irvine CMS, et al. Measuring the availability of human resources for health and its relationship to universal health coverage for 204 countries and territories from 1990 to 2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* 2022; **399**(10341): 2129-54.

94. Ozgediz D, Galukande M, Mabweijano J, et al. The Neglect of the Global Surgical Workforce: Experience and Evidence from Uganda. *World J Surg* 2008; **32**(6): 1208-15.

95. O'Flynn E, Andrew J, Hutch A, et al. The Specialist Surgeon Workforce in East, Central and Southern Africa: A Situation Analysis. *World J Surg* 2016; **40**(11): 2620-7.

96. Dewan MC, Rattani A, Fieggen G, et al. Global neurosurgery: the current capacity and deficit in the provision of essential neurosurgical care. Executive Summary of the Global Neurosurgery Initiative at the Program in Global Surgery and Social Change. *J Neurosurg* 2019; **130**(4): 1055-64.

97. Silverstein J. Most of the World Doesn't Have Access to X-Rays. The Atlantic. 2016-07-16.

98. Mullan F, Frehywot S, Omaswa F, et al. Medical schools in sub-Saharan Africa. *The Lancet* 2011; **377**(9771): 1113-21.

99. Henry JA, Frenkel E, Borgstein E, Mkandawire N, Goddia C. Surgical and anaesthetic capacity of hospitals in Malawi: key insights. *Health Policy and Planning* 2015; **30**(8): 985-94.

100. Qureshi JS, Young S, Muyco AP, et al. Addressing Malawi's surgical workforce crisis: A sustainable paradigm for training and collaboration in Africa. *Surgery* 2013; **153**(2): 272-81.

101. Pollock JD, Love TP, Steffes BC, Thompson DC, Mellinger J, Haisch C. Is it Possible to Train Surgeons for Rural Africa? A Report of a Successful International Program. *World J Surg* 2011; **35**(3): 493-9.

102. Ozgediz D, Kijjambu S, Galukande M, et al. Africa's neglected surgical workforce crisis. *Lancet* 2008; **371**: 627-8.

103. Shrime MG, Verguet S, Johansson KA, Desalegn D, Jamison DT, Kruk ME. Task-sharing or public finance for the expansion of surgical access in rural Ethiopia: an extended cost-effectiveness analysis. *Health Policy Plan* 2016; **31**(6): 706-16.

104. Federspiel F, Mukhopadhyay S, Milsom PJ, Scott JW, Riesel JN, Meara JG. Global surgical, obstetric, and anesthetic task shifting: A systematic literature review. *Surgery* 2018; **164**(3): 553-8.

105. Aluttis C, Bishaw T, Frank MW. The workforce for health in a globalized context – global shortages and international migration. *Global Health Action* 2014; 7(1): 23611.

106. Hagopian A, Thompson MJ, Fordyce M, Johnson KE, Hart LG. The migration of physicians from sub-Saharan Africa to the United States of America: measures of the African brain drain. *Hum Resour Health* 2004; **2**(1): 17.

107. Hagander LE, Hughes CD, Nash K, Ganjawalla K. Surgeon migration between developing countries and the United States: train, retain, and gain from brain drain. *World J Surg* 2013: 37:14–23.

108. Botezat A, Ramos R. Physicians' brain drain - a gravity model of migration flows. *Globalization Health* 2020; **16**(1): 7.

109. Taylor AL, Dhillon IS. The WHO Global Code of Practice on the International Recruitment of Health Personnel: The Evolution of Global Health Diplomacy. *Global Health Governance* 2011.

110. Tankwanchi ABS, Vermund SH, Perkins DD. Monitoring Sub-Saharan African Physician Migration and Recruitment Post-Adoption of the WHO Code of Practice: Temporal and Geographic Patterns in the United States. *PLoS ONE* 2015; **10**(4): e0124734.

111. WHO. User's Guide: The WHO Global Code of Practice on the International Recruitment of Health Personnel: The World Health Organisation, 2010.

112. Siyam A, Zurn P, Rø OC, et al. Monitoring the implementation of the WHO Global Code of Practice on the International Recruitment of Health Personnel. *Bulletin of the World Health Organization* 2013; **91**(11): 816-23.

113. Mullan F. The Metrics of the Physician Brain Drain. *New Engl J Medicine* 2005; **353**(17): 1810-8.

114. OECD. Policy Brief: International Migration of Health Workers, 2010.

115. Lantz A, Holmer H, Finlayson SRG, et al. Measuring the migration of surgical specialists. *Surgery* 2020; **168**(3): 550-7.

116. Saluja S, Rudolfson N, Massenburg BB, Meara JG, Shrime MG. The impact of physician migration on mortality in low and middle-income countries: an economic modelling study. *BMJ Global Health* 2020; **5**(1): e001535 - 8.

117. Mills EJ, Kanters S, Hagopian A, et al. The financial cost of doctors emigrating from sub-Saharan Africa: human capital analysis. *BMJ* 2011; **343**(nov23 3): d7031.

118. Kirigia JM, Gbary AR, Nyoni J, Seddoh A, Muthuri LK. The cost of health-related brain drain to the WHO African Region. *Afr J Heal Sci* 2006; **13**(3): 1-12.

119. Tankwanchi AS, Hagopian A, Vermund SH. International migration of health labour: monitoring the two-way flow of physicians in South Africa. *BMJ Global Health* 2019; **4**(5): e001566 - 9.
120. Blacklock C, Heneghan C, Mant D, Ward AM. Effect of UK policy on medical migration: a time series analysis of physician registration data. *Hum Resour Health* 2012; **10**: 35.
121. Kruk ME, Gage AD, Arsenault C, et al. High-quality health systems in the Sustainable Development Goals era: time for a revolution. *Lancet Global Heal* 2018; **6**(11): e1196-e252.
122. Kruk ME, Gage AD, Joseph NT, Danaei G, García-Saisó S, Salomon JA. Mortality due to low-quality health systems in the universal health coverage era: a systematic analysis of amenable deaths in 137 countries. *The Lancet* 2018; **392**(10160): 2203-12.
123. Leslie HH, Malata A, Ndiaye Y, Kruk ME. Effective coverage of primary care services in eight high-mortality countries. *BMJ Global Health* 2017; **2**(3): e000424 - 12.
124. Starr N, Capo-Chichi N, Moore J, et al. Perioperative Provider Safety in Low- and Middle-income Countries During the COVID-19 Pandemic. *Ann Surg* 2021; **274**(6): e525-e627.
125. Ng M, Misra A, Diwan V, Agnani M, Levin-Rector A, Costa AD. An assessment of the impact of the JSY cash transfer program on maternal mortality reduction in Madhya Pradesh, India. *Global Health Action* 2014; **7**(1): 24939.
126. Semrau KEA, Hirschhorn LR, Delaney MM, et al. Outcomes of a Coaching-Based WHO Safe Childbirth Checklist Program in India. *New Engl J Medicine* 2017; **377**(24): 2313-24.
127. Donaldson MS. Measuring the Quality of Health Care: The National Roundtable on Health Care Quality, Institute of Medicine, 1990.
128. Leatherman S, Ferris TG, Berwick D, Omaswa F, Crisp N. The role of quality improvement in strengthening health systems in developing countries. *International Journal for Quality in Health Care* 2010; **22**(4): 237 - 43.
129. Nepogodiev D, Martin J, Biccard B, et al. Global burden of postoperative death. *The Lancet* 2019; **393**(10170): 401 - 1.
130. GlobalSurg Collaborative. Mortality of emergency abdominal surgery in high-, middle- and low-income countries. *Brit J Surg* 2016; **103**(8): 971-88.
131. Biccard BM, Kluyts H-L, Munlemvo DM, et al. Perioperative patient outcomes in the African Surgical Outcomes Study: a 7-day prospective observational cohort study. *The Lancet* 2018; **391**(10130): 1589 - 98.

132. Bishop D, Dyer RA, Maswime S, et al. Maternal and neonatal outcomes after caesarean delivery in the African Surgical Outcomes Study: a 7-day prospective observational cohort study. *Lancet Global Heal* 2019; 7(4): e513-e22.

133. Sobhy S, Arroyo-Manzano D, Murugesu N, et al. Maternal and perinatal mortality and complications associated with caesarean section in low-income and middle-income countries: a systematic review and meta-analysis. *The Lancet* 2019; **393**(10184): 1973-82.

134. Ng-Kamstra JS, Arya S, Greenberg SLM, et al. Perioperative mortality rates in low-income and middle-income countries: a systematic review and meta-analysis. *BMJ Global Health* 2018; **3**(3): e000810 - 12.

135. Felizaire M-R, Paradis T, Beckett A, et al. Perioperative Mortality Rates as a Health Metric for Acute Abdominal Surgery in Low- and Middle-Income Countries: A Systematic Review and Future Recommendations. *World J Surg* 2019; **43**(8): 1880 - 9.

136. Ariyaratnam R, Palmqvist CL, Hider P, et al. Toward a standard approach to measurement and reporting of perioperative mortality rate as a global indicator for surgery. *Surgery* 2015; **158**(1): 17-26.

137. Badia JM, Casey AL, Petrosillo N, Hudson PM, Mitchell SA, Crosby C. Impact of surgical site infection on healthcare costs and patient outcomes: a systematic review in six European countries. *Journal of Hospital Infection* 2017; **96**(1): 1 - 15.

138. Allegranzi B, Nejad SB, Combescure C, et al. Burden of endemic health-care-associated infection in developing countries: systematic review and meta-analysis. *The Lancet* 2011; **377**(9761): 228 - 41.

139. WHO. Report on the Burden of Endemic Health Care-Associated Infection Worldwide: WHO, 2011.

140. GlobalSurg Collaborative. Surgical site infection after gastrointestinal surgery in high-income, middle-income, and low-income countries: a prospective, international, multicentre cohort study. *Lancet Infect Dis* 2018; **18**(5).

141. Sway A, Nthumba P, Solomkin J, et al. Burden of surgical site infection following cesarean section in sub-Saharan Africa: a narrative review. *Int J Womens Health* 2019; **Volume 11**: 309 - 18.

142. 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* 2014; **39**(2): 350 - 5.

143. Nkurunziza T, Kateera F, Sonderman K, et al. Prevalence and predictors of surgical-site infection after caesarean section at a rural district hospital in Rwanda. *Br J Surg* 2019; **106**(2): e121 - e8.

144. Brima N, Morhason-Bello IO, Charles V, Davies J, Leather AJM. Improving quality of surgical and anaesthesia care in sub-Saharan Africa: a systematic review of hospital-based quality improvement interventions. *BMJ Open* 2022; **12**(10): e062616.

145. Allegranzi B, Aiken AM, Kubilay NZ, et al. A multimodal infection control and patient safety intervention to reduce surgical site infections in Africa: a multicentre, before-after, cohort study. *Lancet Infect Dis* 2018; **18**(5): 507 - 15.

146. Forrester JA, Starr N, Negussie T, et al. Clean Cut (adaptive, multimodal surgical infection prevention programme) for low-resource settings: a prospective quality improvement study. *Brit J Surg* 2020; **108**(6): 727-34.

147. Biccard BM, Toit Ld, Lesosky M, et al. Enhanced postoperative surveillance versus standard of care to reduce mortality among adult surgical patients in Africa (ASOS-2): a cluster-randomised controlled trial. *Lancet Global Heal* 2021; **9**(10): e1391-e401.

148. Oodit R, Biccard BM, Panieri E, et al. Guidelines for Perioperative Care in Elective Abdominal and Pelvic Surgery at Primary and Secondary Hospitals in Low-Middle-Income Countries (LMIC's): Enhanced Recovery After Surgery (ERAS) Society Recommendation. *World J Surg* 2022; **46**(8): 1826-43.

149. Santhirapala V, Peden CJ, Meara JG, et al. Towards high-quality peri-operative care: a global perspective. *Anaesthesia* 2020; **75 Suppl 1**: e18-e27.

150. Powell BL, Nkurunziza T, Kateera F, et al. Synthesizing postpartum care pathways, facilitators, and barriers for women after cesarean section: a qualitative analysis from rural Rwanda. *J Global Heal Reports* 2021; **5**.

151. Matousek A, Paik K, Winkler E, et al. Community health workers and smartphones for the detection of surgical site infections in rural Haiti: a pilot study. *Lancet* 2015; **385 Suppl 2**: S47.

152. Sonderman KA, Nkurunziza T, Kateera F, et al. Using mobile health technology and community health workers to identify and refer caesarean-related surgical site infections in rural Rwanda: a randomised controlled trial protocol. *BMJ Open* 2018; **8**(5): e022214.

153. Kateera F, Riviello R, Goodman A, et al. The Effect and Feasibility of mHealth-Supported Surgical Site Infection Diagnosis by Community Health Workers After Cesarean Section in Rural Rwanda: Randomized Controlled Trial. *Jmir Mhealth Uhealth* 2022; **10**(6): e35155.

154. Shrime MG, Dare AJ, Alkire BC, O'Neill K, Meara JG. Catastrophic expenditure to pay for surgery worldwide: a modelling study. *Lancet Global Heal* 2015; **3**: S38 - S44.

155. Boerma T, Eozenou P, Evans D, Evans T, Kieny M-P, Wagstaff A. Monitoring Progress towards Universal Health Coverage at Country and Global Levels. *PLoS Med* 2014; **11**(9): e1001731 - 8.
156. Arsenault C, Fournier P, Philibert A, et al. Emergency obstetric care in Mali: catastrophic spending and its impoverishing effects on households. *Bulletin of the World Health Organization* 2013; **91**(3): 207-16.
157. Xu K, Evans DB, Kadama P, et al. Understanding the impact of eliminating user fees: Utilization and catastrophic health expenditures in Uganda. *Soc Sci Med* 2006; **62**(4): 866-76.
158. Laokri S, Soelaeman R, Hotchkiss DR. Assessing out-of-pocket expenditures for primary health care: how responsive is the Democratic Republic of Congo health system to providing financial risk protection? *Bmc Health Serv Res* 2018; **18**(1): 451.
159. Shrime MG, Hamer M, Mukhopadhyay S, et al. Effect of removing the barrier of transportation costs on surgical utilisation in Guinea, Madagascar and the Republic of Congo. *BMJ Global Health* 2017; **2**(Suppl 4): e000434.
160. Sood N, Wagner Z. Social health insurance for the poor: lessons from a health insurance programme in Karnataka, India. *BMJ Global Health* 2018; **3**(1): e000582.
161. Kabia E, Goodman C, Balabanova D, Muraya K, Molyneux S, Barasa E. The hidden financial burden of healthcare: a systematic literature review of informal payments in Sub-Saharan Africa. *Wellcome Open Res* 2021; **6**: 297.
162. Anderson GA, Ilcisin L, Kayima P, et al. Out-of-pocket payment for surgery in Uganda: The rate of impoverishing and catastrophic expenditure at a government hospital. *PLoS ONE* 2017; **12**(10): e0187293.
163. Shrime MG, Sekidde S, Linden A, Cohen JL, Weinstein MC, Salomon JA. Sustainable Development in Surgery: The Health, Poverty, and Equity Impacts of Charitable Surgery in Uganda. *PLoS ONE* 2016; **11**(12): e0168867.
164. Rickard JL, Ngarambe C, Ndayizeye L, Smart B, Majyambere JP, Riviello R. Risk of Catastrophic Health Expenditure in Rwandan Surgical Patients with Peritonitis. *World J Surg* 2018; **42**(6): 1603 - 9.
165. Nguyen H, Ivers R, Jan S, Pham C. Cost of surgery and catastrophic expenditure in people admitted to hospital for injuries: estimates from a cohort study in Vietnam. *The Lancet* 2015; **385**: S50.
166. Ntambue AM, Malonga FK, Cowgill KD, Dramaix-Wilmet M, Donnen P. Incidence of catastrophic expenditures linked to obstetric and neonatal care at 92 facilities in Lubumbashi, Democratic Republic of the Congo, 2015. *BMC Public Health* 2019; **19**(1): 948.

167. Chemouni B. The political path to universal health coverage: Power, ideas and community-based health insurance in Rwanda. *World Development* 2018; **106**: 87-98.
168. Koch R, Nkurunziza T, Rudolfson N, et al. Does community-based health insurance protect women from financial catastrophe after cesarean section? A prospective study from a rural hospital in Rwanda. *Bmc Health Serv Res* 2022; **22**(1): 717.
169. Bloom DE, Canning D, Jamison DT. Health, Wealth, and Welfare. *Finance & Development* 2004.
170. Bloom DE. The Global Economic Burden of Non-communicable Diseases, 2011.
171. Bloom DE, Canning D. The Health and Wealth of Nations. *Science* 2000.
172. Bloom DE, Fink G. The economic case for devoting public resources to health, 2013.
173. WHO. Macroeconomics and health: investing in health for economic development, 2001.
174. WHO Commission on Macroeconomics and Health: Working Group 1. Health, Economic Growth, and Poverty Reduction, 2002.
175. Bhargava A, Jamison DT, Lau LJ, Murray CJL. Modeling the effects of health on economic growth. *J Health Econ* 2001; **20**(3): 423-40.
176. Jamison DT, Summers LH, Alleyne G, et al. Global health 2035: a world converging within a generation. *The Lancet* 2013; **382**(9908): 1898-955.
177. Appendix 2 to Global Health 2035: A world Converging within a Generation: Summary of the Evidence on the Association Between Health and Income. *The Lancet* 2013.
178. WHO. World Health Report 1999: Making a Difference, 1999.
179. Fan VY, Bloom DE, Ogbuoji O, Prettner K, Yamey G. Valuing health as development: going beyond gross domestic product. *BMJ* 2018; **363**: k4371.
180. Kennedy RF. Remarks at the University of Kansas, March 18, 1968.
181. United Nations Development Programme. Human Development Report 2021/2022, 2022.
182. Sachs JD, Lafortune G, Kroll C, Fuller G, Woelm F. Sustainable Development Report 2022. From Crisis to Sustainable Development: the SDGs as a Roadmap to 2030 and Beyond, 2022.
183. Usher D. An Imputation to the Measure of Economic Growth for Changes in Life Expectancy. 1973: 193 - 232.

184. Alkire B, Hughes CD, Nash K, Vincent JR, Meara JG. Potential economic benefit of cleft lip and palate repair in sub-Saharan Africa. *World J Surg* 2011; **35**(6): 1194-201.

185. Alkire BC, Vincent JR, Burns CT, Metzler IS, Farmer PE, Meara JG. Obstructed labor and caesarean delivery: the cost and benefit of surgical intervention. *PLoS ONE* 2012; 7(4): e34595.

186. Warf BC, Alkire BC, Bhai S, et al. Costs and benefits of neurosurgical intervention for infant hydrocephalus in sub-Saharan Africa: Clinical article. *J Neurosurg Pediatrics* 2011; **8**(5): 509-21.

187. Abegunde DO, Mathers CD, Adam T, Ortegon M, Strong K. The burden and costs of chronic diseases in low-income and middle-income countries. *The Lancet* 2007; **370**(9603): 1929-38.

188. Abegunde D, Stanciole A. An estimation of the economic impact of chronic noncommunicable diseases in selected countries: World Health Organization, 2006.

189. Alkire BC, Peters AW, Shrime MG, Meara JG. The Economic Consequences Of Mortality Amenable To High-Quality Health Care In Low- And Middle-Income Countries. *Health Affairs* 2018; **37**(6): 988 - 96.

190. Alkire BC, Shrime MG, Dare AJ, Vincent JR, Meara JG. Global economic consequences of selected surgical diseases: a modelling study. *Lancet Glob Health* 2015; **3 Suppl 2**: S21-7.

191. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009; **42**(2): 377-81.

192. Program in Global Surgery and Social Change. National Surgical, Obstetric and Anaesthesia Planning (NSOAP) Surgical Indicators - Financial Risk Protection Survey. https://www.pgssc.org/_files/ugd/d9a674_8da150554fe348f4bfcba71613faad9d.pdf.

193. OpenStreetMap contributors. OpenStreetMap. www.openstreetmap.org.

194. Global Administrative Areas database. www.gadm.org.

195. National Institute of Statistics Rwanda. https://www.statistics.gov.rw/data-portals.

196. Lantz A, Holmer H, Finlayson S, et al. International migration of surgeons, anaesthesiologists, and obstetricians. *Lancet Glob Health* 2015; **3 Suppl 2**: S11-2.

197. Thoma A, Khuthaila D, Rockwell G, Veltri K. Cost-utility analysis comparing free and pedicled TRAM flap for breast reconstruction. *Microsurgery* 2003; **23**(4): 287 - 95.

198. Gheorghe A, Moran G, Duffy H, Roberts T, Pinkney T, Calvert M. Health Utility Values Associated with Surgical Site Infection: A Systematic Review. *Value in Health* 2015; **18**(8): 1126-37.
199. Martin E. A Cost-effectiviness Modelling Study of Strategies to Prevent Post-Caesarean Surgical Site Infeciont: Queensland University of Technology; 2017.
200. WHO. Global Health Observatory. https://www.who.int/data/gho.
201. Pardee Center for International Futures. International Futures. https://korbel.du.edu/pardee.
202. Groningen Growth and Development Centre. Penn World Tables. https://febpwt.webhosting.rug.nl.
203. International Labor Organization. ILOSTAT. https://ilostat.ilo.org.
204. UN Department of Economic and Social Affairs. World Population Prospects. https://population.un.org/wpp/.
205. Xu K, Evans DB, Kawabata K, Zeramdini R, Klavus J, Murray CJL. Household catastrophic health expenditure: a multicountry analysis. *The Lancet* 2003; **362**(9378): 111 - 7.
206. Wagstaff A, Flores G, Hsu J, et al. Progress on catastrophic health spending in 133 countries: a retrospective observational study. *Lancet Global Heal* 2018; **6**(2): e169 - e79.
207. Rios-Diaz AJ, Lam J, Ramos MS, et al. Global Patterns of QALY and DALY Use in Surgical Cost-Utility Analyses: A Systematic Review. *PLoS ONE* 2016; **11**(2): e0148304.
208. WHO. WHO Guide to Cost-Effectiveness Analysis. 2003: 1 - 329.
209. Sassi F. Calculating QALYs, comparing QALY and DALY calculations. *Health Policy and Planning* 2006; **21**(5): 402 - 8.
210. Gräler B, Pebesma E, Heuvelink G. Spatio-Temporal Interpolation using gstat. *The R Journal* 2016.
211. Cobb CW, Douglas PH. A Theory of Production. *American Economic Review* 1928; (18): 139-65.
212. Kniesner TJ, Viscusi WK. Oxford Research Encyclopedia of Economics and Finance. 2019.
213. Aldy JE, Viscusi WK. Adjusting the Value of a Statistical Life for Age and Cohort Effects. *Rev Econ Stat* 2008; **90**(3): 573-81.
214. Viscusi WK, Gayer T. Chapter 20 Quantifying and Valuing Environmental Health Risks. *Handb Environ Econ* 2005; **2**: 1029-103.
215. Viscusi WK, Aldy JE. The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. *J Risk Uncertainty* 2003; **27**(1): 5-76.

216. Hammitt JK. Valuing Changes in Mortality Risk: Lives Saved Versus Life Years Saved. *Rev Env Econ Policy* 2007; **1**(2): 228-40.

217. Robinson LA, Hammitt JK, O'Keeffe L. Valuing Mortality Risk Reductions in Global Benefit-Cost Analysis. *Journal of Benefit-Cost Analysis* 2019; **10**(S1): 15-50.

218. Robinson LA, Hammitt JK, Jamison DT, Walker DG. Conducting Benefit-Cost Analysis in Low- and Middle-Income Countries: Introduction to the Special Issue. *Journal of Benefit-Cost Analysis* 2019; **10**(S1): 1 - 14.

219. OECD. Mortality Risk Valuation in Environment, Health and Transport Policies. 2012.

220. Hammitt JK, Robinson LA. The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations. *Journal of Benefit-Cost Analysis* 2011; **2**(1): 1-29.

221. Viscusi W, Masterman C. Income Elasticities and global values of a statistical life. *J Benefit Cost Anal* 2017; **8**: 226-50.

222. Masterman C, Viscusi W. The income elasticity of global values

of a statistical life: stated preference evidence. *J Benefit Cost Anal* 2018; **9**: 407–34.

223. Kneisner T, Viscusi W. Policy relevant heterogeneity in the value

of statistical life: new evidence from panel data Quantile regressions. *Center for Policy Research* 2009; **48**.

224. WHO. Global status report on road safety 2013: supporting a decade of action, 2013.

225. Weiser TG, Regenbogen SE, Thompson KD, et al. An estimation of the global volume of surgery: a modelling strategy based on available data. *The Lancet* 2008; **372**(9633): 139-44.

226. Larsson J, Gustafsson P. A case study in fitting area-proportional euler diagrams with ellipses using eulerr. *Plos One* 2018; **2116**(7): 84 – 91.

227. R Core Team. R: A Language and Environment for Statistical Computing. 2021.

228. Microsoft Corporation. Excel. Redmond, WA, USA.

229. StataCorp. Stata. College Station, TX, USA.

230. Wickham H, Averick M, Bryan J, et al. Welcome to the tidyverse. *Journal of Open Source Software* 2019; **4**(43): 1686.

231. Comtois D. summarytools: Tools to Quickly and Neatly Summarize Data. 2021.

232. Tierney N, Cook D, McBain M, Fay C. naniar: Data Structures, Summaries, and Visualisations for Missing Data. 2021.

233. Robinson D. fuzzyjoin: Join Tables Together on Inexact Matching. 2020.

234. Grolemund G, Wickham H. Dates and Times Made Easy with lubridate. *Journal of Statistical Software* 2011; **40**(3): 1-25.
235. Elbers B. tidylog: Logging for 'dplyr' and 'tidyr' Functions. 2020.
236. Wickham H, Bryan J. readxl: Read Excel Files. 2019.
237. Robinson D, Hayes A, Couch S. broom: Convert Statistical Objects into Tidy Tibbles. 2022.
238. Xie Y. Dynamic Documents with R and knitr. 2015.
239. Zhu H. kableExtra: Construct Complex Table with 'kable' and Pipe Syntax. 2021.
240. Lüdecke D. sjPlot: Data Visualization for Statistics in Social Science. 2022.
241. Hugh-Jones D. huxtable: Easily Create and Style Tables for LaTeX, HTML and Other Formats. 2022.
242. Yoshida K, Bartel A. tableone: Create 'Table 1' to Describe Baseline Characteristics with or without Propensity Score Weights. 2021.
243. Pedersen TL. patchwork: The Composer of Plots. 2022.
244. Slowikowski K. ggrepel: Automatically Position Non-Overlapping Text Labels with 'ggplot2'. 2021.
245. Hijmans RJ. raster: Geographic Data Analysis and Modeling. 2022.
246. Pebesma E. Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal* 2018; **10**(1): 439-46.
247. Bivand RS, Pebesma E, Gomez-Rubio V. Applied spatial data analysis with R, Second edition. 2013.
248. Appelhans T, Detsch F, Reudenbach C, Woellauer S. mapview: Interactive Viewing of Spatial Data in R. 2022.
249. Tennekes M. tmap: Thematic Maps in R. *Journal of Statistical Software* 2018; **84**(6): 1-39.
250. Müller K. here: A Simpler Way to Find Your Files. 2020.
251. Arel-Bundock V, Enevoldsen N, Yetman CJ. countrycode: An R package to convert country names and country codes. *Journal of Open Source Software* 2018; **3**(28): 848.
252. Bache SM, Wickham H. magrittr: A Forward-Pipe Operator for R. 2020.
253. Csárdi G, FitzJohn R. progress: Terminal Progress Bars. 2019.
254. Dorai-Raj S. binom: Binomial Confidence Intervals For Several Parameterizations. 2014.
255. Schliep K, Hechenbichler K. kknn: Weighted k-Nearest Neighbors. 2016.

256. Ray N, Ebener S. AccessMod 3.0: computing geographic coverage and accessibility to health care services using anisotropic movement of patients. *Int J Health Geogr* 2008; 7(1): 63 - 17.

257. Bouanchaud P, Macharia PM, Demise EG, et al. Comparing modelled with self-reported travel time and the used versus the nearest facility: modelling geographic accessibility to family planning outlets in Kenya. *BMJ Global Health* 2022; 7(5): e008366.

258. Whitaker J, Brunelli G, Boeckel TPV, et al. Access to care following injury in Northern Malawi, a comparison of travel time estimates between Geographic Information System and community household reports. *Inj* 2022; **53**(5): 1690-8.

259. Banke-Thomas A, Wong KLM, Ayomoh FI, Giwa-Ayedun RO, Benova L. "In cities, it's not far, but it takes long": comparing estimated and replicated travel times to reach life-saving obstetric care in Lagos, Nigeria. *BMJ Global Health* 2021; **6**(1): e004318.

260. Duinen AJv, Adde HA, Fredin O, et al. Travel time and perinatal mortality after emergency caesarean sections: an evaluation of the 2-hour proximity indicator in Sierra Leone. *BMJ Global Health* 2020; **5**(12): e003943.

261. Adde HA, Duinen AJv, Andrews BC, et al. Mapping population access to essential surgical care in Liberia using equipment, personnel, and bellwether capability standards. *Brit J Surg* 2022.

262. Banke-Thomas A, Wong KL, Collins L, et al. An assessment of geographical access and factors influencing travel time to emergency obstetric care in the urban state of Lagos, Nigeria. *Health Policy and Planning* 2021; **36**(9): czab099-.

263. Rudolfson N, Gruendl M, Nkurunziza T, et al. Validating the Global Surgery Geographical Accessibility Indicator: Differences in Modeled Versus Patient-Reported Travel Times. *World J Surg* 2020; **44**(7): 2123 - 30.

264. Stewart J, Clark D, Clark PF. Migration and Recruitment of Healthcare Professionals: Causes, Consequences and Policy Responses. *Policy Brief Focus Migration* 2007; 7.

265. Padovany MMN, Patterson RH, Bowder AN, et al. Impact of out-of-pocket expenses for surgical care on households in rural Haiti: a mixed-methods study. *BMJ Open* 2022; **12**(5): e061731.

266. Naidu P, Ataguba JE, Shrime M, Alkire BC, Chu KM. Surgical Catastrophic Health Expenditure and Risk Factors for Out-of-Pocket Expenditure at a South African Public Sector Hospital. *World J Surg* 2022; **46**(4): 769-75.

267. Weiss DJ, Nelson A, Gibson HS, et al. A global map of travel time to cities to assess inequalities in accessibility in 2015. *Nature* 2018; **553**(7688): 333 - 6.

268. Weiss DJ, Nelson A, Vargas-Ruiz CA, et al. Global maps of travel time to healthcare facilities. *Nat Med* 2020; **26**(12): 1835-8.

269. Maina J, Ouma PO, Macharia PM, et al. A spatial database of health facilities managed by the public health sector in sub Saharan Africa. *Scientific Data* 2019: 1 - 8.

270. WHO. WHO Guidelines for Safe Surgery 2009: Safe Surgery Saves Lives, 2009.

271. Program in Global Surgery and Social Change. Strategic Plan 2021-2025. Boston, MA, USA.

272. Sonderman KA, Citron I, Meara JG. National Surgical, Obstetric, and Anesthesia Planning in the Context of Global Surgery: The Way Forward. *JAMA Surg* 2018; **153**(10): 959.

273. WHO. Surgical Care Systems Strengthening: Developing National Surgical, Obstetric and Anaesthesia Plans, 2017.

274. Citron I, Chokotho L, Lavy C. Prioritisation of Surgery in the National Health Strategic Plans of Africa: A Systematic Review. *World J Surg* 2016; **40**(4): 779-83.

Study I

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SURGERY IN LOW AND MIDDLE INCOME COUNTRIES

Validating the Global Surgery Geographical Accessibility Indicator: Differences in Modeled Versus Patient-Reported Travel Times

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Abstract

Background Since long travel times to reach health facilities are associated with worse outcomes, geographic accessibility is one of the six core global surgery indicators; this corresponds to the second of the "Three Delays Framework," namely "delay in reaching a health facility." Most attempts to estimate this indicator have been based on geographical information systems (GIS) algorithms. The aim of our study was to compare GIS derived estimates to self-reported travel times for patients traveling to a district hospital in rural Rwanda for emergency obstetric care.

Methods Our study includes 664 women who traveled to undergo a Cesarean delivery in Kirehe, Rwanda. We compared self-reported travel time from home to the hospital (excluding waiting time) with GIS estimated travel times, which were computed using the World Health Organization tool AccessMod, using linear regression.

Results The majority of patients used multiple modes of transportation (walking = 48.5%, public transport = 74.2%, private transport = 2.9%, and ambulance 70.6%). Self-reported times were longer than GIS estimates by a factor of 1.49 (95% CI 1.40–1.57). Concordance was higher when the GIS model took into account that all patients in Rwanda are referred via their health center ($\beta = 1.12$; 95% CI 1.05–1.18).

Conclusions To our knowledge, in this largest to date GIS validation study for geographical access to healthcare in low- and middle-income countries, a standard GIS model was found to significantly underestimate real travel time, which likely is in part because it does not model the actual route patients are travelling. Therefore, previous studies of 2-h access to surgery will need to be interpreted with caution, and future studies should take local travelling conditions into account.

Niclas Rudolfson and Magdalena Gruendl are co-first authors.

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Introduction

Surgical conditions account for approximately 30% of the global burden of disease, yet 5 billion people lack access to safe, affordable, and timely surgical and anesthesia care [1]. In 2015, The Lancet Commission on Global Surgery recommended six key indicators to assess and track progress of access to surgical services and outcomes. These core indicators measure provider density, operative volume, surgical safety, and financial and geographical access [1].

This last indicator—geographical access—was defined by the Lancet Commission as the percentage of the population who can access, within 2 h, a facility capable of performing the three so-called bellwether procedures: Cesarean section (C section), laparotomy, and open fracture repair [2]. The 2-h cutoff point was chosen from its previously known marker as the critical time from postpartum hemorrhage to death if no intervention is provided [3]. Further, long travel times to reach surgical care including C sections are associated with worse outcomes [4–7]. Therefore, understanding gaps of access within a certain time frame to a facility would allow governments to have an evidence-based method for placement of surgical facilities and staff. This specifically addresses the second delay of the "Three Delays" framework, which outlines three time intervals before treatment is started, [1] delay in seeking care; [2] delay in reaching a health facility; and [3] delay in receiving care [8].

A challenge with the geographical access indicator has been finding high quality, systematic ways to measure it. The gold standard for reporting geographical access is measuring the actual time it takes for patients to travel to the nearest surgically capable hospital. This obviously requires extensive primary data collection, which is both cumbersome, and highly resource intensive, and therefore a significant barrier in low- and middle-income countries. Additionally, it risks missing those patients who needed surgical care but could not reach a hospital due to travel barriers. For this reason, geographic information system (GIS) models, which simulate travel along the road network of a country, have been the primary methodology used to quantify geographical access [9–16], and the results of such studies inform national health planning policy [17–19].

Two large studies in sub-Saharan Africa, which used GIS to model the access to emergency care [16] and to timely and essential surgical care [12], estimated that 71% and 92.5% of the population reside in areas within 2 h of a major hospital catchment, respectively. However, concerns have been raised that commonly employed GIS models underestimate actual travel times in low- and middle-income countries [9]. While GIS may accurately estimate patient travel times in high-income countries [20, 21], there is very limited data on validity of these models in low- and middle-income countries. Given this, the aim of our study was to compare GIS estimates to patient-reported travel times for patients travelling to a district hospital in rural Rwanda for emergency obstetric care.

Methods

Study setting

This study was conducted at Kirehe District Hospital (KDH), located in the Eastern Province, Rwanda. KDH—managed by the Rwandan Ministry of Health with support from Partners In Health/Inshuti Mu Buzima (PIH/IMB)—serves a catchment population of nearly 340,000 residents [22]. In Kirehe District, basic outpatient primary care is provided at 16 health centers, from which patients can be transferred to KDH for medical problems requiring hospital care. KDH provides basic secondary level care, including some minor surgical procedures and Cesarean deliveries. Patients needing more complex care are referred to tertiary facilities in Kigali, approximately 3 h away.

In Rwanda, 91% of women deliver in health facilities [23]. The majority of laboring women first seek care at their assigned health center. In cases of emergency, she is then transferred to the district hospital, often by ambulance, where a C section can be performed if needed.

Study sample, data sources, and data collection

All female patients 18 years or older, who were residents of Kirehe District and delivered via C section at KDH between June 2017 and January 2018 were eligible for inclusion.

Data collectors interviewed patients prior to discharge from the hospital to collect baseline demographic and economic data. Data were collected using REDCap [24], a secure, Web-based application designed to support data capture for research studies in areas with low connectivity, using Android tablets. The following data was gathered on study participants: the name of their home village, whether the patient went to a health center before going to the hospital, the mode of transport from their home to the health center and from the health center to the hospital, the duration of each leg of the journey, the wait time at the health center or hospital admission area, and the cost of the trip.

Study staff informed patients about the study and obtained written consent. Approvals were received from the Partners In Health/Inshuti Mu Buzima (PIH/IMB)

Research Committee and the Rwandan National Health Research Committee, and ethical approvals from the Rwanda National Ethics Committee (Kigali, Rwanda; no. 848/RNEC/2016) and Partners Human Research Committee (Boston, Massachusetts, USA; no. 2016P001943/MGH). The study was approved by the Rwandan Ministry of Health before the start of data collection.

GIS methodology

We reconciled patient-reported village names with official location names from the National Institute of Statistics Rwanda [25]. For each of the 612 villages in Kirehe District, we calculated the geographical centroid. Patients matched to that village were assumed to be starting their journey at this central location. The geographic boundaries of Rwandan villages were obtained from the Global Administrative Areas database [26].

GIS estimated travel times were computed using the WHO tool AccessMod, software version 5.0 [27]. AccessMod calculates the shortest possible travel time from every point in the analyzed region, taking travel speed into account. The region is discretized into cells, which are assigned a travel speed. The analysis was performed with a cell size of roughly 100 m. In order to emulate previous GIS studies [9, 13–16], roads were classified into primary, secondary, and tertiary roads, and the travel speed was assumed to be 100, 50, and 30 km/h, respectively. All remaining cells were set to a speed of 5 km/h (approximate walking speed), apart from those representing rivers or bodies of water, which were set as non-traversable. Data on the Rwandan road network, rivers, and bodies of water were obtained from OpenStreetMaps [28].

Two scenarios were calculated. In the first, patients were assumed to travel the most direct route possible from home to Kirehe District Hospital. We refer to this model as the "standard model" as this is the pathway patients are assumed to take in most studies that utilize GIS methodology. In the second, patients were assumed to first travel to their assigned health center, and then from the health center to the hospital, as this is the prescribed referral pattern in the Rwanda public health sector.

Statistical analysis

In our analyses, we compared patient-reported travel times to GIS estimated travel times. For patient-reported travel time, we only included time in transit (time from home to health center and health center to hospital) and did not include patient wait times at the health center or hospital. This method was chosen because it is most comparable to the GIS estimated travel times which would also not include any delays in the estimates.

We used univariable linear regression to compare patient-reported and GIS estimated travel times. We did not include an intercept in the regression specification. Maps were produced to illustrate patient-reported and GIS estimated travel times, using the raw output of the AccessMod tool and an interpolated surface of patient-reported travel times. The interpolation was produced using inverse distance weighting. All analyses were performed in R (version 3.4.1, R Foundation for Statistical Computation, Vienna, Austria).

Results

Demographics

A total of 664 women who underwent a C section at Kirehe District Hospital were included in the study. The location of the home village of included patients is displayed in Figure S1. We excluded three patients from analysis because their data were outliers deemed to be likely caused by data entry errors. The median age was 26 years (interquartile range (IQR): 23, 31 years), most had primary education (470 patients, 70.8%), and a monthly household monetary income of less than 10,000 Rwandan francs (approximately USD $12, 518 patients, 78.0%) (Table 1). The most common mode of transportation from home to the health center was public transport (477 patients, 71.8%) and walking (183 patients, 27.6%), with only a small fraction of patients reporting private transport or ambulance. Conversely, the most common form of transport from the health center to the hospital was the use of an ambulance (467 patients, 70.3%) and walking (164 patients, 24.4%). All patients who reported walking to the hospital came from the nearby Kirehe Health Center.

Travel time

The total transport time reported by patients, not including waiting at the health center, was longer than the time estimated by the standard AccessMod estimate (mean 88.3 and 47.7 min, respectively). In the linear regression analysis, the patient-reported estimate was 1.5 times greater than the AccessMod estimate [$\beta = 1.49$, 95% confidence interval (CI) 1.40, 1.57] (Figs. 1 and 2).

For the estimates that accounted for journeying via the assigned health center, the total AccessMod estimates were closer to travel times reported by patients (mean 62.3 min, $\beta = 1.12$; 95% CI 1.05, 1.18) (Fig. 3). The AccessMod slightly underestimated the patient-reported travel time for the home-to-health center leg, ($\beta = 0.89$; 95% CI 0.82, 0.97) and overestimated the patient-reported time from the

Table 1 Demographics of the study population

Variable	*n* (%)
n	664
Age [median (IQR)]	26 [23, 31]
Education level	
No education	59 (8.9)
Primary education	470 (70.8)
Secondary or higher education	135 (20.3)
Household monthly income	
0–10,000 Rwf	518 (78.0)
10,000–20,000 Rwf	69 (10.4)
20,000–30,000 Rwf	26 (3.9)
>30,000 Rwf	51 (7.7)
Modes of transportation used from home to health center[a]	
Walking	183 (27.6)
Public	477 (71.8)
Private	12 (1.8)
Ambulance	8 (1.2)
Modes of transportation used from health center to hospital[a]	
Walking	162 (24.4)
Public	36 (5.4)
Private	9 (1.4)
Ambulance	467 (70.3)

[a]Multiple answers were allowed

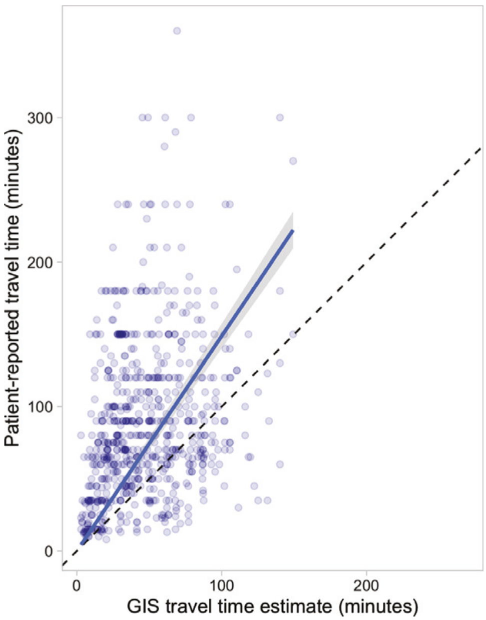

Fig. 1 Relationship between patient-reported and GIS estimated travel times in the standard GIS model. The dashed line represents equality between the two estimates, and the solid line linear regression

health center to the hospital ($\beta = 1.11$; 95% CI 1.04, 1.19] (Fig. 4).

Discussion

At a time when there is a global interest and movement in expanding surgical care in low- and middle-income countries, it is imperative that an accurate tool is accepted as a way to measure geographic access. GIS has readily been used in high-income countries to measure just this, but the utility in LMICs has largely been unknown. Our study found that the standard approach to estimate geographical accessibility underestimates the true patient experience, as the GIS estimated travel times were significantly lower than those reported by patients. Adjusting the model to account for the fact that patients access hospital care via the health center results in estimates considerably closer to the patient-reported travel time, although it should be noted that wait times to secure an ambulance at the health center to travel to the hospital were not included.

In high-income countries, validation studies have shown GIS to be a relatively accurate estimator of patient travel times in both elective and emergency cases. For example, a study of 475 cancer patients in the North of England demonstrated that 90% of travel time estimates were within 15 min, [20] and a study by Patel et al. [21] that looked at the ground ambulance pre-hospital times for emergency adult patient trips within the Calgary area, Canada found that GIS estimates were slightly underestimating real travel time. In LMICs, three small studies from Uganda, Ghana, and Afghanistan [29–31] have compared GIS estimates to patient-reported travel times, although none have used travel speed assumptions similar to those used in the global surgery literature. To our knowledge, ours is the largest to date validation of GIS modeling travel time in an LMIC and the first study to use AccessMod.

The results presented in this study pose important implications for further studies of the geographical access to surgery and emergency care. We found a standard GIS model to systematically underestimate travel time. There are several potential reasons for this discrepancy, including assumptions about travel speeds, modes of transport, and travel routes. Previous studies of 2-h access will need to be interpreted with caution, and in light of the local context. Decision makers will need to take this into account when planning the scale-up of surgical capacity, and it seems

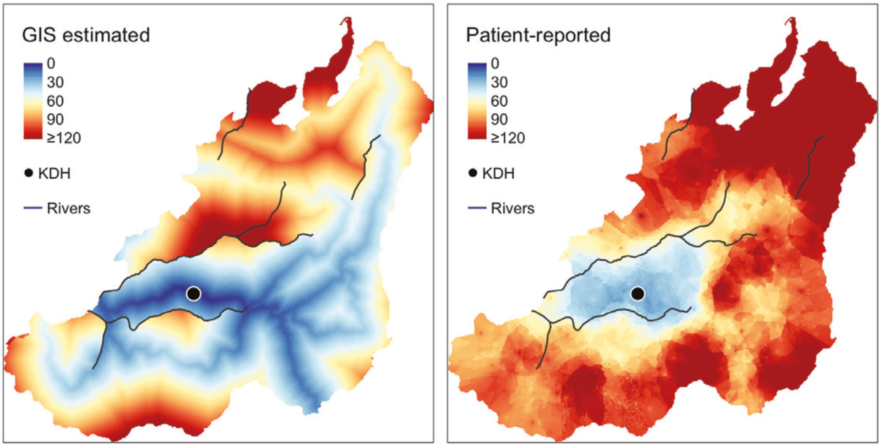

Fig. 2 Map comparison of GIS estimated and patient-reported travel times, time in minutes from home to the Kirehe District Hospital

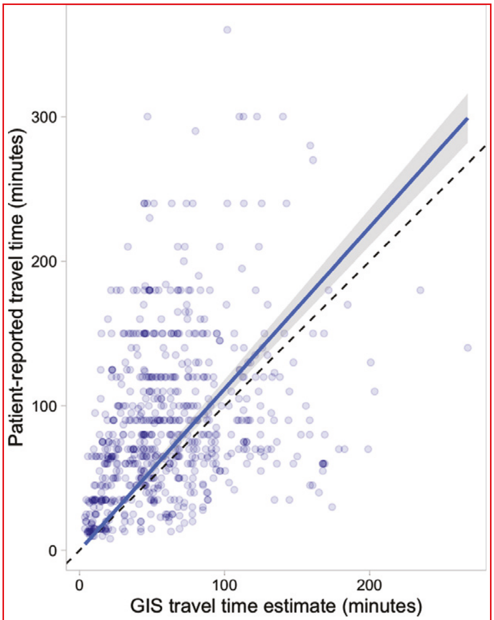

Fig. 3 Relationship between patient-reported and GIS estimated travel times when accounting for journeying via a Health Center in the GIS model. The dashed line represents equality, and the solid line linear regression

likely that previous estimates stating that 71–92% of the sub-Saharan population is able to reach emergency care within 2 h [13, 16] is overly optimistic. If patients cannot reach hospital care within 2 h when travelling via a health center, then policies requiring such stepwise referrals may need to be reconsidered. At the very least, in countries where this is the case, this additional delay will need to be accounted for in planning of infrastructure and deploying new capacity for surgical services to existing facilities. It should also be noted GIS only models one delay in reaching care, travelling to the hospital. Table 2 outlines the three delay framework, how it relates to GIS modeling, and some potential sources of error in GIS modeling.

The results of this study need to be interpreted in light of some limitations. Most importantly, the study only includes one district in Rwanda, and it is possible that GIS models would perform better or worse in different conditions based on infrastructure conditions, geographic topology, and various other factors. However, most of sub-Saharan Africa does require the health center-to-hospital referral for surgical care and we posit that the failure to account for this in model estimates will result in systematic underestimates even if the exact parameters are not generalizable. We note that we only modeled one set of travelling speed assumptions, chosen due to its predominance in the literature [9, 13–16] but that in theory a Rwanda-specific set of speeds could be generated and could yield more accurate results. Further, self-reported travel time may contain recall bias or rounding errors, but were collected within days of the trip.

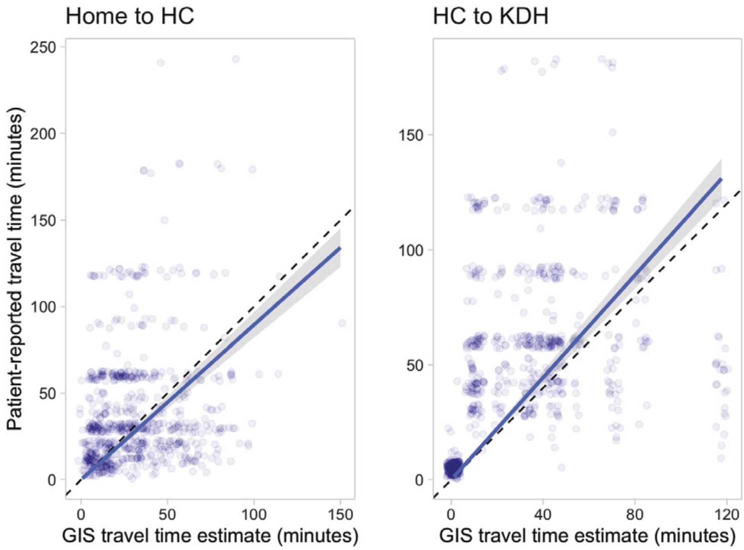

Fig. 4 Relationship between patient-reported and GIS estimated travel times, from home to the health center (left) and from the health center to Kirehe District Hospital (right). The dashed line represents equality, and the solid line linear regression. *HC* Health Center, *KDH* Kirehe District Hospital

Table 2 Assumptions of GIS calculations and the three delay framework, including factors which complicate modeling and examples of delays which current models generally do not account for

Assumption	Three Delay framework	Potential difficulties in measurement	Example of unaccounted delay
Patients will decide to seek care directly when need arises	First delay	Patient and disease specific	Securing funds for travel and/or care
Patients can start their travel right away	Second delay	Highly context and patient specific	Waiting for transport, e.g., ambulance or private
Patients can travel at declared speed	Second delay	Context specific	Poor road conditions, using slower modes of transport
Patients choose the fastest route	Second delay	Depends on setting, referral system	Travels another route, e.g., via lower tier hospital
Upon arrival, there is capacity to take care of patient	Third delay	Costly, may vary depending on time of day	No surgeon on site, overfilled ER

Note that GIS is used to quantify the second delay

To the best of our knowledge, this is the largest study to date comparing GIS modeling to real-world data in a low- and middle-income country and the first using a standard method for generating data for the geographic access for surgery indicator. While we found a high degree of correlation between travel times as estimated by our GIS model and reported by patients, GIS estimates were systematically lower. Changing the GIS model to take the health center detour into account significantly improved the concordance of modeled and patient-reported results. More research will be needed to further understand the transport conditions in varying contexts, and future GIS modeling studies on geographical access should take those local conditions into account.

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Buzima, Kigali, Rwanda. Niclas Rudolfson was supported by Ronda Stryker and William Johnston fund at Harvard Medical School.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

Statement of informed consent and study approval Study staff informed patients about the study and obtained written consent. Approvals were received from the Partners In Health/Inshuti Mu Buzima (PIH/IMB) Research Committee and the Rwandan National Health Research Committee, and ethical approvals from the Rwanda National Ethics Committee (Kigali, Rwanda; no. 848/RNEC/2016) and Partners Human Research Committee (Boston, Massachusetts, USA; no. 2016P001943/MGH). The study was approved by the Rwandan Ministry of Health before the start of data collection.

References

1. Meara JG, Leather AJM, Hagander L et al (2015) Global surgery 2030: evidence and solutions for achieving health, welfare, and economic development. Lancet (Lond Engl) 386:569–624. https://doi.org/10.1016/S0140-6736(4)60160-X
2. O'Neill KM, Greenberg SLM, Cherian M et al (2016) Bellwether procedures for monitoring and planning essential surgical care in low- and middle-income countries: caesarean delivery, laparotomy, and treatment of open fractures. World J Surg 40:2611–2619. https://doi.org/10.1007/s00268-016-3614-y
3. World Health Organization, United Nations Population Fund, Mailman School of Public Health, Averting Maternal Death and Disability & United Nations Children's Fund (UNICEF) (2009) Monitoring emergency obstetric care: a handbook. World Health Organization. https://apps.who.int/iris/handle/10665/44121
4. Stewart BT, Tansley G, Gyedu A et al (2016) Mapping population-level spatial access to essential surgical care in Ghana using availability of bellwether procedures. JAMA Surg 151:e161239. https://doi.org/10.1001/jamasurg.2016.1239
5. Niyitegeka J, Nshimirimana G, Silverstein A et al (2017) Longer travel time to district hospital worsens neonatal outcomes: a retrospective cross-sectional study of the effect of delays in receiving emergency cesarean section in Rwanda. BMC Pregnancy Childbirth 17:242. https://doi.org/10.1186/s12884-017-1426-1
6. Nyirahabimana N, Ufashingabire CM, Lin Y et al (2017) Maternal predictors of neonatal outcomes after emergency cesarean section: a retrospective study in three rural district hospitals in Rwanda. Matern Heal Neonatol Perinatol 3:11. https://doi.org/10.1186/s40748-017-0050-4
7. Engjom HM, Morken N-H, Norheim OF, Klungsøyr K (2014) Availability and access in modern obstetric care: a retrospective population-based study. BJOG 121:290–299. https://doi.org/10.1111/1471-0528.12510
8. Dare AJ, Ng-Kamstra JS, Patra J et al (2015) Deaths from acute abdominal conditions and geographical access to surgical care in India: a nationally representative spatial analysis. Lancet Glob Heal 3:e646–e653. https://doi.org/10.1016/S2214-109X(4)00079-0
9. Thaddeus S, Maine D (1994) Too far to walk: maternal mortality in context. Soc Sci Med 38:1091–1110. https://doi.org/10.1016/0277-9536(94)90226-7
10. Holmer H, Bekele A, Hagander L et al (2019) Evaluating the collection, comparability and findings of six global surgery indicators. Br J Surg 106:e138–e150. https://doi.org/10.1002/bjs.11061
11. Chen YN, Schmitz MM, Serbanescu F et al (2017) Geographic access modeling of emergency obstetric and neonatal care in Kigoma Region, Tanzania: transportation schemes and programmatic implications. Glob Heal Sci Pract 5:430–445. https://doi.org/10.9745/GHSP-D-17-00110
12. Raykar NP, Bowder AN, Liu C et al (2015) Geospatial mapping to estimate timely access to surgical care in nine low-income and middle-income countries. Lancet 385:S16. https://doi.org/10.1016/S0140-6736(4)60811-X
13. Juran S, Broer PN, Klug SJ et al (2018) Geospatial mapping of access to timely essential surgery in sub-Saharan Africa. BMJ Glob Heal 3:e000875. https://doi.org/10.1136/bmjgh-2018-000875
14. Knowlton LM, Banguti P, Chackungal S et al (2017) A geospatial evaluation of timely access to surgical care in seven countries. Bull World Heal Organ 95:437–444. https://doi.org/10.2471/BLT.16.175885
15. Esquivel MM, Uribe-Leitz T, Makasa E et al (2016) Mapping disparities in access to safe, timely, and essential surgical care in Zambia. JAMA Surg 151:1064–1069. https://doi.org/10.1001/jamasurg.2016.2303
16. Ouma PO, Maina J, Thuranira PN et al (2018) Access to emergency hospital care provided by the public sector in sub-Saharan Africa in 2015: a geocoded inventory and spatial analysis. Lancet Glob Heal 6:e342–e350. https://doi.org/10.1016/S2214-109X(17)30488-6
17. Mukhopadhyay S, Lin Y, Mwaba P et al (2017) Implementing world health assembly resolution 68.15: national surgical, obstetric, and anesthesia strategic plan development-the Zambian experience. Bull Am Coll Surg 102(6):28–35
18. World Health Organization (2017) Surgical care systems strengthening: developing national surgical, obstetric and anaesthesia plans. World Health Organization, Geneva
19. Calovi M, Seghieri C (2018) Using a GIS to support the spatial reorganization of outpatient care services delivery in Italy. BMC Health Serv Res 18:883. https://doi.org/10.1186/s12913-018-3642-4
20. Haynes R, Jones AP, Sauerzapf V, Zhao H (2006) Validation of travel times to hospital estimated by GIS. Int J Health Geogr 5:40. https://doi.org/10.1186/1476-072X-5-40
21. Patel AB, Waters NM, Blanchard IE et al (2012) A validation of ground ambulance pre-hospital times modeled using geographic information systems. Int J Health Geogr 11:42. https://doi.org/10.1186/1476-072X-11-42
22. National Institute of Statistics of Rwanda (NISR), Ministry of Finance and Economic Planning (MINECOFIN) [Rwanda]

(2012) Rwanda Fourth Population and Housing Census. District Profile: Kirehe
23. Rwanda (2014–2015) Demographic and health survey key findings. https://www.dhsprogram.com/pubs/pdf/SR229/SR229.pdf. Accessed 8 Apr 2018
24. Harris PA, Taylor R, Thielke R et al (2009) Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform 42:377–381. https://doi.org/10.1016/j.jbi.2008.08.010
25. Rwanda NI of S Geodata portal: list of village names and codes. http://geodata-nisr.opendata.arcgis.com/datasets/32e1f5c0f5974681ac32d31a9f2cf166_0. Accessed 19 Apr 2018
26. Hijmans R (2012) GADM database of global administrative areas—version 2.8. http://gadm.org/
27. Ray N, Ebener S (2008) AccessMod 3.0: computing geographic coverage and accessibility to health care services using anisotropic movement of patients. Int J Health Geogr 7:63. https://doi.org/10.1186/1476-072x-7-63
28. OpenStreetMap. https://www.openstreetmap.org. Accessed 19 Mar 2018
29. Davis JL, Handley MA, Haguma P et al (2015) Investigating barriers to tuberculosis evaluation in Uganda using geographic information systems. Am J Trop Med Hyg 93:733–738. https://doi.org/10.4269/ajtmh.14-0754
30. Gething PW, Johnson FA, Frempong-Ainguah F et al (2012) Geographical access to care at birth in Ghana: a barrier to safe motherhood. BMC Public Health 12:991. https://doi.org/10.1186/1471-2458-12-991
31. Hirose A, Borchert M, Cox J et al (2015) Determinants of delays in travelling to an emergency obstetric care facility in Herat, Afghanistan: an analysis of cross-sectional survey data and spatial modelling. BMC Pregnancy Childbirth 15:14. https://doi.org/10.1186/s12884-015-0435-1

Study II

South Africa and the surgical diaspora – a hub for surgical migration and training

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Abstract

Background

The shortage of trained surgeons, anesthesiologists, and obstetricians is a major contributor to the unmet need for surgical care in low- and middle-income countries, and the shortage is aggravated by migration to higher-income countries.

Methods

We performed a cross-sectional observational study, combining individual-level data of 43,621 physicians from the Health Professions Council of South Africa with data from the registers of 14 high-income countries, and international statistics on surgical workforce, in order to quantify migration to and from South Africa in both absolute and relative terms.

Results

Of 6,670 surgeons, anesthesiologists, and obstetricians in South Africa, a total of 713 (11%) were foreign medical graduates, and 396 (6%) were from a low- or middle-income country. South Africa was an important destination primarily for physicians originating from low-income countries; 2% of all surgeons, anesthesiologists, and obstetricians from low- and middle-income countries were registered in South Africa, and 6% in the other 14 recipient countries. A total of 1,295 (16%) South African surgeons, anesthesiologists, and obstetricians worked in any of the 14 studied high-income countries.

Conclusion

South Africa is an important regional hub for surgical migration and training. A notable proportion of surgical specialists in South Africa were medical graduates from other low- or middle-income countries, whereas migration out of South Africa to high-income countries was even larger.

Introduction

One of the most prominent barriers to surgical care is the acute shortage and maldistribution of trained surgeons, anesthesiologists, and obstetricians (SAO specialists) in low- and middle-income countries, [1, 2] exacerbated by migration of these individuals to more affluent countries.[3] International health workforce mobility is often beneficial for training purposes, and professionally rewarding individually, yet higher-income countries' dependency on SAO workforce from lower income settings maintains the current maldistribution and prevents countries from strengthening self-sustainable domestic health systems of surgical care.[4-9]

South Africa has previously been described as an exporter of well-trained physicians to high-income countries,[4, 6, 10, 11] but while physicians from South Africa indeed migrate to high-income countries, South Africa also acts as a recipient of trainees and specialists from sub-Saharan countries.[10, 12-16] Consequently, South Africa has been described as an African hub of physician migration.[4, 17-19] However, the migration patterns of SAO specialists to and from South Africa have previously not been well characterized. Therefore, the objectives of this study were to quantify the current number of foreign medical graduates in surgery, anesthesia, and obstetrics, both immigrating from low- and middle-income countries to South Africa and emigrating from South Africa to high-income countries. Further, to estimate the proportion relative to the total SAO workforce from the perspective of both sending and receiving countries.

Methods

Study design

We performed a cross-sectional observational study of surgeons, anesthesiologists, and obstetricians licensed to practice in South Africa and compared this cadre with the WHO global surgery workforce database [20] and with more detailed workforce data of SAO specialists working in 14 major high-income countries.

SAO specialists in South Africa

We included all physicians registered to practice in South Africa (Figure 1). Data on physicians in South Africa were obtained from the public iRegister database provided by the Health Professions Council of South Africa (HPCSA).[21] We considered as SAO specialists any physician licensed within surgery, pediatric surgery, ophthalmology, plastic and reconstructive surgery, orthopedics, otorhinolaryngology, urology, neurosurgery, cardiothoracic surgery, anesthesiology, or obstetrics & gynecology. We excluded all non-active physicians. Reasons for exclusion from the calculations on SAO specialists in South Africa included suspension, de-registration, emigration from South Africa, and death. Data were for 2016, corresponding to the 2016 update of the WHO surgical workforce database, the last year for which complete world-wide data are available. [22, 23]

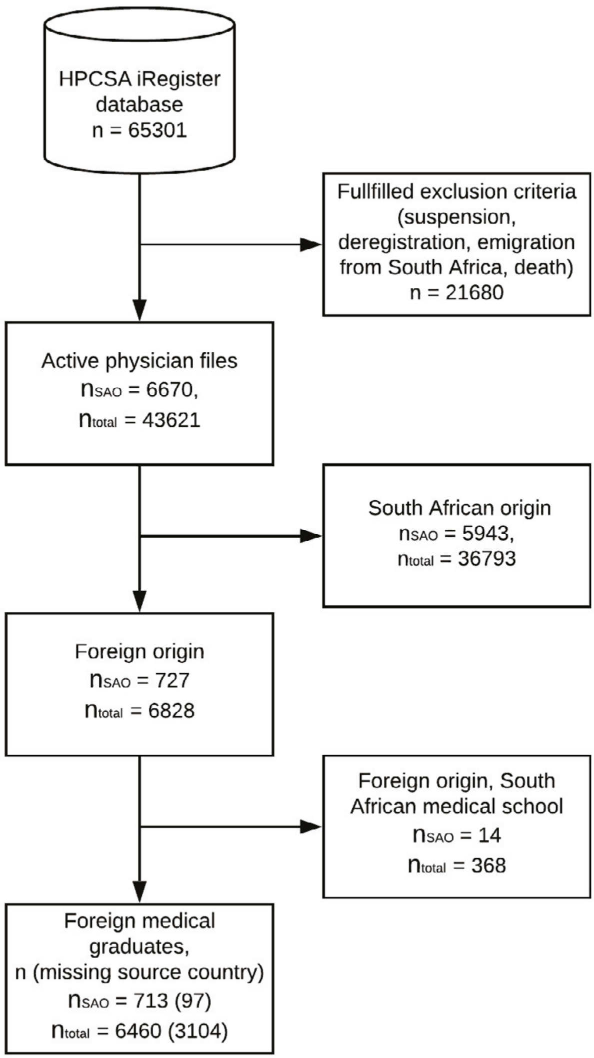

Figure 1. Inclusion of South African foreign medical graduates and the subgroup of surgeons, anesthesiologists and obstetricians. The HPCSA iRegister database includes South African physicians from the Health Professions Council of South Africa.[21] n_{total} = number of physicians, n_{SAO} = number of surgeons, anesthesiologists, and obstetricians.

Foreign SAO specialists in South Africa

The HPCSA database contains information on the specialty of health practitioners, medical school, foreign origin, and postgraduate credentials. We defined the source country as the country of earliest available medical qualification. A foreign medical graduate was defined as a non-South African, with a medical degree from outside South Africa.

South African SAO specialists working abroad

Data on SAO specialists from South Africa working abroad were retrieved from the national databases of 14 HICs,[3] and the included countries were Australia, Austria, Canada, Estonia, Finland, Ireland, Israel, New Zealand, Norway, Slovakia, Slovenia, Sweden, The United Kingdom, and the United States. These were the countries for which data were available, though we note they also capture the vast majority of migration to South Africa.[19] The specialist designation was defined according to the regulations of the destination country, and South African physicians were identified by their medical school graduation.

Outcomes and statistical analysis

The primary outcome was the number of foreign SAO specialists in South Africa, and the number of South African SAO specialists working abroad. Two proportions were calculated to contextualize these numbers. (1) From the perspective of receiving country, we calculated the South African dependency on SAO specialists from low- and middle-income countries (LMICs) by dividing the number of foreign medical graduates from LMICs by the total number of South African SAO specialists. (2) From the perspective of source country, we calculated the emigrated proportion of SAO specialists from each source country, defined as $A/(A+B)$, where A is the number of SAO specialists from a source country who have emigrated, and B is the number of SAO specialists remaining in the source country. Finally, we calculated the correlation between the proportion of emigrated SAO specialists in a source country with gross national income per capita and the density of SAO specialists, using linear regression.

Information on source country was missing for a subset of foreign medical graduates in South Africa. These were assigned an origin country based on the proportion in the observed data, i.e. a missing completely at random assumption was made. Calculations were performed in R (version 4.1.0, R core team, Vienna, Austria, 2021).

Auxiliary data sources

Data on the total number of SAO specialists in the source countries were obtained from the WHO surgical workforce database, [20, 24] which in turn sources data (in order of preference) from governmental sources, professional bodies, WHO/OECD/Eurostat databases, scientific publications, and other reports. Where data were not available, estimations based on a multiple imputation prediction model were used; [22] estimated number of SAO specialists from the Democratic People's Republic of Korea were excluded due to data quality concerns. Data on Gross National Income per capita in purchasing power parity and population were obtained from the World Bank World Development Indicators database.[24] Countries were categorized by World Bank Group income classification and regions were categorized by WHO classification.[17, 24]

Ethical considerations

The project was exempt from full ethical review by the institutional review board at Boston Children's Hospital (IRB-P00024135).

Results

We identified 43,621 physicians in South Africa, of whom 3,685 were surgeons, 1,749 anesthesiologists, and 1,236 obstetricians, corresponding to a total of 6,670 (15%) SAO specialists, or 12.1 per 100,000 population (Figure 1). In addition, 1,295 SAO specialists (16%) in the 14 assessed high-income countries originated from South Africa (Figure 2).

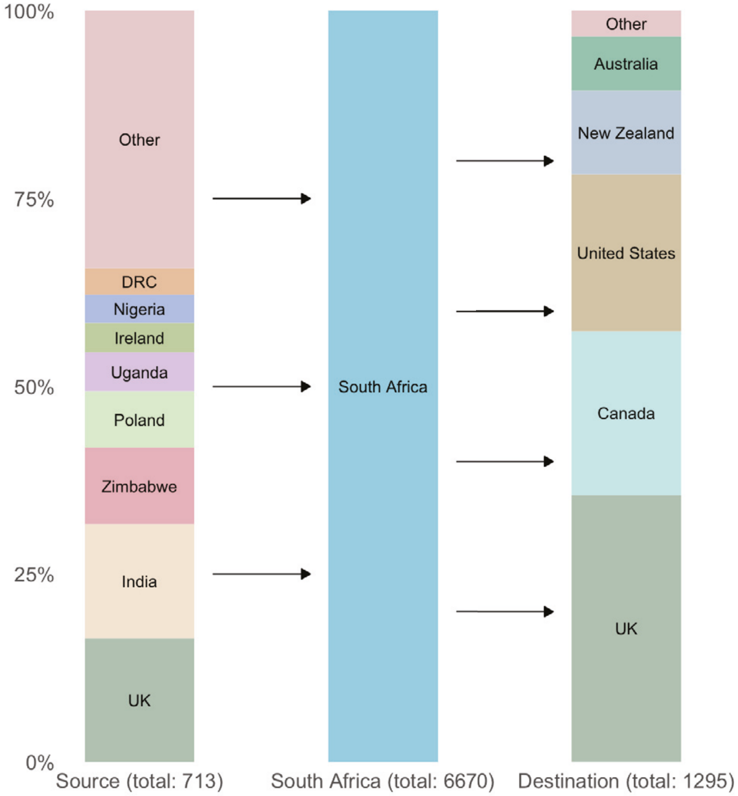

Figure 2. The leading source and destination countries for surgery, anesthesia, and obstetric specialists who have migrated in and out of South Africa. In addition to the 8 origin countries displayed here, an additional 49 countries sent at least 1 SAO specialist to South Africa, although no country in the "other" category sent more than 25.

Of the 6,670 SAO specialists in South Africa, a total of 713 (11%) were foreign medical graduates, and 396 (5.9%) were from an LMIC, mostly from Africa (201, 3.0%) and Southeast Asia (131, 2.0%) (Figure 3).

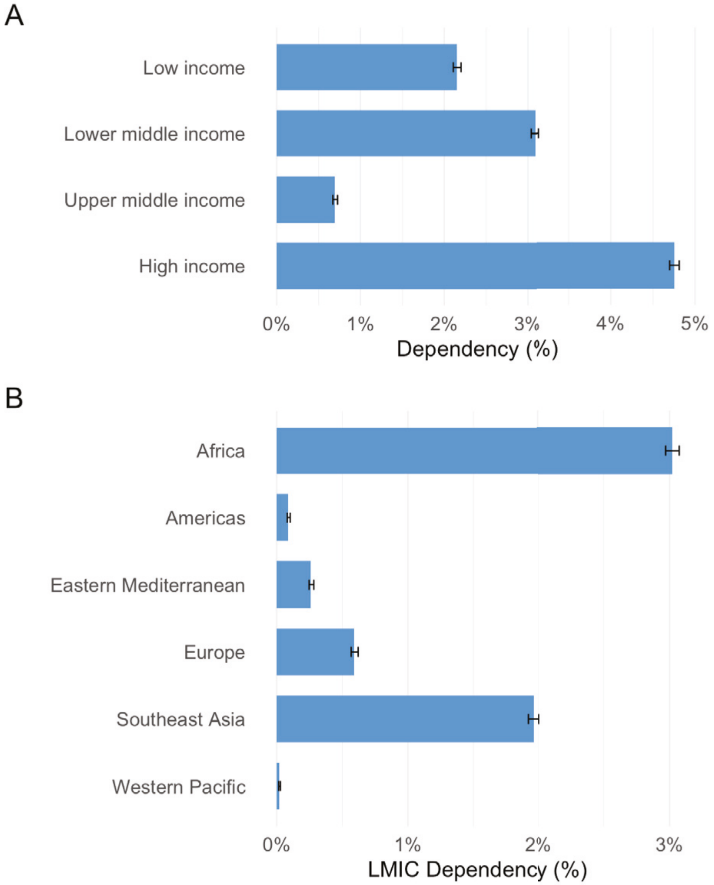

Figure 3 a & b. The South African dependency on foreign medical graduates in surgery, anesthesia, and obstetrics. (A) by World Bank income group, (B) by WHO region, including only low- and middle-income source countries. Dependency is the number of foreign medical graduates divided by the total number of physicians.

The South African dependency on foreign medical graduates from LMICs was lower for SAO specialists compared to physicians in general (5.9% and 8.8%, respectively), and among SAO specialists, the dependency was highest for obstetricians (9.2%), and lowest for anesthesiologists (3.3%) (Figure 4).

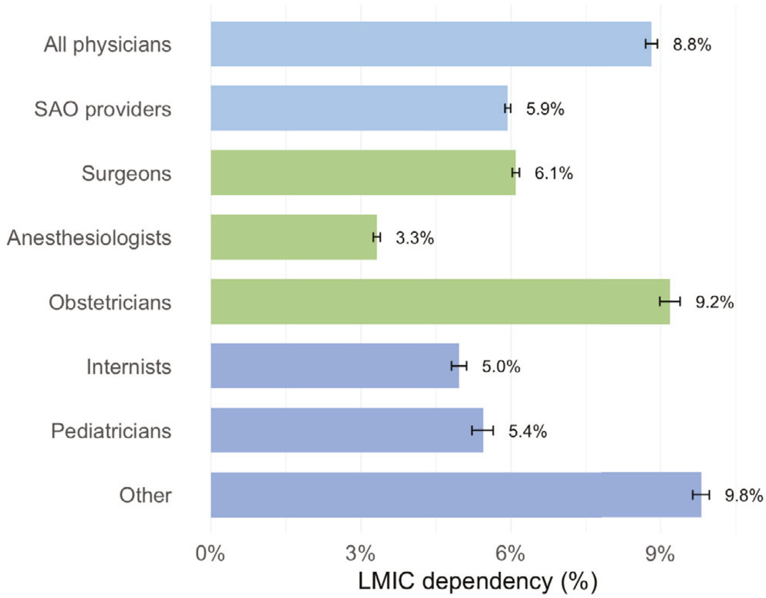

Figure 4. The South African dependency on foreign medical graduates from low- and middle-income countries, by specialty. Dependency is the number of foreign medical graduates divided by the total number of physicians in each specialty.

Figure 5 displays the proportion of SAO specialists from individual countries and by income class which have migrated to HICs or to South Africa. Of all SAO specialists originating from low-income countries, a total of 8.2% worked in any of the included destination countries, 6.1% in one of the 14 assessed high-income countries and 2.1% in South Africa. For SAO specialists originating in lower-middle income countries, these figures were 6.1% and 0.06%, and for upper-middle income countries 0.10% and 0.005% (Figure 5).

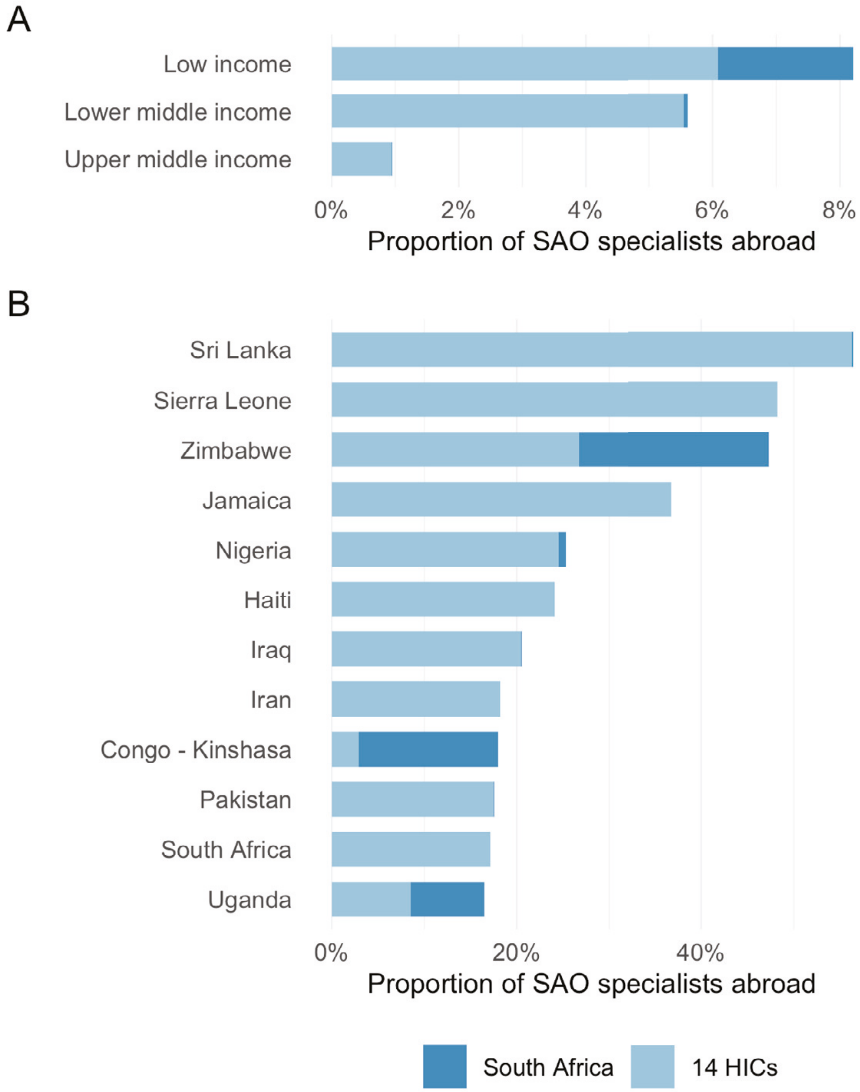

Figure 5 a & b. The proportion of SAO specialists abroad in South Africa and 14 high income countries (HICs), (A) by world bank income group, and (B) by country, displaying the top countries. The proportion was defined as $A/(A+B)$, where A is the number of SAO specialists who have emigrated and B is the number of SAO specialists remaining in the source country or region.

For every 1000$ increase in the gross national income, there was a 6.3% (95% CI 2.9 – 9.6%, $p < 0.001$) decrease in the proportion of specialists abroad in South Africa, and for every increase in surgeon, anesthesiologist, and obstetrician density of 1/100 000, there was a 2.8% (95% CI 1.5% - 4.1%, $p < 0.001$) decrease in the proportion of specialists abroad in South Africa (Figure 6).

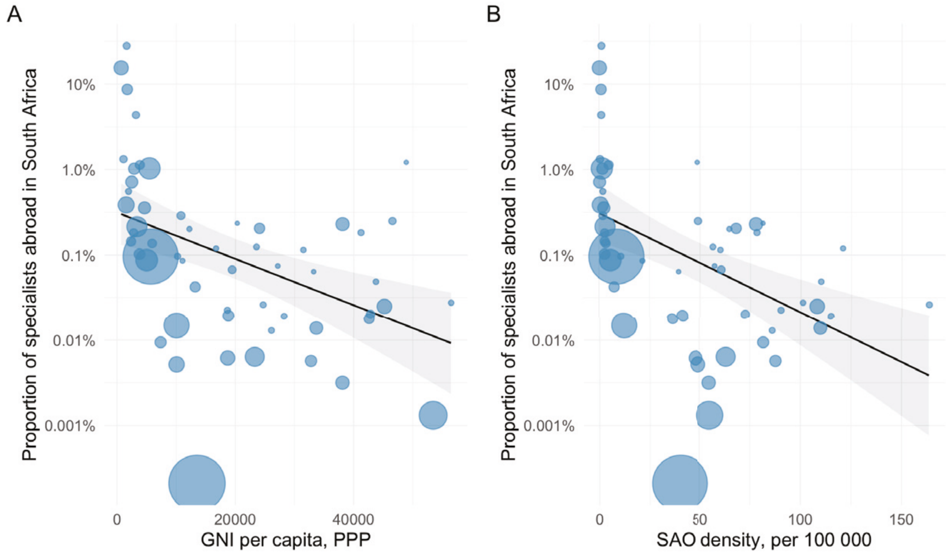

Figure 6 a & b. The correlation between the proportion of surgery, anesthesia and obstetric specialists abroad in South Africa and (A) Gross national income per capita, (B) and the remaining density of SAO specialists per 100 000 population. The proportion was defined as *A*/(*A*+*B*), where A is the number of SAO specialists from a source country who have emigrated to South Africa, and B is the number of SAO specialists remaining in the source country. Bubble sizes represent source country population size.

Discussion

In this study, we provide a mobility analysis of the SAO specialist workforce in South Africa. Sixteen percent of South African SAO specialists currently work in a high-income country, and 6% of the SAO specialists currently in South Africa originate from another LMIC. Given the severe shortage of SAO providers in Sub-Saharan Africa, many neighboring countries have a large diaspora of SAO specialists currently working in South Africa.

The maldistribution of SAO specialists in the world is exacerbated by specialist migration to more affluent regions. Our study shows that South Africa is an important hub for physician migration into and out of sub-Saharan Africa. It is possible that the large emigration from South Africa has created a physician shortage that in turn is partly replaced with migrants from other LMICs and that this in turn impacts source countries with an already insufficient supply of SAO providers. For example, Zimbabwe, The Democratic Republic of the Congo, and Uganda have a particularly high proportion of SAO specialists currently working in South Africa, especially when considering that these countries also lose large numbers of medical graduates to high-income countries. The South African dependency on SAO specialists originating from LMICs was 5.9%, as compared to a previous study which reported 9.7% for high-income countries, with a range of 0.3% to 15.6%.[3]

The effects of physician migration are certainly not all negative, and it is reasonable to also underline the potential for "brain gain". Emigration can bring benefits to the source country in several ways. First, the temporary or permanent return of gifted individuals having spent time abroad can bring valuable knowledge and skill sharing,[2, 25, 26] and considerable interaction between the "surgical diaspora" and the source countries has been described.[27] SAO trainees or fellows temporarily attending training programs abroad can in many circumstances be an appropriate strategy to mitigate national shortages of SAO specialists, with South Africa in particular suppling training opportunities for sub-Saharan African SAO trainees[28] Second, many emigrated physicians send home remittances, which in some cases are quite considerable.[6, 25, 26] Third, the opportunity for migration to more affluent circumstances can potentially serve as an incentive for education.[25] Emigration also poses a chance for the individual to gain better prospects for career opportunities, postgraduate training opportunities that may not exist in the home country, better working conditions, and higher salary.[6] Indeed, a report by the South African Migration Programme found that a significant number of South African physicians had worked temporarily in other countries, primarily in Western countries, often to pay off student loans or gain valuable skills.[29] Finally, the considerable size of this "surgical diaspora" in relation to the remaining workforce in some source countries could potentially serve as a valuable pool of temporarily or permanently returning highly-trained specialists, either providing clinical services directly or teaching younger colleagues. Return migration from HIC to South Africa has led to a decreased net emigration especially in the last two decades,[11] with time-limited employment in HICs and social and environmental factors in South Africa being the main driving forces for return migration.[30] It should also be noted that drivers of migration are complex and multifaceted, often divided into push and pull factors. Push factors are motivations for migration in the source country, such as poor working conditions and remuneration. In particular, a lack of stable employment opportunities in the home country represents a major push factor for both primary migration and hinders return migration, both for South Africa [30] and for other sub-Saharan African countries.[31, 32] Pull factors are motivations for migration in the receiving country, such as better opportunities for career development and training.[15, 26, 33] Some qualitative studies have suggested push factors to be more important than pull factors.[13, 33-35]

The large-scale migration of skilled health workers has stirred a vehement ethical debate in the international community,[6, 13, 36, 37] bringing into opposition the right of the health worker to free mobility with the right to health for the population of the source country. Adding to the controversy, the countries with the most severe shortage of skilled healthcare workers are often the most affected, as evident by the negative correlation between SAO specialist density and emigrated proportion in our data. Since medical education is often subsidized by the state, the migration of physicians also constitutes a financial loss for sending countries, on the order of several billion USD.[38, 39] Several important steps need to be taken to minimize any compromise of either principle. Some authors make a distinction between active and passive recruitment, where the former can include recruiting elements such as advertisements and information sessions encouraging and promoting migration.[10, 36] Such active practices are often discouraged.[36, 40, 41] Policies that increase worker retention by decreasing the effects of push factors can circumvent the ethical dilemma by instead working to increase job satisfaction in the source countries.[26, 36, 42] Other important measures include careful risk-benefit analysis, transparency in hiring and remuneration practices and supporting the healthcare capacity building of developing countries.[40] In 2010, after determined advocacy from some African countries,[6] all member states of the United Nations adopted the non-binding

"WHO Code of Practice on the International Recruitment of Health Workers", which lays a framework for the ethical recruitment practices of health workers.[9, 40] Per the Global Strategy on Human Resources for Health,[43] adopted by the 69^{th} World Health Assembly through resolution WHA69.19, member states should strive to halve their dependency on foreign medical graduates by 2030, and to gather and track relevant data to enable policy to be driven by evidence.[43, 44]

It should be noted that South Africa in particular has attempted to reduce its recruitment of physicians from other LMICs, especially from the Southern African Development Community area.[12, 13] They have also signed Memoranda of Agreement with some African countries not to employ their citizens after graduation from medical training in South Africa.[13, 45] The efficiency of these policies has been questioned; some report ready movement into South Africa despite these policies,[13, 19] while some argue the policies have merely redirected the flow of migrants to northern countries.[15] South Africa has also instituted training programs in SAO specialties open to foreign medical graduates, where they are expected to return after training to their country of origin. Since longitudinal data were not available, we were not able to draw any conclusions on the yearly flow of SAO specialists which would enable us to evaluate immigration policy changes, both to and from South Africa. In particular, it is possible that policies enacted by South Africa as outlined above have lowered the influx of physicians from other African countries, and that many of the current SAO specialists migrated before current policies were put in place. A longitudinal analysis of South African physician immigration between 2000 – 2014 found an increase in immigration during that period,[19] while emigration from South Africa to high-income countries has decreased over the past decades, with the proportion of physicians registered abroad decreasing from a peak of a 34% in 2005 to 22% in 2017.[11] Data are not available broken down by specialty however. Future studies may also elucidate if the Covid-19 pandemic affected physician migration. There is a paucity of data and it would be valuable if future studies focused on the temporal patterns of SAO specialists migration. One potential avenue forward would be to include not only the SAO density, but also key metrics affecting SAO density such as graduation, retirement, and migration, in the measurement and evaluation strategies of National Surgical, Obstetric and Anesthesia plans.[46]

It is important to consider some limitations of our study. Similar to previous studies, it was not possible to distinguish at which point in the training the SAO specialists migrated, i.e. before or after postgraduate training. National databases may contain SAO specialists who are no longer actively practicing in said country but have not yet deregistered, with practices differing between countries, although deregistration upon return migration to South Africa is commonplace.[11] Some physicians migrating to a new country may fail to obtain a license and go into some other occupation, causing an underestimation.[12, 14] For a proportion of physicians, data were not available on source country, and we adjusted the estimates proportionally to account for the missing data. If, in fact, there is a systematic bias to the way the data is missing, our results could under- or over-estimate the number of physicians originating in individual countries. Due to data limitations, our study did not include non-physician SAO providers, who play an important role in the provision of surgical care in some countries.[47] The study also does not capture physicians currently in surgical training, who may be especially mobile.

Conclusion

South Africa is a major hub for physician migration, and 6% of SAO specialists in South Africa were medical graduates from other low- or middle-income countries, whereas 16% of SAO specialists from South Africa have migrated to high-income countries. Eight per cent of SAO specialists originating in low-income countries have emigrated abroad, a fourth of which have migrated to South Africa.

References

1. 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
2. Ozgediz D, Kijjambu S, Galukande M, et al (2008) Africa's neglected surgical workforce crisis. Lancet 371:627-628
3. Lantz A, Holmer H, Finlayson S, et al (2015) International migration of surgeons, anaesthesiologists, and obstetricians. Lancet Glob Health 3 Suppl 2:S11-12
4. Bidwell P, Laxmikanth P, Blacklock C, et al (2014) Security and skills: the two key issues in health worker migration. Glob Health Action 7:24194
5. Taylor AL, Dhillon IS (2011) The WHO Global Code of Practice on the International Recruitment of Health Personnel: the evolution of global health diplomacy. Global Health Governance
6. Blacklock C, Heneghan C, Mant D, et al (2012) Effect of UK policy on medical migration: a time series analysis of physician registration data. Hum Resour Health 10:35
7. Tankwanchi AB, Ozden C, Vermund SH (2013) Physician emigration from sub-Saharan Africa to the United States: analysis of the 2011 AMA physician masterfile. PLoS Med 10:e1001513
8. Naicker S, Plange-Rhule J, Tutt RC, et al (2009) Shortage of healthcare workers in developing countries - Africa. Ethnicity & Disease 19:60
9. User's Guide: The WHO Global Code of Practice on the International Recruitment of Health Personnel, The World Health Organisation, 2010.http://apps.who.int/iris/bitstream/10665/70525/1/WHO_HSS_HRH_HMR_2010.2_eng.pdf
10. Dambisya YM, Mamabolo MH (2012) Foreign advertisements for doctors in the SAMJ 2006 - 2010. S Afr Med J 102:669-672
11. Nwadiuko J, Switzer GE, Stern J, et al (2021) South African physician emigration and return migration, 1991-2017: a trend analysis. Health Policy Plan 36:630-638
12. Bateman C (2008) Slow progress in doctor placement kickback probe. S Afr Med J 98:664, 666, 668

13. Labonte R, Sanders D, Mathole T, et al (2015) Health worker migration from South Africa: causes, consequences and policy responses. Hum Resour Health 13:92
14. Migration Dialogue for Southern Africa (MIDSA)Promoting Health and Development: Migration Health in Southern Africa, Dar es Salaam, International Office for Migration, 2009
15. Sanders D, Lloyd B (2005) Human Resources: International Context. South African Health Review 6:67-87
16. Tankwanchi AB, Vermund SH, Perkins DD (2015) Monitoring Sub-Saharan African physician migration and recruitment post-adoption of the WHO code of practice: temporal and geographic patterns in the United States. PLoS One 10:e0124734
17. Ehman AJ, Sullivan P (2001) South Africa appeals to Canada to stop recruiting its MDs. CMAJ 164:387-388
18. Chikanda A, Medical leave: the exodus of health professional from Zimbabwe (2005) Crush J (ed) Southern African Migration Project, Cape Town, South Africa
19. Tankwanchi AS, Hagopian A, Vermund SH (2019) International migration of health labour: monitoring the two-way flow of physicians in South Africa. BMJ Global Health
20. Holmer H, Lantz A, Kunjumen T, et al (2015) Global distribution of surgeons, anaesthesiologists, and obstetricians. Lancet Glob Health 3 Suppl 2:S9-11
21. iRegister database, Health Professions Council of South Africa.https://hpcsaonline.custhelp.com/app/i_reg_form
22. Holmer H, Bekele A, Hagander L, et al (2019) Evaluating the collection, comparability and findings of six global surgery indicators. Br J Surg 106:e138-e150
23. Global Health Observatory data, The World Health Organisation.http://www.who.int/gho/en/
24. World Development Indicators, The World Bank.http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators
25. Moullan Y (2014) The International Migration of Doctors: Impacts and Political Implications. Questions d’économie de la santé:1-7
26. Friedman EA An Action Plan to Prevent Brain Drain: Building Equitable Health Systems in Africa, Boston, MA, Physicians for Human Rights, 2004

27. Hagander LE, Hughes CD, Nash K, et al (2013) Surgeon migration between developing countries and the United States: train, retain, and gain from brain drain. World J Surg:37:14–23
28. Naidu P, Fagan JJ, Lategan C, et al (2020) The role of the University of Cape Town, South Africa in the training and retention of surgeons in Sub-Saharan Africa. Am J Surg 220:1208-1212
29. Crush J Rethinking the Medical Brain Drain NarrativeSAMP Migration Policy Series, Southern African Migration Programme, 2019
30. Crush J, Chikanda A, Bourgeault I, et al Brain Drain and Regain: The Migration Behaviour of South African Medical ProfessionalsSouthern African Migration Programme, 2014
31. Sirili N, Frumence G, Kiwara A, et al (2019) "Doctors ready to be posted are jobless on the street..." the deployment process and shortage of doctors in Tanzania. Hum Resour Health 17:11
32. Mureithi F KMPDU raises red flag over unemployment of graduate doctorsNation, 2022
33. Oberoi SS, Lin V (2006) Brain drain of doctors from southern Africa: brain gain for Australia. Aust Health Rev 30:25-33
34. Reardon C, George G (2014) An examination of the factors fueling migration amongst Community Service practitioners. Afr J Prim Health Care Fam Med 6:E1-9
35. Arnold PC, Lewinsohn DE (2010) Motives for migration of South African doctors to Australia since 1948. Med J Aust 192
36. Mills EJ, Schabas WA, Volmink J, et al (2008) Should active recruitment of health workers from sub-Saharan Africa be viewed as a crime? Lancet 371:685-688
37. Farham B (2005) Migration of health professionals. Lancet 366:199
38. Mills EJ, Kanters S, Hagopian A, et al (2011) The financial cost of doctors emigrating from sub-Saharan Africa: human capital analysis. BMJ 343:d7031
39. Saluja S, Rudolfson N, Massenburg BB, et al (2020) The impact of physician migration on mortality in low and middle-income countries: an economic modelling study. BMJ Glob Health 5:e001535
40. WHA63.16: WHO Global code of practice on the international recruitment of health personnel, The World Health Organisation, 2010
41. Sidley P (2004) South Africa and Britain reach agreement to curb poaching of healthcare staff. BMJ 329:532

42. Arnold PC (2011) Why the ex-colonial medical brain drain? J R Soc Med 104:351-354
43. Global strategy on human resources for health: workforce 2030, Geneva, Switzerland, The World Health Organisation, 2016
44. National Health Workforce Accounts: A Handbook, Geneva, Switzerland, The World Health Organization, 2017
45. Mandeville KL, Ulaya G, Lagarde M, et al (2015) Early career retention of Malawian medical graduates: a retrospective cohort study. Trop Med Int Health 20:106-114
46. Sonderman KA, Citron I, Mukhopadhyay S, et al (2019) Framework for developing a national surgical, obstetric and anaesthesia plan. BJS Open 3:722-732
47. Federspiel F, Mukhopadhyay S, Milsom PJ, et al (2018) Global surgical, obstetric, and anesthetic task shifting: A systematic literature review. Surgery 164:553-558

Study IV

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RESEARCH ARTICLE

Does community-based health insurance protect women from financial catastrophe after cesarean section? A prospective study from a rural hospital in Rwanda

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Abstract

Background: The implementation of community-based health insurance in (CBHI) in Rwanda has reduced out of pocket (OOP) spending for the >79% of citizens who enroll in it but the effect for surgical patients is not well described. For all but the poorest citizens who are completely subsidized, the OOP (out of pocket) payment at time of service is 10%. However, 55.5% of the population is below the international poverty line meaning that even this copay can have a significant impact on a family's financial health. The aim of this study was to estimate the burden of OOP payments for cesarean sections in the context of CBHI and determine if having it reduces catastrophic health expenditure (CHE).

Methods: This study is nested in a larger randomized controlled trial of women undergoing cesarean section at a district hospital in Rwanda. Eligible patients were surveyed at discharge to quantify household income and routine monthly expenditures and direct and indirect spending related to the hospitalization. This was used in conjunction with hospital billing records to calculate the rate of catastrophic expenditure by insurance group.

Results: About 94% of the 340 women met the World Bank definition of extreme poverty. Of the 330 (97.1%) with any type of health insurance, the majority ($n = 310$, 91.2%) have CBHI. The average OOP expenditure for a cesarean section and hospitalization was $9.36. The average cost adding transportation to the hospital was $19.29. 164 (48.2%) had to borrow money and 43 (12.7%) had to sell possessions. The hospital bill alone was a CHE for 5.3% of patients. However, when including transportation costs, 15.4% incurred a CHE and including lost wages, 22.6%.

Conclusion: To ensure universal health coverage (UHC), essential surgical care must be affordable. Despite enrollment in universal health insurance, cesarean section still impoverishes households in rural Rwanda, the majority of whom already lie below the poverty line. Although CBHI protects against CHE from the cost of healthcare, when adding in the cost of transportation, lost wages and caregivers, cesarean section is still often a catastrophic financial event. Further innovation in financial risk protection is needed to provide equitable UHC.

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Keywords: Developing countries, Economic crisis, Health care reform, Health financing, Maternity services, Policy evaluation

Background

Each year, 81 million people are pushed into poverty due to costs associated with surgical care [1]. Ensuring that all people have access to quality healthcare services while protecting them from financial hardship related to paying for healthcare is a key tenet of universal health coverage (UHC) [2]. With the more recent inclusion of essential and emergency surgery – including caesarean section (c-section) – as components of UHC, this is an area that demands further understanding [1, 3]. According to the World Health Organization (WHO) [4], ensuring increased access to c-section is crucial to achieving decreased maternal and fetal mortality. However, c-section rates in sub-Saharan Africa (SSA) [5], though rising, remain lower than the 10–15% predicted to be associated with decreased maternal and fetal mortality [6].

The financial cost of surgical care is a core barrier to achieving target c-section rates in SSA. In Burkina Faso, where the c-section rate is just 1.8%, c-sections are five times more expensive than vaginal delivery and 10% of households were still paying off debt up to 4 years later [7]. Removing user costs for surgery increases rates of c-section but does not address the multitude of access issues related to poverty [5]. In Rwanda, 97% of women deliver in facilities rather than at home and 13% deliver via c-section [8], but the financial ramifications of requiring this hospital-based procedure is not known.

Over 80% of the Rwandan population live rurally [8] as of the 2015 census. Although only 38.2% live below the Rwandan national poverty line, 55% live in extreme poverty according to the World Bank standard, which is defined as living on less than $1.90 per day [9]. The government spends 7.5% of total Gross Domestic Product on healthcare, which translates to $170 per capita per year [10]. Since 1999, all Rwandans have had access to community-based health insurance (CBHI) – locally called *Mutuelles de Santé*. This scheme was devised to decrease poverty in the post-genocide period, and membership became compulsory by the national CBHI law in 2007 (though there are no direct penalties if citizens do not enroll) leading to high levels of enrollment [11] which have been celebrated internationally. An early study found that having CBHI was associated with a fourfold increase in the likelihood of a patient seeking modern medical care [12]. CBHI covers a basic package of services and drugs from authorized providers anywhere in the country as determined by the Ministry of Health and Rwanda Social Security Board. A referral or transfer from a health center is required to access a higher level of care such as a hospital for c-section.

Household contributions to CBHI are based on a 4-tier wealth system (*Ubudehe*), which classifies the population based on socioeconomic status and property. Rwandans are charged an annual premium plus a co-pay at the point of service provision, both adjusted by their socioeconomic status. Category 1 includes the poorest of the population and Category 4 includes the highest wealth quartile [13]. Those enrolled are eligible to receive the same services, and both pre and postnatal care are included for all categories. *Ubudehe* Category 1 patients do not pay any annual premium or copay [14]; rather, the government and other donors pay 2000 Rwandan Francs (RWF) (~$2.40) per household member per year for them to be insured. Category 2 and 3 patients pay a premium of 3000RWF (~$3.51) per household member annually and a 10% co-pay for all hospital medical services. Category 4 patients pay 7000RWF (~$8.19) per household member annually and cover 10% of hospital medical costs. As of January 2016, 79% of Rwandans were enrolled in CBHI [15]. In the Eastern province, 78.6% of residents have insurance. Of those, 97.7% have CBHI, 4.7% have government or military insurance and 0.2% have private insurance [8]. Those who are uninsured must pay hospital fees daily. The implementation of CBHI in Rwanda has reduced out-of-pocket (OOP) spending by patients, increased utilization of maternal healthcare and decreased catastrophic expenditure [14]. However, a follow up study indicated that these effects were more dramatic for wealthier patients than the poor and had less of a beneficial reduction for those seeking inpatient services [16].

One in ten women in rural Rwanda deliver via c-section [8], thus, a substantial portion of the population is at risk for significant financial burden despite heavy subsidies. Two metrics have been used to quantify the risk of financial hardship from surgical care: the rate of impoverishing expenditure, defined as expenditure that pushes a household below the poverty line, and the rate of catastrophic health expenditure (CHE), defined as spending greater than 10% of total annual household expenditure [17]. Because nonmedical costs such as transportation, food while in the hospital, and lost wages during the hospitalization contribute to financial hardships [18], these must be considered when determining the overall financial risk for patients. Recent systematic review found rates of CHE for patients in

SSA undergoing c-section to be 56–67% [19]. Understanding CHE related to a specific pathology, in this case from c-section deliveries, can help governments better protect their citizens from financial disaster [20].

No patient should experience financial catastrophe seeking essential surgical care. While previous work in Rwanda has estimated the cost of c-section delivery at a rural district hospital to be approximately $339 [21], the risk of catastrophic expenditure due to c-section has yet to be studied. We hypothesized that given the poverty of the population, this expense, even when subsidized by the government, would be catastrophic for many households, particularly when considering the added nonmedical costs of hospitalization. Using descriptive methodology, we analyzed data collected from patient surveys and hospital billing data to assess the rates of CHE in our patient population. The goal of this study was to measure the economic burden associated with having a c-section at a district hospital in Rwanda and the financial risk protection conferred by CBHI.

Methods

Study setting

This study was conducted at Kirehe District Hospital (KDH) which is located in the Eastern province of Rwanda, an approximately three-hour drive from the capital, Kigali. KDH is a 226-bed hospital with a catchment area of 350,000, which is run by the Ministry of Health with addtional support from Partners in Health, a USA-based non-governmental organization (NGO). Kirehe district has sixteen health centers that refer patients to KDH when a higher level of care is needed.

Women in labor first seek care at their local health center and are then transferred to KDH if a higher level of obstetric care, such as a c-section, is indicated. Once at KDH, women are assessed by the on-call General Practitioner, a bachelors-level physician with some additional training on cesarean deliveries, or the Obstetrician-Gynecologist who performs a c-section if the physician determines it to be necessary. The cost of the procedure is not discussed preoperatively. On average, women who deliver by c-section are discharged on postoperative day (POD) 3. The maternity department keeps paper charts to record details of the medical care provided. The billing department maintains a separate electronic record for each patient and collects payment from hospitalized patients daily. Though informal payments for healthcare are common in some parts of Africa [22], this is not the case in the Rwandan healthcare context; none of our patients reported using anything other than the Rwandan currency to pay.

Study design and population

This cross-sectional study was nested in a parent study on c-section-associated surgical site infections [23]. In the parent study, all women ≥18 years who underwent c-section at KDH between November 2017 and October 2018 were enrolled ($n = 1116$). For this unfunded sub-study, we included a subset of the study population: women enrolled over a 3-month period between April 21 and July 28, 2018 in order to obtain 300 patients. The parent study excluded patients from the Mahama refugee camp and patients residing outside of Kirehe District as their c-section referral and follow-up patterns as well as base income levels were considered different from the general population. From previous work done in the region, we know that the demographic of this district closely resembles that of the other rural districts in Rwanda.

Data collection and questionnaire

As part of the parent study, trained data collectors interviewed consenting patients on POD 1 to collect demographic data and details on transportation (time and costs) to the hospital. At the time of discharge, usually on POD 3, data collectors extracted additional data on clinical course from the hospital chart.

For this study, data collectors interviewed enrolled patients who agreed to respond to additional financial questions at the time of discharge outside the maternity ward to maintain confidentiality. The questions (Additional file 1: Appendix 1) were adapted from the Program in Global Surgery and Social Change (PGSSC) National Surgical Obstetric Anesthesia Plan surgical indicator questionnaire which was originally developed, validated and piloted by a group working in Uganda [24] [25]. We added the following to the core questionnaire: estimates of monthly household income; routine monthly or annual expenditures for food and drink, transportation, livestock, housing, school fees, and healthcare; and whether the patient had to borrow money or sell possessions to pay for the current hospitalization. Non-monetary income such as agricultural harvest was converted into RWF using the local goods prices at the time. All study data were entered directly during the interview into REDCap software [26]on tablets. Data collectors used the hospital billing online record (OpenMRS) to verify the insurance type for patients and the total cost, categorized by type of expense, charged to each patient for the hospitalization. Data collected from this system were recorded in Excel, to allow data collectors to adjust for variability in the formatting of billing receipts, and the extracted data were then merged into a single dataset for analysis. Participants received no compensation for their participation in this or any part of the study.

Key variables

We grouped expenses into the following categories: direct medical, direct non-medical, and indirect. Direct medical expenses included surgery, anesthesia, nursing care, imaging, lab work, and medicine. Direct non-medical expenses were expenses related to transportation to the hospital and food during the stay. Indirect expenses were the lost opportunity costs incurred by the hospitalization. This included lost wages for the household during the hospitalization as well as the transportation, food, and lodging for the caregivers who come to care for a woman while she delivers.

CHE is typically defined either as spending greater than 10% of total annual household expenditure or greater than 40% of annual expenditure, not including subsistence needs [27, 28]. For this paper, we used the 10% of total expenditure definition to align with the Sustainable Development Goal 3.8.2 [29]. We used the World Bank definitions for poverty, defined as a daily expenditure of less than $3.20 in purchasing power parity (PPP) per person per day, and extreme poverty, defined as a daily expenditure below $1.90 per person per day [30, 31]. C-section expenses are thus defined as an impoverishing expenditure if the addition of the c-section expenses pushed the individual below the $3.20 per person per day poverty line or further into poverty below the $1.90 per person per day threshold [32, 33].

Data analysis

We report demographic data with frequencies or with median and interquartile ranges (IQRs). Medians were used for data involving expenditures and income which are skewed. Patient reported household expenses were summed to obtain the annual total household expenditure. We calculated whether the direct medical costs, all direct costs, or all (direct + indirect) costs met the definition of CHE (i.e. >10% of the calculated annual total household expenditures). We report the CHE overall and stratified by *Ubudehe* categories.

To determine impoverishing expenditure, we calculated the daily expenditure per person in the household and then subtracted the c-section-related expenses. We report the number and percent of households that were below the poverty thresholds before and after incurring the c-section expenses. For all estimates, we report 95% confidence intervals calculated using the Wilson method. We used the Chi-squared test to compare groups.

In addition to reporting on catastrophic and impoverishing expenditures for this population, we modeled hypothetical scenarios of different insurance strategies. The modeled scenarios were as follows: Scenario 1, assuming there is no insurance coverage for anyone; Scenario 2, 64% of medical costs are covered for everyone (the mean covered proportion in sub-Saharan low-and middle-income countries (LMICs) [34]); Scenario 3, 90% of medical costs are covered for everyone; Scenario 4, 100% coverage of medical costs are covered for all patients; and Scenario 5, 100% coverage of medical costs and ambulance fees are covered for all patients. In each of these scenarios, the modelled population replicates the observed one, and only the above possible insurance strategies are altered. To do this, we first estimated the total cost for services in the absence of insurance coverage by multiplying the medical costs and ambulance fees for all CBHI-paying (*Ubudehe* categories 2–4) patients by 10, since patients in those categories have a 10% copay. Since medical costs were only known for patients covered in *Ubudehe* Categories 2 or 3 (no patients in *Ubudehe* Category 4 were observed in our study, and *Ubudehe* Category 1 patients have 0% copay), we bootstrapped costs from this subgroup to fill in the missing data for patients under other insurance coverage, keeping other variables as collected. We performed 1000 bootstrap replicates and assessed the posterior distributions using diagnostic plots (Supplemental Fig. 1). We did a Monte Carlo analysis on the resulting datasets, replicating the main analysis by calculating the proportion of patients who experienced CHE in each dataset and then reporting the average under each scenario.

For descriptive tables, all tradable expenses (such as medications and travel costs) were converted from RWF to United States Dollars (USD) using the nominal exchange rate at the beginning of the study (854.13), and all non-tradeable expenses (such as salaries) using the purchasing power parity exchange rate. (Rwanda PPP for personal consumption 2017 = 322.21) [35]. Calculations for impoverishing and CHE were performed in RWF. Our results were not sensitive to the choice of exchange rate. Data analysis was performed using R (version 3.5.1, Vienna, Austria).

Ethical approval

All women were enrolled after providing a written informed consent. Ethical approval for the study was granted by the Rwandan National Ethics Committee (Kigali, Rwanda, No. 848/RNEC/2016) and the Partners Human Research Committee (Boston, USA, No. 2016P001943/MGH).

Results

In total, 340 patients were interviewed with a median age of 26 years (IQR: 22, 31) (Table 1). Three (0.9%) had HIV, but the rest had no major medical problems. Nearly all ($n = 330$, 97.1%) patients had insurance, the majority ($n = 310$, 91.2%) with CBHI. Median household size was four (IQR: 3, 5) and most women were

Table 1 Patient characteristics for c-section patients at KDH ($N = 340$)

	Median (IQR) or n (%)
Age	26 (22–31)
Insurance	330 (97.1%)
None	10 (2.9%)
Private	20 (5.9%)
CBHI:	310 (91.2%)
Ubudehe Category 1	50 (16.1%)
Ubudehe Category 2/3	260 (83.9%)
Travel time to health center (min)	30 (15–45)
Travel time to hospital (min)	240 (60–720)
Length of stay (days)	3 (3–4)
Health conditions ($n = 339$)	
HIV	3 (0.9%)
Obesity	0 (0%)
Diabetes	0 (0%)
Anemia	0 (0%)
Occupation	
Farmer	234 (68.8%)
Unskilled labor	43 (12.6%)
Employed	29 (8.5%)
Self-employed	30 (8.8%)
House-wife	4 (1.2%)
Household size	4 (3–5)
Marital status ($n = 339$)	
Single	32 (9.4%)
Married	133 (39.2%)
Living with a partner	173 (51.0%)
Divorced	0 (0.0%)
Widowed	1 (0.3%)
Reported Annual Income[a]	$1489.71 ($893.83–$2234.57)
Expenditures ($n = 338$)	
Calculated annual household expenditure[b]	$439.01 (259.04, 610.87)
Daily expenditure/person, median[b]	$0.30 ($0.17–$0.45)

[a] Converted to USD using 2017 PPP

[b] Converted to USD using 2018 nominal exchange rate

either married ($n = 133$, 39.2%) or living with their partner ($n = 173$, 51.0%). About 15% ($n = 50$) of the insured study patients were in the lowest *Ubudehe* category. Median travel time from home to the health center was 30 minutes (IQR: 15, 45) and from the health center to the hospital was 4 hours (IQR: 1, 12). Median length of stay in the hospital was 3 days (IQR: 3, 4). Over two-thirds ($n = 234$, 68.8%) of patients were farmers. The summed median annual nominal total household expenditure was $439.01 ($259.04, $610.87), or $1163.99 (IQR: 686.82, 1619.67 using PPP), equating to a nominal median daily expenditure per person of $0.30 (IQR: $0.17, $0.45), or $0.80 (IQR: $0.45, $1.22) using PPP. Nearly all patients ($n = 334$, 98.8%) resided in households that would be classified as poor with 93.5% ($n = 316$) residing in extremely poor households.

The median medical expenditure paid OOP per patient at time of service was $9.36 (IQR: $7.83, $10.52), with consumables, medications, and the surgical procedure being the costliest expenses (Table 2). Median transportation cost to the health center was $1.17 (IQR: $0, $2.34) and from the health center to the hospital was $1.83 (IQR: $0, $2.81). Two patients took an ambulance from their home to the health center and 235 (67.9%) took one from the health center to the hospital. The median direct cost, including transportation, was $19.29 (IQR: $15.54, $25.22). Finally, when all direct and indirect costs are added together, median cost paid by the patient for c-section was $29.78 (IQR: $22.29, $39.81).

Figure 1 shows substantially higher rates of CHE for all patients and by *Ubudehe* category when adding direct and indirect costs to the medical costs alone. When only considering medical costs paid to the hospital, the risk of CHE is 5.3%; but when direct costs are added, this rises to 15.4% ($p < 0.001$), and with indirect costs, 22.6% of households experienced CHE ($p < 0.001$). The risk of CHE is higher for patients in the *Ubudehe* 2 and 3 categories than for patients in the *Ubudehe* 1 category ($p = 0.0026$). Before the hospitalization, 98.8% of patients were poor and 93.5% were extremely poor by the World Bank definitions. After hospitalization, these numbers rose to 99.4 and 96.7% respectively. Nearly half ($n = 164$, 48.2%) of patients borrowed money to pay for OOP costs related to the c-section with a median amount borrowed of $16.39 (IQR: $10.53, $23.41). Paying patients in *Ubudehe* categories 2 and 3 were more likely to have to borrow money to pay for care than patients with other insurance ($p < 0.001$), but at least one third of patients in all groups had to borrow money (Fig. 1). 43 patients (12.7%) had to sell possessions and one lost a job due to the surgery. Six patients paid for a caregiver during the hospitalization.

Under the assumptions of the insurance scheme modeling, CBHI dramatically reduces the rates of CHE. If there was no insurance coverage, 88% of households would experience CHE paying for medical costs alone and 95% if all direct costs are included (Fig. 1). At 64% coverage, the rates of CHE would be 35 and 56% for medical and all direct costs respectively. For 90% coverage, the CHE rates are 4 and 17% respectively. Finally, the model shows that even if all medical costs and transportation costs were covered, 3–4% of patients would still experience CHE from indirect costs.

Table 2 Summary of out-of-pocket expenditures for c-section hospitalization, direct and indirect costs by paying status (USD)[a]

	Total Median (IQR) ($n = 340$)	*Ubudehe* Category 1 Median (IQR) ($n = 50$)	*Ubudehe* Category 2/3 Median (IQR) ($n = 50$)	No Insurance Median (IQR) ($n = 10$)	Private Insurance Median (IQR) ($n = 20$)
Direct Medical					
Consumables	$2.51 (1.92–3.03)	$0.00	$2.56 (2.20–2.94)	$21.59 (14.49–27.58)	$3.94 (3.23–4.30)
Medications	$2.12 (1.57–2.58)	$0.00	$2.21 (1.82–2.57)	$17.87 (15.05–25.18)	$2.72 (2.52–3.31)
Procedure	$1.91 (1.91–1.91)	$0.00	$1.91 (1.91–1.91)	$66.97 (66.97–66.97)	$7.68 (7.34–7.68)
Labs	$1.18 (0.23–1.18)	$0.00	$1.18 (0.39–1.18)	$27.18 (13.55–40.81)	$4.44 (1.47–4.44)
Consultations	$0.31 (0.27–0.38)	$0.00	$0.31 (0.31–0.35)	$7.69 (7.39–10.18)	$1.09 (0.97–1.20)
Nursing care	$0.27 (0.15–0.35)	$0.00	$0.28 (0.21–0.34)	$9.63 (7.18–10.66)	$1.09 (0.80–1.19)
Imaging	$0.25 (0.00–0.25)	$0.00	$0.25 (0.00–0.25)	$0.00 (0.00–6.42)	$0.85 (0.00–0.92)
Hospitalization	$0.22 (0.11–0.28)	$0.00	$0.22 (0.17–0.28)	$5.82 (3.88–7.27)	$0.70 (0.62–0.90)
TOTAL	**$9.36 (7.83–10.52)**	**$0.00**	**$9.53 (8.54–10.38)**	**$158.89 (143.41–173.33)**	**$22.45 (21.28–24.72)**
Direct Non-Medical					
Food	$4.68 (2.93–5.85)	$3.51 (2.34–5.85)	$4.10 (2.93–5.85)	$2.34 (2.34–2.93)	$9.60 (5.85–11.71)
Transportation to health center	$1.17 (0.00–2.34)	$1.17 (0.00–1.76)	$1.17 (0.00–2.34)	$1.76 (1.32–1.90)	$0.59 (0.00–0.59)
Transportation to hospital	$1.83 (0.00–2.81)	$0.05 (0.00–2.26)	$1.87 (0.00–2.81)	$18.73 (3.71–28.09)	$0.00 (0.00–2.02)
Caregiver	$2.34 (0.00–5.85)	$1.87 (0.00–5.71)	$2.34 (0.00–5.33)	$0.70 (0.00–1.11)	$6.44 (3.07–11.91)
TOTAL DIRECT	**$19.29 (15.54–25.22)**	**$8.08 (5.27–15.22)**	**$20.18 (16.69–25.14)**	**$187.25 (156.36–208.95)**	**$42.55 (29.37–51.16)**
Indirect					
Lost wages	$9.31 (6.52–15.52)	$9.31 (6.52–14.90)	$9.31 (6.52–15.52)	$6.52 (6.52–8.61)	$17.07 (0.00–31.04)
TOTAL WITH INDIRECT	**$29.78 (22.29–39.81)**	**$16.33 (14.13–25.38)**	**$30.47 (24.66–39.16)**	**$201.94 (177.54–221.37)**	**$55.44 (44.74–69.78)**

[a] Converted to USD using nominal exchange rate

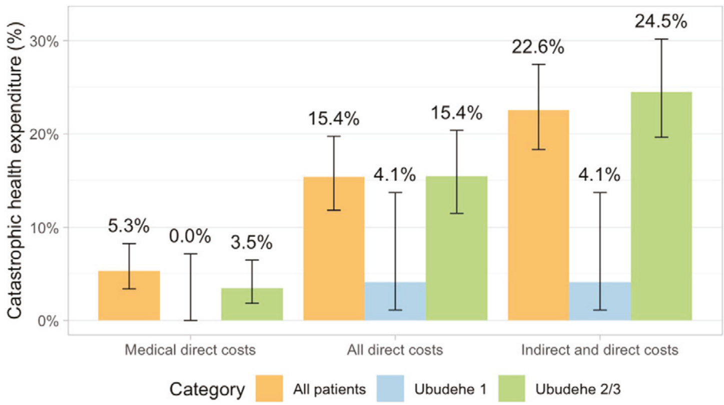

Fig. 1 Rates of CHE by CBHI category

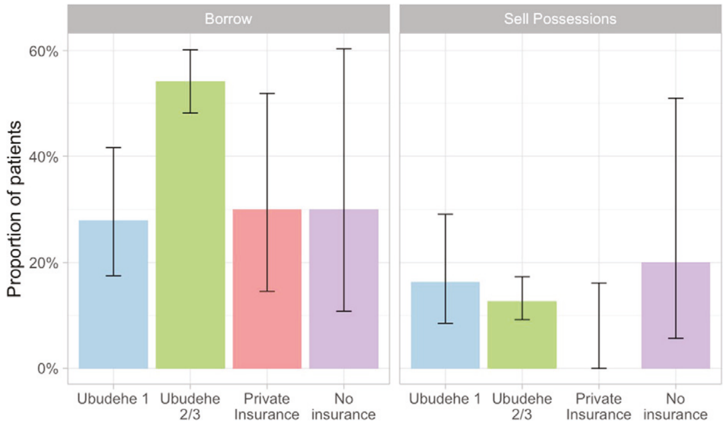

Fig. 2 Proportion of patients who borrowed money or sold possessions to pay for c-section expenses by insurance type

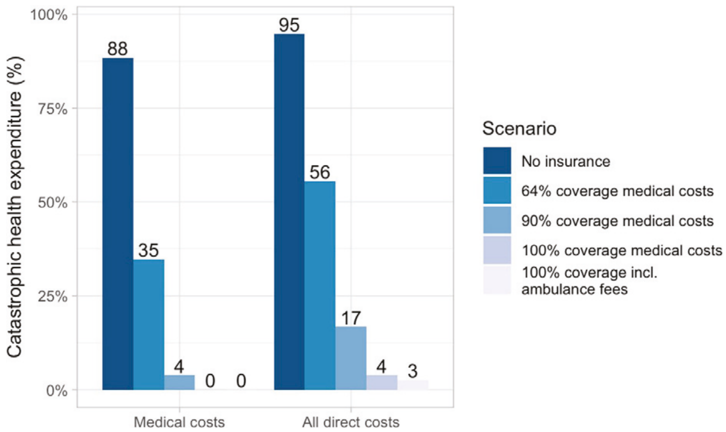

Fig. 3 Rates of CHE by insurance coverage models

Discussion

Despite nearly universal access to CBHI in Rwanda, up to a quarter of patients in our study still experienced CHE when paying for the direct and indirect costs of this essential surgical care. Eliminating the medical cost of care is not sufficient to alleviate this burden as it is the addition of transportation, food, and other indirect costs that cause financial catastrophe for many patients. Even modest nonmedical direct and indirect costs such as the median of $30 for a c-section are nontrivial for poor patients. Additional informal payments are noted in some African contexts [22], and these would certainly increase this OOP expenditure and rates of CHE. However, given strongly enforced anti-corruption policies throughout Rwanda, hospital leadership felt that such payments are rare, and hence this was not assessed in our study. There are, however, other nonmonetary costs even when patients are able to find the finances for surgical care: nearly half of patients had to borrow money from family or friends to pay their bill, thereby incurring an informal debt they would have to repay [36], and 12% had to sell possessions.

Though we found disappointingly high rates of CHE, these rates would be exponentially higher if there was no insurance at all. Our model showed that those with subsidized care had lower rates of CHE. Even if medical costs and transportation are fully subsidized, there will still be a low rate of CHE (3–4%) for impoverished patients. Not surprisingly, though, we found that when a higher percentage of costs are covered by insurance or by the government, far fewer patients are in danger of CHE. Consequentially, in the current system, the poorest patients who are fully subsidized with free care are better protected, while those in the next tier are more vulnerable to financial catastrophe. Notably, for all groups, c-section is not categorized as *impoverishing*. This is largely because across the *Ubudehe* categories, these women and their families are already classified as poor and most are extremely poor, hence are not considered impoverished by the expense according to the definitions used. Despite the introduction of *CBHI,* which reduced rates of OOPs and CHE, inequalities in the population have not been reduced [37]. Thus, further strategies are needed to target the challenges to accessing care for those living in poverty. Informal insurance structures have been shown to be of particular utility in reducing CHE in SSA [38]. In Ghana and Ethiopia, rates of CHE are also much higher in uninsured patients, and CBHI in particular was found to decrease rates of CHE by up to 23.2% [39, 40]. However, studies have also shown inequalities in who chooses to access CBHI with the rich utilizing it more and dropout rates being highest among those required to pay a premium for services [41]. This dynamic has also been anecdotally reported in Rwanda where patients may feel they are being taxed by the compulsory enrollment. In this scenario, voluntary enrollment with more community-level governance could be benficial [11].

Our findings suggest that there is need for greater financial protection for impoverished households in order to achieve the best medical and social outcomes for patients requiring hospital services and surgical care. In the Democratic Republic of Congo, 16% of women experienced CHE related to obstetric and neonatal care, particularly if there were any complications, while in Ghana, substantial rates of CHE were found due to transportation and indirect costs, particularly among patients with complications, despite free maternal health care [42, 43]. These issues extend beyond maternal health and c-sections, with studies from Malawi and Uganda demonstrating high rates of CHE for other surgical conditions despite free surgeries or no user fees [44–47]. A study by Mercy Ships (which provides free surgery to patients) demonstrated that paying for transportation decreased the no-show rate for surgery by 45% [48]. Policy makers could consider such initiatives as well as others that either offset the cost of transportation or decrease the need for transportation for these patients. Strategies to avoid compounding the financial risk in the post-operative period while obtaining the best outcomes might include vouchers to offset the cost of post-operative follow-up, home-based follow-up utilizing community health workers (CHWs), and empowering CHWs with mobile applications on smartphones to facilitate effective detection of surgical site infection and other post-operative complications, thus reducing the demand for in-person post-operative follow up [23].

Importantly, we note that true rates of CHE may be underestimated if patients choose not to have surgery due to associated costs. This is less likely for c-section patients in Rwanda, for whom surgery is usually urgent or emergent. However, when extrapolating to other types of operations including those considered elective initially or definitively, some patients may lack access to care based on financial capacity to pay. Poverty in Rwanda is correlated with lower health care services coverage [49], which suggests that despite financial protection for essential services, overall access to medical care for uncovered services is still threatened. The rate of CHE reported here is likely an underestimate as we did not include post-discharge costs or the cost of care for complications. Our group, in a previous study, found that the cost of travel from home-to-health center was a significant predictor of surgical site infection[50], potentially suggesting that these expenses are prohibiting the necessary follow-up care.

Limitations

This study had several key limitations. First, it was only conducted at a single site, which may have local geographic features, though culturally and socioeconomically the population does resemble other parts of rural Rwanda in terms of care seeking behavior and resources. Rwanda also has a unique political context, particularly relating to the CBHI program, and so the results and ensuing policy recommendations may not fully generalize to other LMICs. Second, this study may not capture any patients who did not seek hospital care due to inability to pay for services. That number is likely very small based on the high penetration of CBHI membership in the community around Kirehe. Furthermore, this study only looks at the rates of CHE for one essential procedure which is of value to an entire household, therefore the rates may not represent the financial risk of other surgical procedures which may be considered elective by either the family, the medical community, or the government.

Another limitation of our study is that we focused exclusively on the expenses incurred peripartum – from onset of labor up through discharge. These expenses should be considered in addition to any prenatal care expenses as well as postpartum care expenses, particularly for those who experienced complications after discharge. This study may thus underestimate the financial burden of c-section. A subsequent study to capture the expenses and CHE for women delivering via c-section through 30 days post-delivery is underway to better understand total financial risk for this population.

Another known limitation of this type of data collection is that the calculated household expenditure depends on patient memory of their regular expenses and therefore suffers from recall bias. Interestingly, when patients were asked their total monthly expenditure, the amount was generally higher than the sum of its components. Furthermore, in a rural population, households may not have regular expenses but rather have occasional larger purchases related to agriculture or home maintenance. Therefore, estimating daily expenditure may not be a consistent measure of a patient's true resources. Finally, indirect costs are likely underestimated since lost wages also include recovery time at home post-operatively.

Conclusions

In conclusion, OOP expenditure for essential surgery confers significant financial risk on already impoverished households, even where government acts in support of promoting UHC via initiatives such as financial subsidization through CBHI. Specifically, this study found that transportation costs to the hospital were a significant burden to families who needed transfer to the hospital for a c-section.. Providing solutions to this, such as providing free or discounted transport for peripartum women in rural areas, could be an area of focus. Additionally, we recognize that the merit of the impoverishment thresholds set by the international community are limited in utility as most of the patients in our study were already below the poverty threshold even prior to emergency surgery. Given that the cost of surgery is already low, rather than reducing cost, consideration ought to be given to ways of decreasing poverty rates in rural Rwanda and increasing the subsidies for those in *Ubudehe* groups 2 and 3 who are most affected. Our study highlights issues around surgical hospitalization bills-driven financial impoverishment and insurance effects for an extremely poor population. Policy makers need to complement the merits of CBHI by devising strategies that address more complex barriers to care that women face when delivering by c-section. This will ensure mitigation of the risk of financial catastrophe while optimizing good health outcomes for mothers and babies at the time of delivery.

Abbreviations

CHE: Catastrophic health expenditure; c-section: Cesarean section; CBHI: Community-based health insurance; CHW: Community health worker; IQR: Interquartile range; KDH: Kirehe District Hospital; LMIC: Low and middle income country; NGO: Non-governmental organization; OOP: Out of pocket; POD: Postoperative day; PGSSC: Program in Global Surgery and Social Change; PPP: Purchasing power parity; RWF: Rwandan Francs; SSA: Sub-Saharan Africa; UHC: Universal health coverage; USD: United States Dollar; WHO: World Health Organization.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12913-022-08101-3.

Additional file 1.

Additional file 2.

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Not applicable.

Authors' contributions

RK designed the study, interpreted results and wrote the manuscript, TN assisted with conception of the study and acquisition of data, NR performed data analysis, modeling and interpretation, JN and LB performed data acquisition, HI and KS assisted with conception of the paper, RR was a contributor to major draft revisions, BHG assisted with data analysis and significantly contributed to draft revision, MS assisted with study conception, design and analysis, and FK assisted with contextualization of results and manuscript revision. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All women were enrolled after providing a written informed consent. Study approval was granted by the Rwandan National Ethics Committee (Kigali, Rwanda, No. 848/RNEC/2016) and the Partners Human Research Committee (Boston, USA, No. 2016P001943/MGH).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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References

1. Meara JG, Leather AJM, Hagander L, et al. Global Surgery 2030: evidence and solutions for achieving health , welfare , and economic development. https://doi.org/10.1016/S0140-6736(15)60160-X.
2. Organization WH. Universal Health Coverage. Accessed 28 Feb 2019. https://www.who.int/healthsystems/universal_health_coverage/en/
3. Mock CN, Donkor P, Gawande A, et al. Essential surgery: key messages from disease control priorities, 3rd edition. Lancet. 2015. https://doi.org/10.1016/S0140-6736(15)60091-5.
4. Organization WH. WHO Statement on Caesarean Section Rates; 2015.
5. Harrison MS, Goldenberg RL. Cesarean section in sub-Saharan Africa. Matern Health Neonatol Perinatol. 2016;2(1):1–10. https://doi.org/10.1186/s40748-016-0033-x.
6. Molina G, Weiser TG, Lipsitz SR, et al. Relationship between cesarean delivery rate and maternal and neonatal mortality. JAMA. 2015;314(21):2263–70. https://doi.org/10.1001/jama.2015.15553.
7. Filippi V, Ganaba R, Calvert C, Murray SF, Storeng KT. After surgery: the effects of life-saving caesarean sections in Burkina Faso. BMC Pregnancy Childbirth. 2015;15(1). https://doi.org/10.1186/s12884-015-0778-7.
8. National Institute of Statistics of Rwanda. Rwanda Demographic and Health Survey 2014–15 - Final Report.; 2015. doi: March, 2016.
9. Bank W. Rwanda. Poverty & Equity Data Portal. Accessed 15 Aug 2018. http://povertydata.worldbank.org/poverty/country/RWA
10. Organization WH. Rwanda. Published 2014. Accessed 2 Dec 2018. https://www.who.int/countries/rwa/en
11. Chemouni B. The political path to universal health coverage: power, ideas and community-based health insurance in Rwanda. World Dev 2018;106(August 2015):87–98. doi:https://doi.org/10.1016/j.worlddev.2018.01.023.
12. Schneider P, Diop F. Community-based health Insurance in Rwanda. Health financing for poor people: Resource Mobilization and Risk Sharing 2005;(November):251–272.
13. Rwanda R of. Community-led Ubudehe categorisation kicks off. Published 2015. Accessed 6 Jan 2020. http://www.gov.rw/news_detail/?tx_ttnews%5Btt_news%5D=1054&cHash=a315a8b0054e76f9c699f05ce24d3eb8
14. Lu C, Chin B, Lewandowski JL, et al. Towards universal health coverage: an evaluation of Rwanda Mutuelles in its first eight years. PLoS One. 2012;7(6). https://doi.org/10.1371/journal.pone.0039282.
15. USAID. Health insurance profile. Rwanda: African strategies for health; 2013. p. 8–11. Published online
16. Woldemichael A, Gurara D, Shimeles A. The Impact of Community Based Health Insurance Schemes on Out-of-Pocket Healthcare Spending: Evidence from Rwanda. Vol 19. 2019. doi:https://doi.org/10.5089/9781484398074.001
17. Schieber GJ, Gottret P, Fleisher LK, Leive AA. Financing global health: Mission unaccomplished. Health Aff. 2007;26(4):921–34. https://doi.org/10.1377/hlthaff.26.4.921.
18. Rickard JL, Ngarambe C, Ndayizeye L, Smart B, Majyambere JP, Riviello R. Risk of catastrophic health expenditure in Rwandan Surgical patients with peritonitis. World J Surg. 2018;42(6):1603–9. https://doi.org/10.1007/s00268-017-4368-x.
19. Haakenstad A, Coates M, Marx A, Bukhman G, Verguet S. Disaggregating catastrophic health expenditure by disease area: cross-country estimates based on the world health surveys. BMC Med. 2019;17(1):1–9. https://doi.org/10.1186/s12916-019-1266-0.
20. Odhiambo J, Ruhumuriza J, Nkurunziza T, et al. Health facility cost of cesarean delivery at a Rural District Hospital in Rwanda Using Time-Driven Activity-Based Costing. Matern Child Health J. 2019;0:0. https://doi.org/10.1007/s10995-018-2674-z.
21. Masiye F, Kaonga O, Banda CM. Informal payments for primary health services in Zambia: evidence from a health facility patient exit survey. Health Policy OPEN. 2020;1(November):100020. https://doi.org/10.1016/j.hpopen.2020.100020.
22. Sonderman KA, Nkurunziza T, Kateera F, et al. Using mobile health technology and community health workers to identify and refer caesarean-related surgical site infections in rural Rwanda: a randomised controlled trial protocol. BMJ Open. 2018;8(5):1–7. https://doi.org/10.1136/bmjopen-2018-022214.
23. Anderson GA, Ilcisin L, Kayima P, et al. Out-of-pocket payment for surgery in Uganda: the rate of impoverishing and catastrophic expenditure at a government hospital. PLoS One. 2017;12(10):1–13. https://doi.org/10.1371/journal.pone.0187293.
24. Surgical N, Income TM. Financial Risk Protection Survey Financial Risk Protection Survey. :1–3.
25. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)-a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009. https://doi.org/10.1016/j.jbi.2008.08.010.
26. Shrime MG, Dare AJ, Alkire BC, O'Neill K, Meara JG. Catastrophic expenditure to pay for surgery worldwide: a modelling study. Lancet Glob Health. 2015;3(S2):S38–44. https://doi.org/10.1016/S2214-109X(15)70085-9.
27. Xu K, Evans DB, Kawabata K, Zeramdini R, Klavus J, Murray CJL. Household catastrophic health expenditure: a multicountry analysis. Lancet. 2003. https://doi.org/10.1016/S0140-6736(03)13861-5.
28. WHO. Monitoring Sustainable Development Goals –Indicator 3.8.2. Accessed 8 Jun 2019. https://www.who.int/health_financing/topics/financial-protection/monitoring-sdg/en/
29. The World Bank Group. Rwanda. Published 2016. Accessed 2 May 2019. https://data.worldbank.org/indicator/SI.POV.NAHC?locations=RW&view=chart
30. Shrime MG, Alkire BC, Grimes C, Chao TE, Poenaru D, Verguet S. Cost-effectiveness in global surgery: pearls, pitfalls, and a checklist. World J Surg. 2017;41(6):1401–13. https://doi.org/10.1007/s00268-017-3875-0.
31. Debas HT, Donkor P, Gawande A, Jamison DT, Kruk ME, Mock CN. Disease control priorities. 3rd ed; 2015.
32. Boerma T, Eozenou P, Evans D, Evans T, Kieny MP, Wagstaff A. Monitoring Progress towards universal health coverage at country and global Levels : framework, measures and targets. PLoS Med. 2014;11(9):1–12 WHO/HIS/HIA/14.1.
33. The World Bank Group. Out of Pocket Expenditure (% of current health expenditure). Global Health Expenditure Database. Published 2017. Accessed August 16, 2020. C-section rates in Rwanda are 13.0%25 nationally and11.1%25 in rural areas9 putting a significant portion of the population at risk for financial burden despite heavy subsidies.%0D%0A%0D%0A.
34. The World Bank Group. PPP conversion factor. Accessed 15 Nov 2018. https://data.worldbank.org/indicator/PA.NUS.PRVT.PP?locations=RW
35. Husøy OK, Molla SM, Muluken G, Marie MK, Frithof NO, Ingrid M. Selling my sheep to pay for medicines - household priorities and coping strategies in a setting without universal health coverage. BMC Health Serv Res. 2018;18(1):1–12. https://doi.org/10.1186/s12913-018-2943-y.
36. Liu K, Cook B, Lu C. Health inequality and community-based health insurance: a case study of rural Rwanda with repeated cross-sectional data. Int J Public Health. 2019;64(1):7–14. https://doi.org/10.1007/s00038-018-1115-5.
37. Njagi P, Arsenijevic J, Groot W. Understanding variations in catastrophic health expenditure, its underlying determinants and impoverishment in sub-Saharan African countries: a scoping review. Syst Rev. 2018;7(1). https://doi.org/10.1186/s13643-018-0799-1.
38. Aryeetey GC, Westeneng J, Spaan E, Jehu-Appiah C, Agyepong IA, Baltussen R. Can health insurance protect against out-of-pocket and catastrophic expenditures and also support poverty reduction? Evidence from Ghana's National Health Insurance Scheme. Int J Equity Health. 2016;15(1):1–11. https://doi.org/10.1186/s12939-016-0401-1.
39. Mekonen AM, Gebregziabher MG, Teferra AS. The effect of community based health insurance on catastrophic health expenditure in Northeast Ethiopia: a cross sectional study. PLoS One. 2018;13(10):1–13. https://doi.org/10.1371/journal.pone.0205972.
40. Umeh CA, Feeley FG. Inequitable access to health care by the poor in community-based health insurance programs: a review of studies from low-and middle-income countries. Glob Health Sci Pract. 2017;5(2):299–314. https://doi.org/10.9745/GHSP-D-16-00286.
41. Ntambue AM, Malonga FK, Cowgill KD, Dramaix-Wilmet M, Donnen P. Incidence of catastrophic expenditures linked to obstetric and neonatal care at 92 facilities in Lubumbashi, Democratic Republic of the Congo, 2015. BMC Public Health. 2019;19(1):1–15. https://doi.org/10.1186/s12889-019-7260-9.
42. Dalaba MA, Akweongo P, Aborigo RA, et al. Cost to households in treating maternal complications in northern Ghana: a cross sectional study. BMC Health Serv Res. 2015;15(1):1–8. https://doi.org/10.1186/s12913-014-0659-1.

43. Bijlmakers L, Wientjes M, Mwapasa G, et al. Out-of-pocket payments and catastrophic household expenditure to access essential surgery in Malawi - a cross-sectional patient survey. Ann Med Surg. 2019;43(March):85–90. https://doi.org/10.1016/j.amsu.2019.06.003.
44. Yap A, Muzira A, Cheung M, et al. A cost-effectiveness analysis of a pediatric operating room in Uganda. Surgery (United States). 2018;164(5):953–9. https://doi.org/10.1016/j.surg.2018.03.023.
45. MacKinnon N, St-Louis E, Yousef Y, Situma M, Poenaru D. Out-of-pocket and catastrophic expenses incurred by seeking pediatric and adult Surgical Care at a Public, tertiary Care Centre in Uganda. World J Surg. 2018;42(11):3520–7. https://doi.org/10.1007/s00268-018-4691-x.
46. Albutt K, Yorlets RR, Punchak M, et al. You pray to your god: a qualitative analysis of challenges in the provision of safe, timely, and affordable surgical care in Uganda. PLoS One. 2018;13(4):1–16. https://doi.org/10.1371/journal.pone.0195986.
47. Shrime MG, Hamer M, Mukhopadhyay S, et al. Effect of removing the barrier of transportation costs on surgical utilisation in Guinea, Madagascar and the republic of Congo. BMJ Glob Health. 2017;2:4–7. https://doi.org/10.1136/bmjgh-2017-000434.
48. Liu K, Subramanian SV, Lu C. Assessing national and subnational inequalities in medical care utilization and financial risk protection in Rwanda. Int J Equity Health. 2019;18(1):1–10. https://doi.org/10.1186/s12939-019-0953-y.
49. Nkurunziza T, Kateera F, Sonderman K, et al. Prevalence and predictors of surgical-site infection after caesarean section at a rural district hospital in Rwanda. Br J Surg. 2019;106(2):e121–8. https://doi.org/10.1002/bjs.11060.

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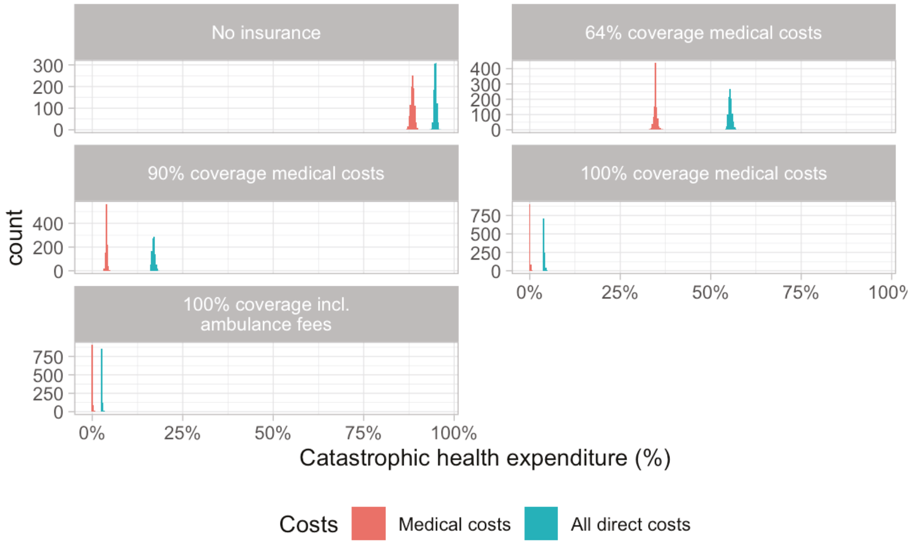
Supplemental Figure 1



Financial Risk Protection Survery

Patient study identification number	__________________________________
What is the size of your household, including yourself and new infant? (how many members normally live in your house)	__________________________________
What occupation is held by the person who makes the most money in your household (primary breadwinner)?	◯ Student ◯ Farmer ◯ Employed (Government / NGO / Private company) ◯ Self-employed ◯ House-wife ◯ Other ◯ Unskilled labor (non-agricultural)
If other, what?	__________________________________
How much does your household earn in an average month?	__________________________________
How much money does your household spend on food (including oil, salt, sugar, cooking petrol) and water, juice or soda to drink per month?	__________________________________
How much money does your household spend on livestock (cows, pigs, goats, chickens etc.) every month? [if not known please indicate yearly expenditure]	__________________________________
How much money does your household spend on transport per month?	__________________________________
How much does your household pay for your house/apartment in rent or mortgage or housing fees per month (if applicable)?	__________________________________
How much money does your household spend on other household items such as clothes, improvements to your house etc per month? [if not known, estimate per year]	__________________________________
How much money does your household spend on education per term for all the children you support, including school fees and books?	__________________________________
Do you have other regular expenditures?	◯ Yes ◯ No
If so what are they and how often do you pay them?	__________________________________
How much are these other expenditures?	__________________________________
Excluding this hospital course, how much money does your household usually spend on health care, including medicines, fees for doctors or hospital visits, fees for traditional healers per year?	__________________________________

Hospitalization Associated Expenditures

How many days were you in the hospital?
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7 or more

How much did you pay each day you were in the hospital?

____

How much money in total did your household spend for (all)/the attendant(s) to come to the hospital to bring food or look after the patient?

____

Did you have to pay any fees or make any informal payments directly to healthcare workers or hospital employees for your surgery or hospitalization?
- ◯ Yes
- ◯ No

If yes, how much did you pay?

____

Did your household pay anyone else to act as an attendant and take care of the patient during this hospitalization?
- ◯ Yes
- ◯ No

Did you household have to borrow money to pay for this hospitalization?
- ◯ Yes
- ◯ No

If yes, how much?

____

Did your household have to sell land or possessions (including livestock) to pay for this hospitalization?
- ◯ Yes
- ◯ No

Did your household have to permanently stop sending children to school, or did you pay reduced school fees in order to pay for this hospitalization?
- ◯ Yes
- ◯ No

What amount did your household spend on food during the hospitalization?

____

What amount in wages has your household lost due to this hospitalization? (ie. calculate based on how many people have missed work and for how many days and their daily wage)

____

Did you or anyone in your household permanently lose a job as a result of this hospitalization?
- ◯ Yes
- ◯ No

How much did you receive in outside funds from charity or from the social worker/hospital fund to pay for your hospitalization for all goods and services?

____

Hospital Expenses

Hospital electronic ID ______________________________

How much money did the patient spend on this hospitalization? ______________________________

How much money did you spend on medications & other consumables? (from hospital records) ______________________________

How much money did your household spend on laboratory tests? (from hospital records) ______________________________

How much money did you spend on procedures, bandages and dressing supplies? (from hospital records) ______________________________

How much money did your household spend on imaging and x-ray? (from hospital records) ______________________________

How much money did your household spend on any other medical supplies? (from hospital records) ______________________________

How much did you spend on ambulance fees? ______________________________

Did you have to pay any other fees to the hospital besides those we have already mentioned?
◯ Yes
◯ No

If yes, how much? ______________________________

Study V

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RESEARCH

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The true costs of cesarean delivery for patients in rural Rwanda: Accounting for post-discharge expenses in estimated health expenditures

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Abstract

Introduction: While it is recognized that there are costs associated with postoperative patient follow-up, risk assessments of catastrophic health expenditures (CHEs) due to surgery in sub-Saharan Africa rarely include expenses after discharge. We describe patient-level costs for cesarean section (c-section) and follow-up care up to postoperative day (POD) 30 and evaluate the contribution of follow-up to CHEs in rural Rwanda.

Methods: We interviewed women who delivered via c-section at Kirehe District Hospital between September 2019 and February 2020. Expenditure details were captured on an adapted surgical indicator financial survey tool and extracted from the hospital billing system. CHE was defined as health expenditure of $\geq$ 10% of annual household expenditure. We report the cost of c-section up to 30 days after discharge, the rate of CHE among c-section patients stratified by in-hospital costs and post-discharge follow-up costs, and the main contributors to c-section follow-up costs. We performed a multivariate logistic regression using a backward stepwise process to determine independent predictors of CHE at POD30 at $\alpha \leq 0.05$.

Results: Of the 479 participants in this study, 90% were classified as impoverished before surgery and an additional 6.4% were impoverished by the c-section. The median out-of-pocket costs up to POD30 was US$122.16 (IQR: $102.94, $148.11); 63% of these expenditures were attributed to post-discharge expenses or lost opportunity costs (US$77.50; IQR: $67.70, $95.60). To afford c-section care, 64.4% borrowed money and 18.4% sold possessions. The CHE rate was 27% when only considering direct and indirect costs up to the time of discharge and 77% when including the reported expenses up to POD30. Transportation and lost household wages were the largest contributors to post-discharge costs. Further, CHE at POD30 was independently predicted by membership in community-based health insurance (aOR = 3.40, 95% CI: 1.21,9.60), being a farmer (aOR = 2.25, 95% CI:1.00,3.03), primary school education (aOR = 2.35, 95% CI:1.91,4.66), and small household sizes had 0.22 lower odds of experiencing CHE compared to large households (aOR = 0.78, 95% CI:0.66,0.91).

Conclusion: Costs associated with surgical follow-up are often neglected in financial risk calculations but contribute significantly to the risk of CHE in rural Rwanda. Insurance coverage for direct medical costs is insufficient to protect

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against CHE. Innovative follow-up solutions to reduce costs of patient transport and compensate for household lost wages need to be considered.

Keywords: Cost of post-operative care, Healthcare cost, Follow-up care, Catastrophic health expenditure, Cesarean, c-section, Rural, Health insurance, Poverty, Healthcare access

Introduction

Access to emergency obstetric care, including cesarean sections (c-sections), is an essential part of a functional health system [1]. However, inequalities in c-section access have been reported across and within countries [2, 3]. Financial barriers are the most cited driver of c-section inaccessibility [4], with poor access most affecting the economically deprived [5–7]. Limited access to c-sections is associated with higher risks of poor outcomes for mothers and their babies [4, 8].

C-sections are considered cost-effective interventions, costing US$251 to US$3,462 per disability adjusted life year saved [9]. However, women who deliver via c-section are at risk of financial hardship. Studies in sub-Saharan Africa have estimated the direct costs of c-section to be $144-$426 [10–12], a considerable amount compared to the average regional gross domestic product (GDP) per capita of $4,195 in 2019 [13]. Even when direct costs are heavily subsidized, indirect costs put a woman and her family in financial risks [14]. Studies have shown that surgery in general [9, 15, 16], and c-sections specifically [17, 18], can be financially catastrophic for a patient's family. However, these studies fail to include the extended costs for surgery, and potentially underestimating the true risk of catastrophic health expenditures (CHEs) due to surgery.

In Rwanda, the location of this study, 28% of patients undergoing peritonitis surgery suffered CHEs as a result of the surgery [19]. While these studies include direct and indirect medical costs up to the time of discharge, we are unaware of any study of surgery in Africa that considers costs associated with postoperative follow-up after discharge. In this paper, we describe the financial costs of c-section care for Rwandan women delivering via c-section at a rural district hospital, including direct and indirect costs of all care received up to postoperative day (POD 30), and estimate the full risk of CHE for these women.

Methods

Study setting

This study was nested in a prospective cohort study conducted at Kirehe District Hospital, which aimed to evaluate the feasibility and acceptability of a telemedicine intervention for the diagnosis of post-hospital discharge surgical site infections by community health workers. Kirehe District Hospital is located in the Eastern Province of Rwanda and is managed by Rwanda's Ministry of Health with technical support from Partners In Health/Inshuti Mu Buzima (PIH/IMB), a Boston-based non-governmental organization that provides technical support to the Ministry of Health.

In Rwanda, c-sections are typically performed at district hospitals by general practitioners (GPs) [20], and at Kirehe District Hospital, c-section is the most commonly performed surgery. After delivery, women are monitored in a post-c-section ward and usually discharged on POD 3. In Rwanda, there are no standardized guidelines for c-section follow-up; however, at Kirehe District Hospital, c-section patients are asked to visit the local peripheral health centers three days post-discharge for wound inspection and dressing change and to continue follow-up until deemed unnecessary by the health center nurse.

Approximately 83% of the Rwandan population has health insurance and 96.1% of insured rural residents are enrolled in the community-based health insurance (CBHI) program [21]. Rwanda's CBHI is based on a 4-tier wealth system called *Ubudehe*, with the bottom tier including the poorest and the upper tier including the wealthiest Rwandans. For those in *Ubudehe* 1, CBHI premium is fully subsidized by the government; individuals in *Ubudehe* 2 and 3 pay CHBI premiums of approximately US$3 per person each year and those in *Ubudehe* 4 pay a premium of US$7 per person per year[22]. Individuals in *Ubudehe* 1 pay no copayment at point of care while those in *Ubudehe 2–4* incur a 10% copayment for direct medical services.

Sample selection

We used a convenient sample of women who delivered via c-section at Kirehe District Hospital between September 23rd, 2019 and February 22nd, 2020, who were eligible for and enrolled in a prospective cohort study aiming to evaluate the feasibility and acceptability of a telemedicine intervention for the diagnosis of post-hospital discharge surgical site infections by community health workers.

Data collection

Enrollment data collection

Women were enrolled after c-section delivery and prior to discharge. All participants provided informed consent prior to data collection. Data collectors administered sociodemographic and clinical characteristics questionnaires before patients were discharged from the hospital; data were directly entered into REDCap data management software [23]. Patients also responded to a financial survey, described below. Data on healthcare expenditures was extracted from OpenMRS, an online database tracking details on patients' medical care and expenses.

Follow-up data collection

At enrollment, respondents provided cell phone numbers (their own, a relative's or a neighbor's) on which they could be contacted. On POD 30 (± 1 day), data collectors administered a phone-based follow-up interview to assess post-discharge follow-up activities. The costs of post-discharge c-section follow-up were assessed in terms of expenses for medical care, expenses for transport, and lost wages due to seeking follow up care at the health centers. Study participants that could not be reached by the phone number they provided at discharge were contacted in person by a local community health worker and a telephone survey was administered on the community health worker's telephone. Three attempts on three different days were made in an effort to maximize the response rate; individuals not contacted after three attempts were considered lost-to-follow-up. The POD30 response rate was 84%.

Financial Survey

Our financial survey was adapted from a standardized financial questionnaire developed and validated through the National Surgical Obstetric Anesthesia Planning by the Program in Global Surgery and Social Change [24]. We added the following variables to the core questionnaire: estimates of monthly household income, self-reported routine monthly household expenditure, whether the patient had to borrow money or sell possessions to pay for the current hospitalization, and household monthly consumption as a sum of expenditures for food and drink, transportation, livestock, housing, transportation fees, school fees, and healthcare in the past months. Non-monetary income such as agricultural harvest was converted into Rwandan Franc (RWF) using the price of local goods at the time of data collection. Lost wages were estimated using daily wages for the occupation of the patients and caregiver at the time, and reported in RWF.

Definition of key terms

We stratified expenses into two main categories: in-hospital costs and post-discharge follow-up costs. The in-hospital costs include expenditures from when a woman left her home to seek care for delivery until the time of discharge. In-hospital costs were further grouped into direct medical, direct non-medical, and indirect costs. Direct medical costs included payments for medical supplies, medications, laboratory exams, surgical procedure, imaging, consultation, and hospital bed. Direct non-medical costs included expenses of a caregiver during hospitalization, food and transport from home to hospital. Indirect costs included household lost wages due to hospitalization. Post-discharge follow-up costs included direct medical cost paid at the health center in addition to indirect follow-up costs. The direct non-medical follow-up costs included transport from hospital to home for the patient and caregiver, transportation to the health center for patient and caregiver; while indirect follow-up costs included lost wages due to delayed return to work and lost wages of both the patient seeking follow-up care and that of the accompanying caregiver. We chose to include the cost of transport from the hospital to home after the c-section in the follow-up care costs as these expenses are generally not factored in CHE studies and allows for direct comparability of our results.

Poverty was defined using the World Bank definitions, defined as a daily expenditure below $1.90 per person per day [25]. Catastrophic health expenditure (CHE) has been variously defined as out-of-pocket healthcare expenses that exceeds 10% of total annual household expenditure or income [26, 27], or as spending greater than 40% of the annual household income, excluding subsistence needs, on health care [28]. For this study, we defined CHE as healthcare spending of greater than 10% of annual household consumption to align with the definition of the United Nations' Sustainable Development Goals 3.8.2 [29]. The annual household consumption was defined as a sum of annual expenditures on food and drink, transportation, livestock, housing, transportation fees, school fees, healthcare and other expenses.

Statistical analysis

We restricted our analysis to patients who responded to the financial questionnaires at both time points. We also restricted our analyses to individuals who sought follow-up care at the health center at least once during the first 30 postoperative days so we could estimate the costs associated to follow-up care. All tradeable financial expenses, such as in-hospital expenses and transport fees, were converted into US dollars (US$) using the nominal exchange rate at study start date (October, 2019), and US$1 equated RWF916.17 [30]. All non-tradeable expenses, including income and lost wages were converted to US$ using the 2019 Rwanda purchasing power parity (PPP) conversion factor for personal consumption of 317.18 [31].

We describe our sample, focusing on the demographic characteristics, household characteristics, and clinical features most relevant to understanding the study population and resources and complexity of c-section recovery, using frequency and percentages for categorical variables, mean and standard deviation (SD) for normally distributed continuous variables, and median and interquartile range (IQR) for continuous variables with non-normal distributions. We summarize the financial cost of c-section care stratified by Rwanda's four-tier wealth classification by in-hospital and follow-up care components, using median and interquartile range. We summarize each of the main cost contributors as a percentage of the overall costs. We also calculated incidence of CHE for all expense categories and reported the frequencies and percents. We conducted Chi-square tests for categorical predictor variables and Wilcoxon rank sum test for continuous predictors to assess the association between CHE and patients' characteristics. We then performed a Wald test for multivariate logistic regression to assess independent predictors of CHE at POD30. The bivariate analysis included pre-cesarean section characteristics such as: age, education, type of insurance, occupation, Ubudehe category parity, number of antenatal care visits, number of prior c-sections, mode of transport to health facility, travel time from home to health center, travel time from health center to the hospital and household size. All variables significant at the $\alpha = 0.20$ significance level were considered for the full model; we then reduced the full model using a backward stepwise process and removed non-statistically significant variables one at the time until the final model remained with variables significant at $\alpha = 0.05$ significance level. Our final regression model is specified as:

$$\log\frac{p}{1-p} = \beta_0 + \sum_{i=1}^{m}\beta_i x_i$$

where x_i are the covariates retained in the model corresponding to the coefficients, β_i, that remain significant at the $\alpha = 0.05$ significance level after the backward stepwise process. CHE at POD30 as a dichotomous variable, was the dependent variable in the multivariate regression analysis and level of education, main occupation, health insurance types and household size were the covariates that remained in the final reduced model.

We determined the daily expenditure per person in the household as a sum of individual expenses of the household divided by the household size, and report the proportion of participants who lived below the poverty line, before c-section delivery. We then calculated the total expenditure remaining after paying c-section cost, and estimated the proportion of women whose spending is below poverty line. The percentage of people who were pushed into extreme poverty by c-section delivery reflects people whose annual total expenditure were above poverty line at baseline, but who fell below poverty after paying for the costs of c-section care up through POD30.

Results

In total, 479 patients were included in this study, of whom 68.7% were aged less than 30 years, and the majority (94.8%) were insured by CBHI (Table 1). All c-sections were performed at KDH by general practitioners. Approximately 10% of patients belonged to the lowest *Ubudehe* category, 84.7% were farmers and the median annual household income was US$532.8 (IQR: $232.8, $859.1). The median travel time from home to health center was 30 min (IQR: 15, 60 min) and from health center to hospital was 40 min (IQR: 5, 60 min). For the 433 (81%) patients who first sought care at the health center prior to going to Kirehe District Hospital, 61.6% were transported to the hospital in ambulance and 26.9% walked to the hospital.

The median household size was 4 people (IQR: 3, 6) (Table 1). The annual household expenditure was US$504.8 (IQR: $331.8, $751.8), translating to a daily expenditure of US$0.3 (IQR: $0.2, $0.5) per person. An overwhelming majority of women (90%) were from households living below the international extreme poverty line. Over half of participants (64%) borrowed money and 18.4% sold possessions to cover c-section related costs.

Table 2 summarizes the out-of-pocket costs of c-section by expense categories.

Up to the time of discharge, the median direct medical costs of cesarean section was US$8.8 (IQR: $8.0, $9.7) and indirect costs was USD$15.0 (IQR: $10.1, $21.7). The median total costs up to the time of hospital discharge was US$40.0 (IQR: $30.4, $55.7). These costs ranged from US$23.7 (IQR: $15.3, $38.3) for patients in *Ubudehe 1*, US$37.9 (IQR: $29.9, $54.3) for patients in *Ubudehe 2*, and US$46.0 (IQR: $35.9, $60.5) for patients in *Ubudehe 3 and 4*.

For post-discharge costs, the median number of follow-up visits at the health center was 2 (IQR: 1, 3) and the cost of medical bills was US$0.5 (IQR: $0.3, $0.7). The median post-discharge costs of c-section was US$71.4 (IQR: $60.7, $81.8) for patients in *Ubudehe 1*, US$77.5 (IQR: $67.7, $95.6) for patients in *Ubudehe 2*, US$79.7 (IQR: $71.1, $97.8) for patients in *Ubudehe 3 and 4.*

The total cost of c-section up to POD 30 was US$100.5 (IQR: $87.2, $118.4) for *Ubudehe 1*, US$119.4 (IQR: $102.6, $149.2) for *Ubudehe 2*, and US$134.1 (IQR: $113,

Table 1 Characteristics of c-section patients at Kirehe District Hospital (*N* = 479)

	Frequency	Percent
	***N* = 479**	**(%)**
SOCIODEMOGRAPHIC CHARACTERISTICS		
Age		
< 18	17	3.6
18–30	312	65.1
31–40	131	27.3
> 40	19	4.0
Level of education		
Less than 6 years of primary school	48	10.0
Completed 6 years of primary school	314	65.6
Secondary school or more [¥]	117	24.4
Occupation		
Farmer	406	84.7
Employed	54	11.3
Unemployed	19	4.0
Ubudehe* **categories (*N* = 477)**		
Ubudehe 1	44	9.2
Ubudehe 2	258	54.1
Ubudehe 3 & 4	175	36.7
Insurance Type		
Community Based Health Insurance or *Mutuelle*	454	94.8
Private	25	5.2
CLINICAL CHARACTERISTICS		
Parity		
Primiparous (1)	167	34.9
Multiparous (2–5)	277	57.8
Grand-multiparous (> 5)	35	7.3
Antenatal Care Visits (*N* = 478)		
1 to 4	473	98.9
Greater than 4	5	1.1
Patients with postoperative complications¶	10	2.1
Number of post discharge follow up visits Median (IQR)	2	(1–3)
Number of prior c-section		
None	325	68.4
1	111	23.4
2 or 3	39	8.2
ACCESS TO HOSPITAL AND HEALTH CENTER		
Mode of transport (health center to hospital)		
Ambulance	295	61.6
Walked	129	26.9
Public or private transport	17	3.1
Travel times		
Home to health center (min) Median (IQR)(*N* = 435)	30	(15,60)
Health center to hospital (min) Median (IQR)(*N* = 434)	40	(5,60)
HOUSEHOLD FINANCIAL CHARACTERISTICS		
Household size, Median (IQR)	4	(3,6)
Self-reported annual income, (USD), Median (IQR)	1510.4	(1028.0,2435.5)
Self-reported annual household expenditure, (USD)§, Median (IQR) *N* = 476	504.8	(331.8,751.8)
Daily expenditure/person, (USD)§ median (IQR)	0.3	(0.2–0.5)

Table 1 (continued)

	Frequency	Percent
Living below international poverty line‡	431	90.0
Borrowed money to afford c-section expenses *N* = 478	308	64.4
Sold possessions to afford c-section expenses (*N* = 474)	87	18.4

¥ Secondary school or more: include those who enrolled in high school but didn't complete it, those who completed of high school, and those who have some years of education in a bachelor or masters degrees

[*] 4-tier wealth system the bottom tier represents the least privileged and the upper tier is for the financially better off

[¶] Post-operative complications include surgical site infections, post-partum hemorrhage, wound dehiscence and other wound complication

[§] Converted to USD using nominal exchange rate at study start date (October, 2019) 1 USD = 916.17 RWF

‡International extreme poverty line = 1.9USD

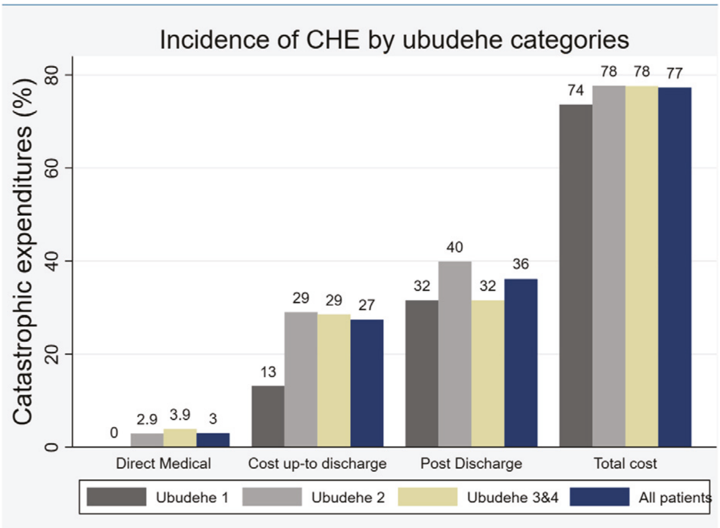

Fig. 1 Incidence of catastrophic health expenditure by *Ubudehe* categories

$161.3) for *Ubudehe 3 and 4*. The cost of post-discharge expenses contributed 64.3% of these costs.

On average, 55.3% of the overall cost was taken up for post discharge lost wages, 15.8% for post discharge follow up at the health center, 13.3% for caregiving and 11.0% for transportation.

When including only the costs up to the time of discharge, the cost of c-section was catastrophic for 3.0% of patients if only accounting for direct medical expenses and 27.0% when non-medical expenses were included (Fig. 1). Patients in *Ubudehe 1* had the lowest rate of CHE up to discharge (13.0%) compared to the rate of 29.0% for patients in *Ubudehe 2* and *Ubudehe 3 and 4*. When considering all costs through POD 30, the overall cost of c-section was catastrophic for 77.0% of patients. An additional 6.4% of patients were pushed into extreme poverty by the cost of the c-section.

From the bivariate analysis, factors associated with CHE that were identified as candidates for the multivariate logistic regression were: level of education ($p < 0.01$), occupation ($p < 0.01$), Ubudehe categories ($p = 0.16$), type of insurance ($p < 0.01$), parity ($p = 0.17$), mode of transport from health center to hospital ($p = 0.03$), travel time from home to health center ($p = 0.01$), and household size ($p = 0.07$). In a final reduced multivariate logistic regression model (Table3), women who completed primary school had 2.35 times higher odds to report CHE at POD30 than those who had secondary school enrollment

Table 2 Summary of total and out-of-pocked expenditure for c-section hospitalization and follow up by *Ubudehe* categories (in US$) (N=477)

N=477	Total expenditure (USD)		Out-of-pocket expenditure (USD)					
	All partcipants		Ubudehe 1 n=44		Ubudehe 2 n=258		Ubudehe 3 and 4 n=175	
	Median(US$)	(IQR)	Median(US$)	(IQR)	Median(US$)	(IQR)	Median(US$)	(IQR)
INHOSPITAL EXPENDITURE								
DIRECT MEDICAL								
Consumables N=395	0.65	(0.65 , 0.73)	0.00	(0,0)	0.65	(0.65,0.73)	0.7	(0.65, 0.73)
Medications N=452	4.13	(3.61 , 4.63)	0.00	(0,0)	4.14	(3.75, 4.60)	4.18	(3.88, 4.97)
Procedure N=455	2.10	(2.00 , 2.17)	0.00	(0,0)	2.11	(2.06, 2.17)	2.13	(2.05, 2.22)
Labs N=452	1.12	(0.85 , 1.12)	0.00	(0,0)	1.12	(1.12, 1.12)	1.12	(1.12, 1.12)
Consultations N=455	0.29	(0.26 , 0.35)	0.00	(0,0)	0.30	(0.29, 0.34)	0.31	(0.29, 0.39)
Imaging N=455	0.23	(0.20 , 0.23)	0.00	(0,0)	0.23	(0.23, 0.23)	0.23	(0.23, 0.23)
Hospitalization /bed N=455	0.16	(0.11 , 0.21)	0.00	(0,0)	0.16	(0.11, 0.21)	0.16	(0.11, 0.27)
TOTAL DIRECT MEDICAL (n=435)	**8.80**	**(8.00,9.66)**	**0.00**	**(0,0)**	**8.83**	**(8.24,9.56)**	**9.08**	**(8.36,10.30)**
DIRECT NON-MEDICAL								
Cost of caregiving N=477	5.55	(2.00,11.10)	5.00	(1.89, 9.99)	4.44	(1.11, 9.99)	6.66	(2.55, 13.32)
Food N=468	5.6	(3.33 , 7.77)	3.89	(2.78, 5.55)	5.55	(3.33, 7.77)	5.55	(3.33, 8.33)
Transport from home to hospital N=468	3.00	(1.11,5.00)	1.11	(0.47,3.09)	3.17	(1.67,5.22)	3.33	(1.33,5.45)
TOTAL DIRECT NON MEDICAL (420)	**15.00**	**(10.10,21.65)**	**10.55**	**(6.34,16.15)**	**14.21**	**(9.99,20.65)**	**16.64**	**(12.21,24.70)**
Household lost wages(N=477)	13.24	(8.82,24.27)	11.82	(7.57,20.02)	12.61	(8.83,22.06)	17.34	(9.46,25.22)
TOTAL IN-HOSPITAL COST (378)	**40.04**	**(30.40,55.72)**	**29.15**	**(20.55,43.52)**	**23.7**	**(15.34,38.32)**	**37.88**	**(29.90,54.30)**
POST-DISCHARGE EXPENDITURE								
Transport from hospital to home ,patient (N=467)	2.78	1.67 ,3.33)	2.78	(1.67, 3.33)	2.78	(1.67, 3.33)	2.78	(1.67, 3.33)
Transport from hospital to home ,caregiver (N=467)	2.78	1.67 ,3.33)	2.78	(1.67, 3.33)	2.78	(1.67, 3.33)	2.78	(1.67, 3.33)
DIRECT MEDICAL (MEDICAL BILL)	0.49	(0.24,0.73)	0.11	(0.04, 0.33)	0.49	(0.24, 0.73)	0.49	(0.24,0.73)
INDIRECT NON-MEDICAL								
Transportation to HC	3.33	(1.78,5.55)	3.33	(2.20, 5.83)	3.33	(2.00, 6.66)	3.33	(1.67, 5.55)
Caregiver's lost wage due to accompanying patient	0.00	(0.00,4.10)	2.21	(0.00, 4.04)	2.21	(0.00, 4.41)	1.11	(0.89, 2.22)
Household lost wages due to care seeking	65.6	(57.38, 81.97)	59.59	(49.18,67.78)	65.58	(57.38,81.97)	67.88	(57.38,81.97)
TOTAL COST OF POST-DISCHARGE FOLLOW	**77.47**	**(67.86,95.85)**	**71.41**	**(60.74,81.83)**	**77.18**	**(67.70, 95.60)**	**79.68**	**(71.05,97.82)**
TOTAL COST OF CS 30 DAYS POSTOPERATIVELY	**122.16**	**(102.94,148.09)**	**100.46**	**(87.18,119.14)**	**119.36**	**102.60,148.172)**	**134.05**	**(113.04,161.27)**

* Expenses are converted to USD using nominal exchange rate at study start date (October, 2019) 1 USD = 916.17 RWF

or more (aOR = 2.35, 95%CI: 1.19, 4.66); farmers had 2.25 times higher odds to report CHE than employed women (aOR = 2.25, 95%CI: 1.00, 3.03); membership into community based health insurance was associated with 3.40 times higher odds of CHE (aOR = 3.40, 95%CI: 1.21,9.60); and small household sizes was associated with 22% lower odds of CHE compared to large household sizes (aOR = 0.78, 95%CI: 0.66,0.91).

Discussion

To our knowledge, this is the first study in a low-income country setting to estimate the comprehensive patient-level cost of c-section while including the cost of follow-up. We reported the direct medical cost of c-section of US$8.8, the cost of post-discharge follow-up of US$77.5 and the overall patient-level cost of c-section of US$122.2 during 30 days after-delivery. Over a third of women experienced financial catastrophe due to the costs associated with post-discharge care alone, and when combined with costs incurred prior to discharge, c-sections were financially catastrophic for over three-quarters of women. The vast majority of women who delivered at Kirehe District Hospital were poor prior to surgery and the cost of cesarean section was further impoverishing to 6.4% of women.

The direct cost of c-section found in this study is significantly lower compared to the costs of c-section in Mali (US$152.0), Nigeria (US$246.0), and the Democratic Republic of Congo (US$79.7) [10, 18, 32]. The substantially lower out-of-pocket payments for c-sections in Rwanda most likely reflects the cost cushion provided by Rwanda's robust health insurance system. In our study, nearly all c-section patients were insured through CBHI. Although CBHI may offset the direct medial costs of c-sections, previously estimated in Rwanda as US$339.0 from the health facility perspective [11], c-section patients paid an additional US$31.4 in non-medical costs while still in the hospital. Moreover, the direct and indirect cost of c-section up to the time of discharge was catastrophic for 27.0% of women, which is comparable to a previous report of CHE among peritonitis patients in Rwanda [19]; but lower compared to the 60.0% incidence of CHE from c-section reported in India [33].

Surprisingly, the full cost of c- section rose to US$122.2 and was catastrophic for 77% of women when follow-up costs were considered. The tripling of out of pocket expenditures by follow-up costs implies that the full

Table 3 Multivariate analysis of pre- cesarean section characteristics independently associated with CHE at POD30 ($N = 428$)

	Full Model			Reduced Model		
	OR	95% CI	*p*-value	OR	95% CI	*p*-value
Level of education						
Less than completed primary school	2.46	(0.61, 9.31)	0.18	3.09	(0.92,10.35)	0.06
Completed primary school	1.88	(0.78, 4.50)	0.03	2.35	(1.19, 4.66)	0.01
Secondary school or more	ref			ref		
Occupation						
Farmer	2.13	(0.82, 5.54)	0.12	2.25	(1.00, 3.03)	0.04
Unemployed	0.56	(0.12, 2.66)	0.47	0.59	(0.17,2.07)	0.41
Employed	ref			ref		
Ubudehe* categories						
I (poorest)	3.51	(0.73, 16.97)	0.12			
II (poor)	1.39	(0.72, 2.69)	0.33			
III &IV (wealthy)	ref					
Insurance Type						
Community Based Health Insurance or *Mutuelle*	4.29	(0.73, 16.97)	0.06	3.40	(1.21, 9.60)	0.02
Private	ref			ref		
Parity						
Primiparous (1)	ref					
Multiparous (2–5)	1.20	(0.59, 2.46)	0.61			
Grand-multiparous (> 5)	0.48	(0.15, 1.58)	0.23			
Mode of transport (health center to hospital)						
Ambulance	ref					
Walked	1.03	(0.50, 2.13)	0.93			
Travel time, from home to health center	1.00	(0.99, 1.00)	0.31			
Household size	0.79	(0.65, 0.96)	0.02	0.78	(0.66, 0.91)	< 0.01

* 4-tier wealth system, the bottom tier represents the least privileged and the upper tier is for the financially better off

financial picture of c-section care can only be truly understood when post-discharge costs are examined. Most costs covered by health insurance globally are expenditures linked to direct medical care, but this misses the substantial follow-up costs. For example, despite full coverage of direct medical cost for people in *Ubudehe 1,* the incidence of CHE in this group within 30 days post-cesarean was 74.0%. Interestingly, women in *Ubudehe* 2 had the highest risk of CHE during their hospital stay, reflecting their increased vulnerability of their low incomes combined with lower coverage of expenses by CBHI. In fact, having membership in CBHI was associated with 2.40 times higher odds of CHE when follow up costs were accounted. This corroborates the argument that health insurance that covers direct medical costs, though essential, is not sufficient to financially protect poor patients [35, 36].

While the majority of women in this study were already poor, c-section delivery exacerbated financial hardship of poor women and threatens their living standards, as reflected by the fact that more than two-thirds of women sold assets or borrowed money to afford c-section surgery and hospitalization. The sales of property in order to afford obstetric surgery care in rural Rwanda was found to be higher than in Ethiopia (4.4%) [37].

Major contributors to overall c-section costs included post discharge lost wages (55.3%), costs of post discharge follow up at health center (15.8%), costs of caregiving (13.3%), and transportation costs (11%). Similarly, major cost drivers of post-discharge expenditure included lost wages (84.7%) and transportation (11.5%). Follow-up interventions and models that reduce lost wages and eliminate transportation costs may contribute to a reduction in CHE [16, 38, 39]. Examples of innovative holistic interventions including transportation interventions, like the Uganda Reproductive Health Voucher Project, [41], can be adapted to the local context. We are also exploring innovative mHealth strategies and contextualized community-based follow-up strategies that allow for home-based care to reduce the cost of follow-up as well as the physical burden of traveling [42].

Addressing lost wages will be challenging. While paid maternity leave for women employed in formal work sectors is a national policy in Rwanda [43], the majority of patients in rural Rwanda are farmers, do not have higher educational attainment and thus do not have access to these job-protected maternity leave packages. This may partly be explained by our finding of 2.25 times higher odds of CHE among farmers compared to those with formal employment; and 2.35 times higher odds of CHE among those who completed primary school compared to those with high school or more education. While efficient execution of Rwanda's community-based health insurance policies serves as a model for other LMICs, it does not cover the key drivers of the overall cost including lost wages and transportation, and thus does not offer full financial protection [44]. Creative health and social financing frameworks should explore options for maternity protection schemes for women working in the informal economy, through social insurance funds or cash transfer schemes [45]. C-sections have been found to impose further health costs if mothers return to work prior to recovery [46], and further studies are needed to explore the appropriate time to resume work after c-cesarean section, with consideration to mitigating lost wages in both the formal work sectors and for farmers.

These findings highlight a need for a more financially protective health financing framework for women who deliver surgically in rural settings. However, similar studies in other field of surgical specialties are necessary to provide a more holistic picture of the relationship between surgical follow-up costs and catastrophic expenditure in Rwanda. Studies in urban settings are also needed to paint a holistic picture of the cost of c-sections for women in both rural and urban settings. A broader view is necessary before specific and wide-reaching policy reforms can be suggested. Modelling studies on the implications of various health policy reforms can help identify viable financial protection frameworks that reduce follow up costs and lost wages. However, the direction of reform should consider covering transportation costs, minimizing of disruptions of caregivers' work, and reimbursement for lost wages as priorities.

Our findings should be interpreted in light of some limitations. Firstly, the calculations of household expenditure depended on patient memory and based on predetermined expense categories. Patients may have failed to accurately report expenditures or missed expenses that did not align with a category. Secondly, estimates of the cost of post-discharge follow-up were based on reports from patients who decided to seek care on their own, because currently, there is no uniform protocol for post-c-section follow-up. Thus, our findings do not fully reflect the true cost of c-section follow, if such follow-up protocols existed. We also recognize that our findings focus on a single district hospital in a single country; however, we believe this is generalizable to much of rural Rwanda and other parts of Africa because of similar post-c-section follow-up norms and similar economic and access challenges. Further, since our study only included individuals during a 5-month period, we may miss some seasonal patterns, for example changes in income due to agricultural cycles in this largely subsistence farming population or changes in costs such as transport which may vary with rainy seasons.

Conclusion

When full costs are considered, c-section care confers significant risk of financial catastrophe on already impoverished households in rural Rwanda, despite the presence of a robust and widespread CBHI policy. Indirect non-medical cost and the full cost of follow-up for c-section from a patient perspective exceeds that of receiving initial medical care, and must be considered in development of policy and relevant interventions. Modelling of the financial implication of various follow up strategies should be encouraged to determine the most efficient and financially protective models of cost subsidy. Maternity protection schemes for women in informal work sectors should be explored to mitigate lost wages associated with extended period of recovery from surgical childbirth.

Ethics statement

This study had ethical approval from the Rwandan National Ethics Committee (Kigali, Rwanda, No.326/RNEC/2019) and Harvard Medical School (IRB18-1033). Adult patients were read information about the study and voluntarily signed the consent prior to enrollment. We obtained voluntary assent from individuals less than 18 years, with signed consent from their parents or guardians.

Abbreviations

C-section: Cesarean section; CHE: Catastrophic Health Expenditure; POD: Post-Operative Day; aOR: Adjusted Odds Ratio; IQR: Interquartile range; 95% CI: 95% Confidence Interval; CBHI: Community-Based Health Insurance; REDCap: Research Electronic Data Capture; OpenMRS: Open Medical Record System; RWF: Rwandan Franc; LMICs: Low- and Middle-Income countries.

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Authors Contribution

AN, BA and BHG conceived this study and drafted the manuscript. AN, LB, DN and EM led the implementation of the parent study and data collection. AN, NR and BA performed data analysis. LB, EM, NR, DN, FK, RR and BHG contributed to the interpretation of findings. All authors revised the manuscript and approved the final draft for submission to publication.

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Data availability
Data is available upon a reasonable request, by emailing niyianne@gmail.com.

Declarations

Consent for publication
We do not disclose any personal information of our participants. Thus, consent for publication is not applicable.

Competing interests
The authors declare no competing interests associated with this study.

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References

1. Burkholder TW, Bergquist HB, Wallis LA. Governing access to emergency care in Africa. African J. Emerg. Med. 2020.
2. Boatin AA, Schlotheuber A, Betran AP, Moller AB, Barros AJD, Boerma T, et al. Within country inequalities in caesarean section rates: Observational study of 72 low and middle income countries. BMJ. 2018;360:k55. https://pubmed.ncbi.nlm.nih.gov/29367432/.
3. Harrison MS, Goldenberg RL. Cesarean section in sub-Saharan Africa. Matern Heal Neonatol Perinatol. 2016;2:6. https://doi.org/10.1186/s40748-016-0033-x
4. Irani M, Deering S. Challenges affecting access to cesarean delivery and strategies to overcome them in low-income countries. Int J Gynaecol Obstet Off organ Int Fed Gynaecol Obstet. United States. 2015;131:30–4.
5. Ushie BA, Udoh EE, Ajayi AI. Examining inequalities in access to delivery by caesarean section in Nigeria. PLoS One. Public Library of Science. 2019;14:e0221778–e0221778. https://pubmed.ncbi.nlm.nih.gov/31465505.
6. Ajayi AI. Inequalities in access to birth by caesarean section in the context of user fee exemption for maternal health services in southwest and north central Nigeria. Int Health [Internet]. 2020; Available from: https://doi.org/10.1093/inthealth/ihz118
7. Olukade T, Yaya S, Bishwajit G, Uthman OA. Socio-demographic determinants of post caesarean neonatal mortality in Nigeria. J Obstet Gynaecol. 2020;40:342–8. https://doi.org/10.1080/01443615.2019.1627300.
8. Volpe FM. Correlation of Cesarean rates to maternal and infant mortality rates: An ecologic study of official international data. Rev Panam Salud Publica/Pan Am J Public Heal. 2011;29:303–8.
9. Alkire BC, Shrime MG, Dare AJ, Vincent JR, Meara JG. Global economic consequences of selected surgical diseases: A modelling study. Lancet Glob Heal. 2015;3:S21-7.
10. Deboutte D, O'Dempsey T, Mann G, Faragher B. Cost-effectiveness of caesarean sections in a post-conflict environment: A case study of Bunia, Democratic Republic of the Congo. Disasters. 2013;37:S105-20.
11. Odhiambo J, Ruhumuriza J, Nkurunziza T, Riviello R, Shrime M, Lin Y, et al. Health Facility Cost of Cesarean Delivery at a Rural District Hospital in Rwanda Using Time-Driven Activity-Based Costing. Matern Child Health J. 2019;23:613–22. https://doi.org/10.1007/s10995-018-2674-z.
12. Mengistu T, Berruti A, Krivelyova A, Swor M, Waite R, Maro G. Cost of providing emergency obstetric care in Tanzania's Kigoma region. Int J Health Plann Manage. 2019;34:e1510–9. https://doi.org/10.1002/hpm.2820.
13. O'Neill A. Sub-Saharan Africa: Gross domestic product (GDP) per capita in current prices from 2014 to 2024 [Internet]. Statista.com. 2021 [cited 2021 Mar 20]. Available from: https://www.statista.com/statistics/805567/gross-domestic-product-gdp-per-capita-in-sub-saharan-africa/
14. Bennis I, De Brouwere V. Fee exemption for caesarean section in Morocco. Arch Public Heal. 2012;70(1):3.
15. Nguyen H, Ivers R, Jan S, Pham C. Cost of surgery and catastrophic expenditure in people admitted to hospital for injuries: estimates from a cohort study in Vietnam. Lancet. 2015;385:S50. https://doi.org/10.1016/S0140-6736(15)60845-5.
16. Shrime MG, Alkire BC, Grimes C, Chao TE, Poenaru D, Verguet S. Cost-Effectiveness in Global Surgery: Pearls, Pitfalls, and a Checklist. World J Surg. 2017;41:1401–13.
17. Ntambue AM, Malonga FK, Cowgill KD, Dramaix-Wilmet M, Donnen P. Incidence of catastrophic expenditures linked to obstetric and neonatal care at 92 facilities in Lubumbashi, Democratic Republic of the Congo, 2015. BMC Public Health. 2019;19:1–15. https://doi.org/10.1186/s12889-019-7260-9.
18. Arsenault C, Fournier P, Philibert A, Sissoko K, Coulibaly A, Tourigny C, et al. Emergency obstetric care in Mali: catastrophic spending and its impoverishing effects on households. Bull World Health Organ. 2013/01/17. World Health Organization. 2013;91:207–16. https://doi.org/10.2471/BLT.12.108969.
19. Rickard JL, Ngarambe C, Ndayizeye L, Smart B, Majyambere JP, Riviello R. Risk of Catastrophic Health Expenditure in Rwandan Surgical Patients with Peritonitis. World J Surg. 2018;42:1603–9. https://doi.org/10.1007/s00268-017-4368-x.
20. Petroze RT, Nzayisenga A, Rusanganwa V, Ntakiyiruta G, Calland JF. Comprehensive national analysis of emergency and essential surgical capacity in Rwanda. Br J Surg England. 2012;99:436–43.
21. Nyandekwe M, Nzayirambaho M, Kakoma JB. Universal health insurance in Rwanda: major challenges and solutions for financial sustainability case study of Rwanda community-based health insurance part I. Pan Afr Med J. The African Field Epidemiology Network. 2020;37:55. https://doi.org/10.11604/pamj.2020.37.55.20376.
22. Mukangendo M, Nzayirambaho M, Hitimana R, Yamuragiye A. Factors Contributing to Low Adherence to Community-Based Health Insurance in Rural Nyanza District, Southern Rwanda. Haughton J, editor. J Environ Public Health. 2018;2018:2624591. https://doi.org/10.1155/2018/2624591.
23. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)–a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009;42:377–81.
24. Program in Global Surgery and Social Change. Financial Risk Protection Survey Financial Risk Protection Survey. :1–3. Available from: https://docs.wixstatic.com/ugd/d9a674_8da150554fe348f4bfcba71613faad9d.pdf
25. The World Bank. Poverty Forecasts [Internet]. 2015 [cited 2021 Sep 23]. Available from: https://www.worldbank.org/en/publication/global-monitoring-report/poverty-forecasts-2015
26. Wagstaff A, Flores G, Hsu J, Smitz M-F, Chepynoga K, Buisman LR, et al. Progress on catastrophic health spending in 133 countries: a retrospective observational study. Lancet Glob Heal England. 2018;6:e169–79.
27. Hailemichael Y, Hanlon C, Tirfessa K, Docrat S, Alem A, Medhin G, et al. Catastrophic health expenditure and impoverishment in households of persons with depression: a cross-sectional, comparative study in rural Ethiopia. BMC Public Health [Internet]. 2019;19:930. Available from: https://doi.org/10.1186/s12889-019-7239-6
28. World Health Organization. Distribution of health payments and catastrophic expenditures Methodology by Ke Xu [Internet]. Geneva PP - Geneva: World Health Organization; 2005. Available from: https://apps.who.int/iris/handle/10665/69030
29. Taylor ZW, Bicak I. Goal 3: Ensure healthy lives and promote well-being for all at all ages. 2019;10:61–5. Available from: https://unstats.un.org/sdgs/metadata/
30. Rwanda Franc to US Dollar Exchange Rate History For 1 November 2019 (01/11/19) [Internet]. [cited 2021 Sep 25]. Available from: https://www.exchangerates.org.uk/RWF-USD-01_11_2019-exchange-rate-history.html
31. The World Bank. PPP conversion factor, GDP (LCU per international $) - Rwanda | Data [Internet]. [cited 2021 Sep 25]. Available from: https://data.worldbank.org/indicator/PA.NUS.PPP?locations=RW

32. Adamu AN, Adamu H, Yabagi AI, Sa'ad Z. O011 Expenditure on Emergency Obstetric Care in a Tertiary Health Centre in Northern Nigeria. Int J Gynecol Obstet. 2012;119:S264-5.
33. Govil D, Mohanty SK, Narzary PK. Catastrophic household expenditure on caesarean deliveries in India. J Popul Res. 2020;37(2):139–59.
34. Abadi T, Mebratie AD. Cost of treating maternal complications and associated factors in Mekelle General Hospital, northern Ethiopia. Risk Manag Healthc Policy. 2021;14:87–95.
35. Ravit M, Philibert A, Tourigny C, Traore M, Coulibaly A, Dumont A, et al. The Hidden Costs of a Free Caesarean Section Policy in West Africa (Kayes Region, Mali). Matern Child Health J [Internet]. 2015;19:1734–43. Available from: https://doi.org/10.1007/s10995-015-1687-0
36. Thomson S, Cylus J, Evetovits T. Can people afford to pay for health care ? Regional report. World Heal Organ. 2019;1:116.
37. Akalu T, Guda A, Tamiru M, Mariam DH. Examining out of pocket payments for maternal health in rural Ethiopia: Paradox of free health care un-affordability. Ethiop J Heal Dev. 2012;26:251–7.
38. LaFranchi H. How a simple travel voucher is saving the lives of pregnant African women. CSMonitor.com. 2014 [cited 2021 Sep 24]. https://www.csmonitor.com/USA/Foreign-Policy/2014/0109/How-a-simple-travel-voucheris-saving-the-lives-of-pregnant-African-women.
39. Xu K, Evans DB, Kawabata K, Zeramdini R, Klavus J, Murray CJL. Household catastrophic health expenditure: a multicountry analysis. Lancet (London, England). England. 2003;362:111–7.
40. Ali M, Farron M, Azmat SK, Hameed W. The logistics of voucher management: The underreported component in family planning voucher discussions. J Multidiscip Health. 2018;11:683–90.
41. The World Bank. Vouchers that Make Having a Baby Safe and Cheap for More Ugandan Women [Internet]. 2017 [cited 2021 Sep 24]. Available from: https://www.worldbank.org/en/news/feature/2017/05/30/vouchers-that-make-having-a-baby-safe-and-cheap-for-some-ugandan-women
42. Sonderman KA, Nkurunziza T, Kateera F, Gruendl M, Koch R, Gaju E, et al. Using mobile health technology and community health workers to identify and refer caesarean-related surgical site infections in rural Rwanda: a randomised controlled trial protocol. BMJ Open. 2018;8: e022214.
43. Anatole Uzayisenga. Rwanda: Relief for Working Mothers As Maternity Leave Benefits Scheme Comes Into Force. [Internet]. New Times. 2016 [cited 2021 Sep 24]. Available from: https://allafrica.com/stories/201611220103.html
44. Nyandekwe M, Nzayirambaho M, Kakoma MJB. Universal health insurance in Rwanda: major challenges and solutions for financial sustainability case study of Rwanda community-based health insurance part I. The Pan African medical journal. 2020;37:55.
45. International Labor Office. Maternity cash benefits for workers in the informal economy [Internet]. 2016[cited 2022 Jan 31]. Available from: https://www.social protection.org/gimi/RessourcePDF.action?id=54094
46. Stoddard C, Stock WA, Hogenson E. The Impact of Maternity Leave Laws on Cesarean Delivery. B E J Econom Anal Policy [Internet]. De Gruyter; 2016 [cited 2021 Sep 24];16:321–64. Available from: https://www.degruyter.com/document/doi/https://doi.org/10.1515/bejeap-2015-0015/html

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Study VI

The economic consequences of neurosurgical disease in low- and middle-income countries

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OBJECTIVE The objective of this study was to estimate the economic consequences of neurosurgical disease in low- and middle-income countries (LMICs).

METHODS The authors estimated gross domestic product (GDP) losses and the broader welfare losses attributable to 5 neurosurgical disease categories in LMICs using two distinct economic models. The value of lost output (VLO) model projects annual GDP losses due to neurosurgical disease during 2015–2030, and is based on the WHO's "Projecting the Economic Cost of Ill-health" tool. The value of lost economic welfare (VLW) model estimates total welfare losses, which is based on the value of a statistical life and includes nonmarket losses such as the inherent value placed on good health, resulting from neurosurgical disease in 2015 alone.

RESULTS The VLO model estimates the selected neurosurgical diseases will result in $4.4 trillion (2013 US dollars, purchasing power parity) in GDP losses during 2015–2030 in the 90 included LMICs. Economic losses are projected to disproportionately affect low- and lower-middle-income countries, risking up to a 0.6% and 0.54% loss of GDP, respectively, in 2030. The VLW model evaluated 127 LMICs, and estimates that these countries experienced $3 trillion (2013 US dollars, purchasing power parity) in economic welfare losses in 2015. Regardless of the model used, the majority of the losses can be attributed to stroke and traumatic brain injury.

CONCLUSIONS The economic impact of neurosurgical diseases in LMICs is significant. The magnitude of economic losses due to neurosurgical diseases in LMICs provides further motivation beyond already compelling humanitarian reasons for action.

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KEYWORDS global health; cost of illness; surgical procedures; operative; neurosurgical procedures; economics

A SIGNIFICANT proportion of the global burden of disease requires surgical care,[38,44,48] yet 5 billion people globally lack access to safe, affordable, and timely surgical care.[6] Moreover, the scarcity of access to surgery is especially bleak with respect to neurosurgical conditions.[12,24] A burgeoning evidence base suggests that surgical interventions, including neurosurgery, can be cost-effective, challenging long-held dogma that deems subspecialty surgery too expensive for resource-poor settings.[19,45]

Poor access to surgical care not only negatively impacts health, but also has the potential to harm the economies of low- and middle-income countries (LMICs). While the exact relationship between health and wealth is the ongoing subject of debate,[3,16,29] microeconomic literature provides evidence for a strong association between improved health and increased income and productivity.[18,40] Additionally, a large body of macroeconomic literature has convincingly demonstrated a positive effect of health on aggregate economic growth.[9,11,13,15,17,18,26,30,31]

ABBREVIATIONS DALY = disability-adjusted life year; EPIC = Projecting the Economic Cost of Ill-health; GBD = Global Burden of Disease; GDP = gross domestic product; HIC = high-income country; IE = income elasticity; IHME = Institute for Health Metrics and Evaluation; LCoGS = Lancet Commission on Global Surgery; LMICs = low- and middle-income countries; PPP = purchasing power parity; TBI = traumatic brain injury; USD = US dollars; VLO = value of lost output; VLW = value of lost economic welfare; VSL = value of a statistical life; VSLY = value of a statistical life year.

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Recent efforts have also highlighted the economic consequences from individual surgical diseases,[5,8,45] as well as broader categories of disease.[2,7,14] To date, however, no study has established the economic consequences of neurosurgical diseases in LMICs at the global level.

This study aims to understand the economic burden of selected neurosurgical diseases in LMICs by adapting the same methodologies that were used for the Lancet Commission on Global Surgery (LCoGS), which estimated the economic consequences of 5 categories of surgical diseases.[7,33] We estimate gross domestic product (GDP) losses and the broader welfare losses attributable to 5 neurosurgical diseases in LMICs.

Methods

Definition and Scope of Neurosurgical Disease

We began by selecting 5 disease categories that regularly require the involvement of a neurosurgeon: traumatic brain injury (TBI), cancers of the brain and nervous system, neural tube defects, cerebrovascular accident, and infections of the CNS. While these disease groupings were chosen in part due to data limitations that precluded inclusion of some diseases, such as degenerative and traumatic spinal conditions, they were also believed to be representative of the majority of the neurosurgical disease burden, especially with respect to mortality.

Burden of disease estimates were obtained from the Institute for Health Metrics and Evaluation's (IHME) most recent Global Burden of Disease (GBD) Study (GBD2015),[42,43] with the exception of TBI. IHME provides disease burden estimates only for causes of injury (e.g., road traffic accidents), and not the nature of injury (e.g., TBI, spinal injury). Details of the methodology for estimating mortality rates for TBI and adjustments to IHME data are provided in the Appendix. To estimate future mortality rates, we attained mortality rates by disease, country, age group, and sex for the years 2005 and 2015, and calculated an annualized rate of change that was used to create mortality rate projections. We should note that while this study does not separately examine hydrocephalus, as it is not a discrete GBD2015 cause, the burden of hydrocephalus is accounted for as sequela in other GBD categories included in this analysis.

Given that the involvement of a neurosurgeon is not always required for all cases of the included disease categories, the burden estimates obtained from IHME were adjusted. To accomplish this, we relied on a survey that asked participants from high-, middle-, and low-income countries to estimate the proportion of patients for each disease that require consultation by a neurosurgeon.[23] The mean results from the survey were applied.

Overview of Approaches

Two economic approaches are used to estimate the macroeconomic consequences of the selected neurosurgical diseases. It is important to note that the models are complementary as they have distinct economic perspectives; consequently, the results should not be directly compared. The value of lost output (VLO) model projects annual GDP losses due to disease during 2015–2030, the same period evaluated by the LCoGS. The value of lost economic welfare (VLW) model estimates total welfare losses resulting from neurosurgical disease in 2015. The VLO and VLW models therefore differ with respect to the meaning of economic loss and the period during which losses are estimated. The counterfactual scenario in both approaches is absence of disease.

Value of Lost Output

The VLO approach relies on a model supplied by the WHO known as EPIC ("Projecting the Economic Cost of Ill-health"), which relates projections of disease-specific mortality rates and the consequent decrease in the labor supply over time to decreased economic output, or GDP.

The EPIC model relies on the Cobb-Douglas production function, which expresses economic output as a function of labor supply, capital, economic productivity, and country- and time-specific factors. By utilizing available projections on these metrics, it can simulate a counterfactual scenario in which one or more of these parameters are changed, in this case mortality-related changes of the labor supply. By utilizing age-, sex-, country-, and year-specific mortality and population estimates, we can account for the changes in size, composition, and average experience of the workforce.[21]

Value of Lost Welfare

The VLW model uses an economic concept termed the value of a statistical life (VSL), which incorporates nonmarket losses such as forgone leisure time and the value placed on good health in and of itself.[41] The VSL is a measure of the maximum amount an individual is willing to give up for mortality risk reductions. It can be derived empirically from wage differentials related to the mortality risks of different occupations, or using survey-based stated-preference methods. Formal VSL studies have been performed primarily in high-income countries, so these estimates need to be adjusted based on the income levels in different countries. The method for transferring VSL estimates from one country to another depends on the income elasticity (IE) of the VSL (IE-VSL). IE-VSLs of around 0.55 are commonly used when transferring estimates between high-income countries, but recent literature suggests a higher value may be more appropriate.[28,41] We have therefore used a more conservative IE-VSL of 1.0. Research suggests that the VSL varies with the age of the individual. Contrary to what intuition might suggest, it follows an inverted U-shape, and we account for this in our model.[4,36]

By treating the VSL as if it were the present value of an annuity, it can be translated into the value of a statistical life year (VSLY), which can, in turn, be used to value disability-adjusted life years (DALYs), a health metric that captures mortality and morbidity.[37] Because of the way DALYs calculate the burden of disease due to premature death,[35] the VLW approach takes a long-run view of mortality and includes the value of lost life in 2015 plus the present value of discounted future effects due to potential life lost. Morbidity effects are based on prevalence estimates, and therefore only include the effects of disease in

TABLE 1. Total value of GDP losses and percentage of potential cumulative GDP lost secondary to neurosurgical diseases (2015–2030)

Disease	Low Income	Lower-Middle Income	Upper-Middle Income
CNS cancer	$3 (0.02%)	$59 (0.02%)	$225 (0.03%)
CNS infection	$21 (0.10%)	$182 (0.05%)	$53 (0.01%)
Neural tube defects	$2 (0.011%)	$5 (0.001%)	$12 (0.002%)
Stroke	$49 (0.24%)	$883 (0.25%)	$1718 (0.23%)
TBI	$20 (0.10%)	$313 (0.09%)	$842 (0.11%)
Total	$96 (0.47%)	$1442 (0.41%)	$2849 (0.39%)

Dollar values given in billions (2013 USD, PPP).

2015.[34] As the VLW approach includes nonmarket welfare losses, incorporates morbidity in addition to mortality, and for the latter includes long-run losses, the VLW results are larger than the VLO results.

Data Sources

The EPIC model was used with data as supplied by the WHO, with the exception of GDP per capita estimates that were obtained from the International Futures modeling system (http://www.ifs.du.edu/ifs/frm_MainMenu.aspx) and estimates of future capital stock and total factor productivity that were obtained from Penn World Tables.[24] Capital depreciation data were obtained from the World Development Indicators (https://data.worldbank.org/data-catalog/world-development-indicators). Data on labor projections were retrieved from the International Labor Organization (http://www.ilo.org/ilostat/).

The VLO model evaluated 90 LMICs, and 151 countries were initially evaluated with the VLW approach based on region and income classification from IHME. However, only 127 of these countries are identified as LMICs by the World Bank, and these are included in the final analysis. The difference in evaluated countries reflects data availability, as the VLO requires several econometric estimates that are not readily availability for many countries. Results are presented in 2013 international dollars (US dollars [USD], adjusted for purchasing power parity [PPP]). For each approach, countries were evaluated by IHME region and their respective 2015 World Bank income classification.[34]

Results

Value of Lost Output (2015–2030)

A total of 90 low- and middle-income countries were evaluated (Appendix Table 1). The selected neurosurgical diseases are estimated to result in $4.4 trillion (2013 USD, PPP) in GDP losses during 2015–2030, with annual losses more than doubling over the same time (Fig. 1, Table 1). As a proportion of annual GDP, economic losses are projected to disproportionately affect low- and lower-middle-income countries, risking up to a 0.6% and 0.54% loss, respectively, in 2030 (Fig. 2). Stroke and TBI are responsible for 85% of total losses, but there is significant variation by region (Fig. 3).

Value of Lost Welfare (2015)

We assessed 127 LMICs and estimate that these countries experienced $3 trillion (2013 USD, PPP) in economic welfare losses in 2015 (Table 2). Stroke and TBI were responsible for 90% of total economic losses. When expressed as equivalent proportion of GDP, stroke dispro-

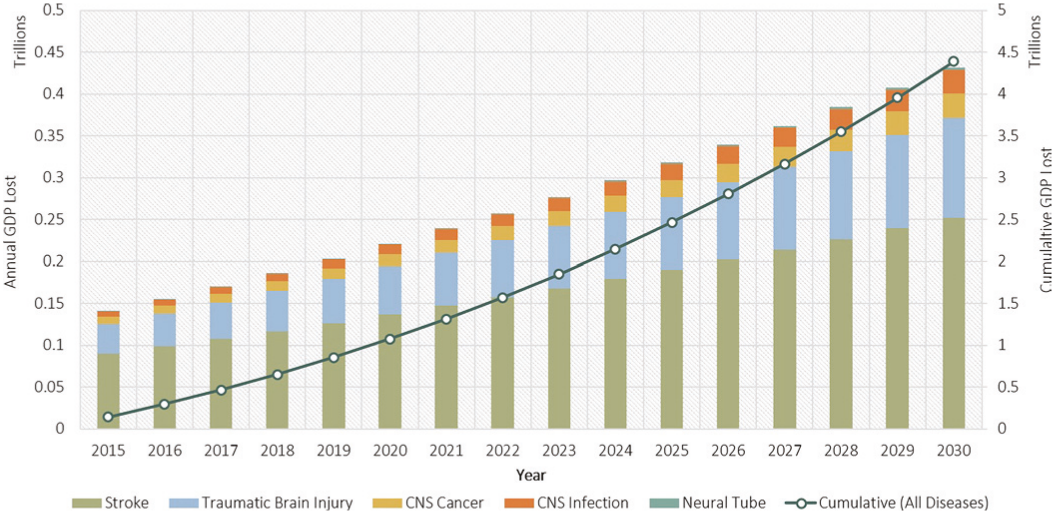

FIG. 1. Projected annual and cumulative GDP lost secondary to neurosurgical disease in LMICs between 2015 and 2030 (given in 2013 USD, PPP). Figure is available in color online only.

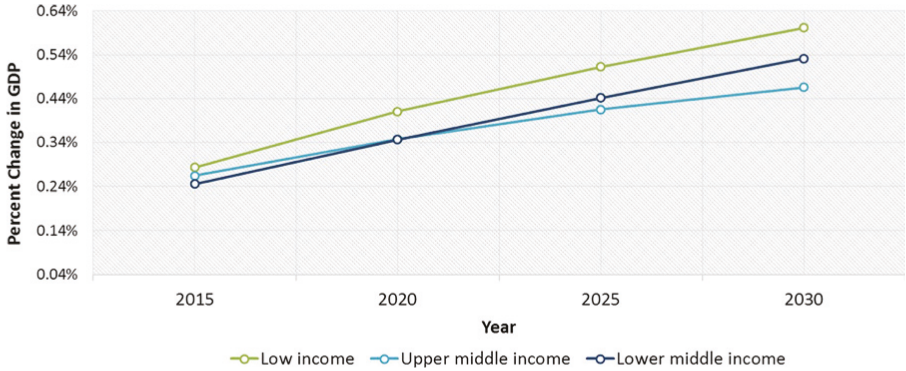

FIG. 2. Projected annual value of lost economic output as a percentage of GDP, stratified by World Bank income classification (given in 2013 USD, PPP). Figure is available in color online only.

portionately affected upper-middle-income countries (4% vs 2% for low-income countries), while CNS infection resulted in 7 times the economic burden in low-income versus upper-middle-income countries (Fig. 4).

Discussion

This study presents an estimate of the economic burden imposed by neurosurgical disease in LMICs using two distinct approaches to evaluate losses in both potential GDP and total economic welfare.

The VLO approach, which assesses market losses between 2015 and 2030, estimates mortality resulting from neurosurgical diseases will account for $4.4 trillion (2013 USD, PPP) in GDP losses in the included 90 LMICs. We project that the economic losses as a share of GDP will not only double over 15 years, but also disproportionately affect low-income countries (Figs. 2 and 3). Low-income countries in sub-Saharan Africa and Southeast Asia are at particularly high risk, with estimates of losses of up to 0.6% of GDP in 2030.

Health and economic growth are mutually reinforcing, and countries can consequently enter virtuous or vicious health-income spirals.[18] The link from income to health through increased spending on prevention and treatment is an often-discussed economic concept. Additionally, a growing body of research has highlighted the role of health not only as an outcome of increased income, but also as an important input.[9,37] The observed correlation between health and income is therefore likely due to a bidirectional and causal relationship between the two.

There are numerous paths in which health and dis-

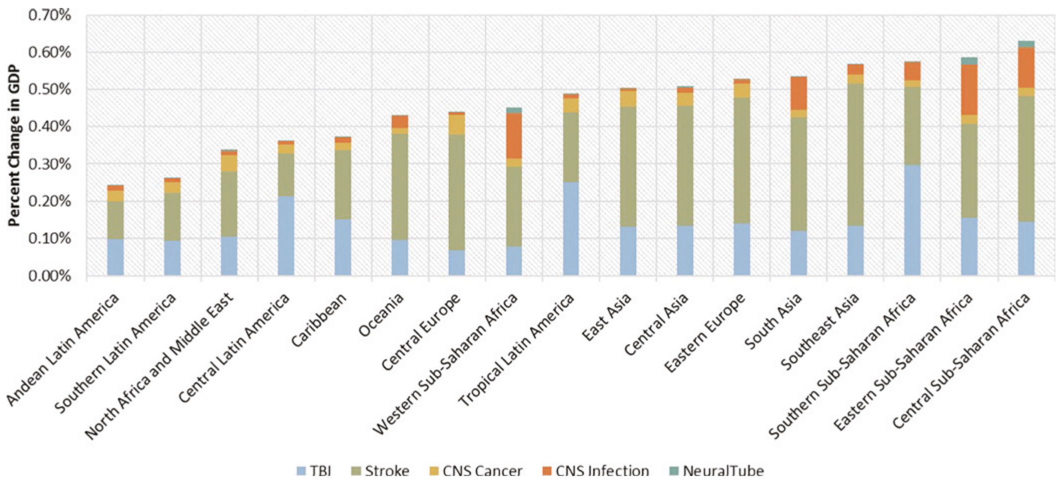

FIG. 3. Projected lost economic output in 2030 as a percentage of GDP, stratified by IHME region and disease category (given in 2013 USD, PPP). Figure is available in color online only.

TABLE 2. Total value of economic welfare losses due to neurosurgical diseases and percentage of equivalent GDP due to disease in 2015

Disease	Low Income	Lower-Middle Income	Upper-Middle Income
CNS cancer	$1 (0.11%)	$30 (0.16%)	$139 (0.35%)
CNS infection	$8 (0.77%)	$86 (0.47%)	$39 (0.10%)
Neural tube defects	$1 (0.07%)	$4 (0.02%)	$11 (0.03%)
Stroke	$19 (1.90%)	$512 (2.80%)	$1605 (4.05%)
TBI	$7 (0.73%)	$125 (0.68%)	$380 (0.96%)
Total	$35 (3.58%)	$757 (4.14%)	$2174 (5.48%)

Dollar values given in billions (2013 USD, PPP).

ease can affect income at the household and societal level. Morbidity results in decreased productivity of the individual worker as well as a lower potential for effective education.[13] Out-of-pocket expenditures for the acute treatment of disease can push households into permanent impoverishment, particularly if they are forced to sell their productive assets.[37] Indeed, some 81 million people annually face catastrophic expenditure accessing surgery.[39] An increased life expectancy can result in an incentive structure beneficial for economic growth. There is more time to capitalize on education, and the incentive for saving for retirement grows stronger, leading to higher national savings, an important driver of economic growth.[30] Improved health also leads to lower fertility, allowing for a higher concentration of resources spent on the education of each child.[30,31]

Some authors have suggested the existence of a high-mortality, high-fertility income trap, as ill health and poverty reinforce each other in a feedback loop. Of note, we estimate low-income countries will incur the largest production losses as measured by the percentage of GDP, suggesting the neurosurgical disease contribution to this feedback loop is particularly important in low-income countries. On the bright side, investments in health have the potential for multiplicative effects, as the improved health is likely to benefit economic growth, which will in turn improve health.

The majority of the GDP losses will result from stroke and TBI, highlighting the need for both preventative measures and increased investment in treatment, including neurosurgery. As stated in the *Methods* section, we made adjustments to account for the fact that not every case of stroke and TBI requires the involvement of a neurosurgeon. Large differences in modeled mortality rates for these diseases between high-income countries (HICs) and LMICs seems to suggest a large part of this burden of disease is avertable. For example, the age-standardized mortality rate for stroke is about 3 times higher in LMICs than in HICs,[46] and our model estimates a difference in TBI mortality rates ranging from 17% to 50%. However, the difference in case mortality rates is likely much larger, as TBI incidence is positively correlated with income through increased vehicle usage.[10] Basic management of TBI and stroke, surgical and nonsurgical, need not be resource-intensive. For example, craniotomy for evacuation of hematoma can be performed safely by trained neurosurgeons in many LMICs (e.g., Ethiopia and Cambodia). Data from Uganda indicate it is possible to perform neurosurgery in an LMIC university hospital setting for as little as US $500, with mean procedure cost ranging from approximately US $300 to US $1200 depending on the complexity of the procedure.[1] Unfortunately, as much as 90% of the population in LMICs do not have access to these and other basic surgical services, often with tragic consequences.[33] *Disease Control Priorities*' (3rd edition) most recent recommendations with regard to essential surgery contains burr hole and shunt placement in its list of essential surgical procedures.[22] While our data appear to suggest a not insignificant burden available to treatment by these two procedures, we also show that a more comprehensive neurosurgical package would be needed to address the full extent of economic losses.

While TBI and stroke account for the majority of the economic burden in every income group, the relative importance of CNS infection is highly correlated with income level; it accounts for 21% of GDP losses in low-income countries, and only 2% in upper-middle-income countries.

Using the VLW approach, we estimate morbidity and mortality resulting from the selected neurosurgical diseases to result in a $3.0 trillion loss in 2015 alone. The VLW method, sometimes referred to as the full income method, attempts to account for both market and nonmar-

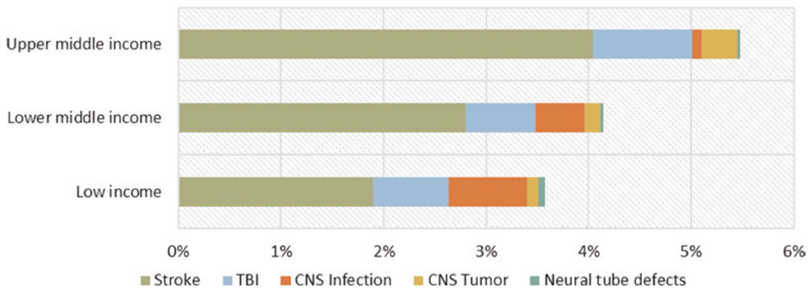

FIG. 4. Total economic welfare losses resulting from neurosurgical disease in 2015, expressed as equivalent percentage of GDP, stratified by World Bank income classification and disease category (given in 2013 USD, PPP). Figure is available in color online only.

ket losses, the latter of which includes the intrinsic value of good health in and of itself. Comparing the economic welfare losses to GDP can give a sense of the scale of the losses incurred; the VLW method estimates losses equaling a startling 5% of GDP. We would caution the reader from interpreting this percentage as lost economic output. The VLW method is inherently meant to measure the impact on general social welfare as valued by the citizens of a country, not to be confused with the rate of GDP growth. However, this distinction does not preclude usefulness of the VLW method. In fact, a major criticism of using GDP to measure development is its failure to include, among other things, a measure of health and well-being. Willingness-to-pay studies have shown most people are willing to pay a large proportion of their income in exchange for reduced mortality risks, and data from such studies underlie the VLW methodology.[28,32,49]

A handful of previous studies have attempted to estimate the global economic consequences of disease using the WHO EPIC model.[2,7,14] Notably, Alkire et al. estimated the global economic consequences of 5 surgical disease categories and projected $12.3 trillion in GDP losses between 2015 and 2030.[7] The scope of that study included some, but not all, neurosurgical burden, and we caution against adding or dividing these results with those of the present study. The only overlap is potentially with trauma and TBI. Bloom et al. investigated the effect of noncommunicable diseases (cardiovascular disease, neoplasm, chronic respiratory disease, mental illness, and diabetes), and estimated $47 trillion in lost GDP between 2011 and 2030,[14] although this estimate included HICs as well. We would caution that differences in scope and assumptions preclude a direct comparison between these studies and our results.

The results of our study need to be interpreted in the light of important limitations. Like most studies of this kind, data availability constraints mean we are reliant on modeled data rather than primarily collected data for our calculations. To account for public health gains and medical advances, we extrapolate based on the trend during the decade preceding the study period. As with any projections about the future, ours contains inherent uncertainty, and disruptive geopolitical events could result in substantially different results.

While the VLW method has clear economic meaning, and allows for estimation of the impact on full economic welfare, applying the method to the low- and middle-income setting is not without methodological difficulties. The lack of willingness-to-pay studies performed in these settings means we must rely on data collected in HICs and apply transformation techniques to adjust for the effect of income on the willingness and ability to pay for mortality risk reductions.[28] There are also limitations in valuing morbidity, including questions about the applicability of VSL techniques to morbidity.[27,47] Due to a lack of available data, we were not able to include TBI-related morbidity in our VLW estimate. The result should, therefore, be interpreted as a conservative lower-bound estimate. Similarly, the exclusion of degenerative and traumatic spine diseases from our analysis would underestimate the welfare losses in the VLW model given that neck and low-back pain are the leading causes of disability in most countries.[34] Finally, the use of a survey to adjust our burden estimates could bias our results upwards if survey respondents overestimate the proportion of diseases that require neurosurgical intervention.

Studies of economic burden should not be used in isolation to prioritize interventions, and our results should be interpreted in light of studies of cost-effectiveness.[20,47] The only such study identified in the literature evaluated treatment for pediatric hydrocephalus, and found it to be cost-effective.[44] In comparison with burden of disease studies, such as measuring lost DALYs, studies of the economic burden of disease can help policymakers more directly compare the cost of increasing access to care to the economic consequences of the status quo. This additional dimension may be of more interest to financial policymakers than studies that only report disease burden as such.

There is significant opportunity for future research in global neurosurgery that would complement our findings. We would suggest that additional cost-effectiveness studies of neurosurgical interventions are crucial for decision-makers. Estimates of the burden of neurosurgical disease, as well as the proportion avertable by prevention and treatment, would also be immensely valuable.

Conclusions

Our study finds that there is a significant economic impact of neurosurgical diseases in LMICs. If cost-utility studies of neurosurgical care in LMICs continue to suggest that it can indeed be cost-effective, previous dogma deeming neurosurgery too complicated and expensive for resource-limited settings would be significantly challenged, especially when accounting for the downstream effects on economic growth as presented in this study. The magnitude of economic losses due to neurosurgical diseases in LMICs provides further motivation for action, beyond the already compelling humanitarian reasons.

References

1. Abdelgadir J, Tran T, Muhindo A, Obiga D, Mukasa J, Ssenyonjo H, et al: Estimating the cost of neurosurgical procedures in a low-income setting: an observational economic analysis. **World Neurosurg 101:**651–657, 2017
2. Abegunde DO, Mathers CD, Adam T, Ortegon M, Strong K: The burden and costs of chronic diseases in low-income and middle-income countries. **Lancet 370:**1929–1938, 2007
3. Acemoglu D, Johnson S: **Disease and Development: The Effect of Life Expectancy on Economic Growth. Working Paper 12269.** Cambridge, MA: National Bureau of Economic Research, 2006 (http://www.nber.org/papers/w12269.pdf) [Accessed January 29, 2018]
4. Aldy JE, Viscusi WK: Adjusting the value of a statistical life for age and cohort effects. **Rev Econ Stat 90:**573–581, 2008
5. Alkire B, Hughes CD, Nash K, Vincent JR, Meara JG: Potential economic benefit of cleft lip and palate repair in sub-Saharan Africa. **World J Surg 35:**1194–1201, 2011
6. Alkire BC, Raykar NP, Shrime MG, Weiser TG, Bickler SW, Rose JA, et al: Global access to surgical care: a modelling study. **Lancet Glob Health 3:**e316–e323, 2015
7. Alkire BC, Shrime MG, Dare AJ, Vincent JR, Meara JG: Global economic consequences of selected surgical diseases: a modelling study. **Lancet Glob Health 3 (Suppl 2):**S21–S27, 2015

8. Alkire BC, Vincent JR, Burns CT, Metzler IS, Farmer PE, Meara JG: Obstructed labor and caesarean delivery: the cost and benefit of surgical intervention. **PLoS One 7:**e34595, 2012
9. Alleyne GAO, Cohen D (eds): **Health, Economic Growth and Poverty Reduction.** Geneva: World Health Organization, 2002 (http://apps.who.int/iris/bitstream/10665/42492/1/9241590092.pdf) [Accessed January 29, 2018]
10. Bhalla K, Ezzati M, Mahal A, Salomon J, Reich M: A risk-based method for modeling traffic fatalities. **Risk Anal 27:**125–136, 2007
11. Bhargava A, Jamison DT, Lau LJ, Murray CJ: Modeling the effects of health on economic growth. **J Health Econ 20:**423–440, 2001
12. Black PM: The future of neurosurgery: a call to leadership. **Clin Neurosurg 54:**185–191, 2007
13. Bleakley H: Disease and development: evidence from hookworm eradication in the American South. **Q J Econ 122:**73–117, 2007
14. Bloom DE, Cafiero E, Jané-Llopis E, Abrahams-Gessel S, Bloom LR, Fathima S, et al: **The Global Economic Burden of Non-Communicable Diseases.** Geneva: World Economic Forum, 2011 (https://www.world-heart-federation.org/wp-content/uploads/2017/05/WEF_Harvard_HE_GlobalEconomicBurdenNonCommunicableDiseases_2011.pdf) [Accessed January 29, 2018]
15. Bloom DE, Canning D: Policy forum: public heath. The health and wealth of nations. **Science 287(5456):**1207, 1209, 2000
16. Bloom DE, Canning D, Fink G: **Disease and Development Revisited.** Cambridge, MA: National Bureau of Economic Research, 2009 (http://www.nber.org/papers/w15137) [Accessed January 29, 2018]
17. Bloom DE, Canning D, Sevilla J: The effect of health on economic growth: a production function approach. **World Dev 32:**1–13, 2004
18. Bloom DE, Fink G: The economic case for devoting public resources to health, in Farrar J, Hotez PJ, Junghanss T, et al (eds): **Manson's Tropical Diseases.** Philadelphia: Saunders, 2014
19. Chao TE, Sharma K, Mandigo M, Hagander L, Resch SC, Weiser TG, et al: Cost-effectiveness of surgery and its policy implications for global health: a systematic review and analysis. **Lancet Glob Health 2:**e334–e345, 2014
20. Chisholm D, Stanciole AE, Tan Torres Edejer T, Evans DB: Economic impact of disease and injury: counting what matters. **BMJ 340:**c924, 2010
21. Cuddington JT: Modeling the macroeconomic effects of AIDS, with an application to Tanzania. **World Bank Econ Rev 7:**173–189, 1993
22. Debas HT, Donkor P, Gawande A, Jamison DT, Kruk ME, Mock CN: **Essential Surgery. Disease Control Priorities, ed 3.** Washington, DC: World Bank, 2015, Vol 1
23. Dewan MC, Rattani A, Baticulon RE, Faruque S, Johnson WD, Dempsey RJ, et al: Operative and consultative proportions of neurosurgical disease worldwide: estimation from the surgeon perspective. **J Neurosurg** [epub ahead of print May 11, 2018. DOI: 10.3171/2017.10.JNS17347]
24. El-Fiki M: African neurosurgery, the 21st-century challenge. **World Neurosurg 73:**254–258, 2010
25. Feenstra RC, Inklaar R, Timmer MP: The next generation of the Penn World Table (Version 9.0). **Am Econ Rev 105:**3150–3182, 2015
26. Gallup JL, Sachs JD: The economic burden of malaria. **Am J Trop Med Hyg 64 (1–2 Suppl):**85–96, 2001
27. Hammitt JK: QALYs versus WTP. **Risk Anal 22:**985–1001, 2002
28. Hammitt JK, Robinson LA: The income elasticity of the value per statistical life: transferring estimates between high and low income populations. **J Benefit Cost Anal 2:**1–29, 2011
29. Jack W, Lewis M: **Health Investments and Economic Growth: Macroeconomic Evidence and Microeconomic Foundations.** Washington, DC: World Bank Group, 2009 (https://openknowledge.worldbank.org/handle/10986/4072) [Accessed January 29, 2018]
30. Jamison DT, Summers LH, Alleyne G, Arrow KJ, Berkley S, Binagwaho A, et al: Global health 2035: a world converging within a generation. **Lancet 382:**1898–1955, 2013 (Erratum in **Lancet 383:**218, 2014)
31. Lorentzen P, McMillan J, Wacziarg R: Death and development. **J Econ Growth 13:**81–124, 2008
32. Madheswaran S: Measuring the value of statistical life: estimating compensating wage differentials among workers in India. **Soc Indic Res 84:**83–96, 2007
33. 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. **Am J Obstet Gynecol 213:**338–340, 2015
34. Murray CJ, Ezzati M, Flaxman AD, Lim S, Lozano R, Michaud C, et al: GBD 2010: design, definitions, and metrics. **Lancet 380:**2063–2066, 2012
35. Murray CJ, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, et al: 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:**2197–2223, 2012 (Erratum in **Lancet 381:**628, 2013)
36. Roman HA, Hammitt JK, Walsh TL, Stieb DM: Expert elicitation of the value per statistical life in an air pollution context. **Risk Anal 32:**2133–2151, 2012
37. Sachs JD (ed): **Macroeconomics and Health: Investing in Health for Economic Development.** Geneva: World Health Organization, 2001 (http://www1.worldbank.org/publicsector/pe/PEAMMarch2005/CMHReport.pdf) [Accessed January 29, 2018]
38. Shrime MG, Bickler SW, Alkire BC, Mock C: Global burden of surgical disease: an estimation from the provider perspective. **Lancet Glob Health 3 (Suppl 2):**S8–S9, 2015
39. Shrime MG, Dare AJ, Alkire BC, O'Neill K, Meara JG: Catastrophic expenditure to pay for surgery worldwide: a modelling study. **Lancet Glob Health 3 (Suppl 2):**S38–S44, 2015
40. Strauss J, Thomas D: Health, nutrition, and economic development. **J Econ Lit 36:**766–817, 1998
41. Viscusi WK, Aldy JE: The value of a statistical life: a critical review of market estimates throughout the world. **J Risk Uncertain 27:**5–76, 2003
42. Vos T, Allen C, Arora M, Barber RM, Bhutta ZA, Brown A, et al: Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. **Lancet 388:**1545–1602, 2016
43. Wang H, Naghavi M, Allen C, Barber RM, Bhutta ZA, Carter A, et al: Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. **Lancet 388:**1459–1544, 2016
44. Warf BC: Pediatric hydrocephalus in East Africa: prevalence, causes, treatments, and strategies for the future. **World Neurosurg 73:**296–300, 2010
45. Warf BC, Alkire BC, Bhai S, Hughes C, Schiff SJ, Vincent JR, et al: Costs and benefits of neurosurgical intervention for infant hydrocephalus in sub-Saharan Africa. **J Neurosurg Pediatr 8:**509–521, 2011
46. World Health Organization: **WHA68.15: Strengthening Emergency and Essential Surgical Care and Anaesthesia as a Component of Universal Health Coverage.** Geneva: World Health Organization, 2015 (http://apps.who.int/medicinedocs/documents/s21904en/s21904en.pdf) [Accessed January 29, 2018]
47. World Health Organization: **WHO Guide to Identifying the Economic Consequences of Disease and Injury.**

Geneva: World Health Organization, 2009 (http://www.who.int/choice/publications/d_economic_impact_guide.pdf) [Accessed January 23, 2018]

48. Winkler AS, Tluway A, Slottje D, Schmutzhard E, Härtl R: The pattern of neurosurgical disorders in rural northern Tanzania: a prospective hospital-based study. **World Neurosurg 73:**264–269, 2010
49. Yaduma N, Kortelainen M, Wossink A: Estimating mortality and economic costs of particulate air pollution in developing countries: the case of Nigeria. **Environ Resour Econ 54:**361–387, 2012

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Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

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Supplemental material

The economic consequences of neurosurgical disease in low- and middle-income countries

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Appendix

Neurosurgical Disease

We extracted estimates of mortality rates and years lived with disability from the Institute for head Metrics and Evaluation (IHME) global burden of disease 2015 (GBD2015) study.[25] IHME assigns diseases and injuries to a hierarchical list of "causes." Cerebrovascular accident, brain and nervous system cancer, and neural tube defects are explicit causes in GBD2015. We combined burden estimates for meningitis and encephalitis to create the CNS infection category.

As traumatic brain injury (TBI) is not an explicit cause in GBD2015, we used the following approach to create estimates of mortality from TBI. Data on the average number of TBI-related deaths in the United States from 2002-2006, broken down by age and external cause, was obtained from the Centers for Disease Control and Prevention (CDC).[11] Since complete information on the external cause was not available for every case of TBI-related death, we accounted for TBI-related deaths in the following categories (as defined by the CDC): falls, assault, struck by or against, motor vehicle-traffic (MVT) occupant, MVT motorcycle, MVT pedestrian and MVT pedal cycle. TBI-related deaths in the categories other/unknown and MVT other or unspecified were not accounted for. Data on the number of injury deaths broken down by age and external cause during 2002-2006 was obtained from the IHME,[1] and the mean was calculated. A ratio for each subgroup defined by external cause and age was calculated by dividing the number of TBI related deaths from the CDC with the corresponding number of injury deaths from the IHME. Global TBI death rates were calculated by multiplying the ratio obtained from US data with injury death rates broken down by country, external cause, age and sex obtained from the IHME.[1]

The data generated using our modeling strategy was validated against available estimates of TBI mortality rates from the literature.[5,18,19,22,23] Our model generated reliable estimates, well within the range of variability of primarily collected data.[19,22] We would, however, caution against direct comparison due to the differing inclusion and exclusion criteria of the available literature, as well as the non-standardized handling of temporal trends.

Country	**Year**	**Estimate from literature**	**Model estimate (Annual deaths per 100 000 pop)**
Austria[18]	2010	17.4	8.60

US[5]	2007	12.7	9.09*
New Zealand[23]	2010	11.1	7.10
Europe[19]	-	10.5	11.80
Europe[22]	-	15.0	12.60

*Average of output from 2005 and 2010

Economic Approaches: Assumptions and Data Sources

A more complete accounting of the VLO and VLW models can be found in the manuscript and supplementary appendix[4] by Alkire *et. al.* that accompanied the Lancet Commission on Global Surgery (LCoGS) report. For concision, the core of each model is discussed below.

Value of lost output

To estimate the effect of neurosurgical disease in LMICs on economic productivity from 2015-2030, we modified the World Health Organization's EPIC model.

The central formula for the EPIC model is the Cobb-Douglas[8] production function:

(1) $Y_{i,t} = \gamma_{i,t} \cdot A_{i,t} \cdot K_{i,t}^{\alpha} \cdot L_{i,t}^{\beta}$

where *Y* = output (GDP), *A* = total factor productivity, *K* = physical capital stock, *L*= labor force, alpha = output elasticity with respect to physical capital stock, beta = output elasticity with respect to labor, *i* = country, and *t* = year. Total factor productivity is defined as the change in economic output not due to changes in the labor force or capital stock and is considered to reflect technological growth.[6] $\gamma_{i,t}$ is a calibration parameter that adjusts the raw model output so that it equals an externally-sourced prediction of GDP for a given country in a given year.

EPIC therefore relies on the assumption that mortality due to disease decreases the labor supply, which consequently decreases economic output.

The cumulative value of lost output for a given country is therefore:

(2) $VLO_i = \sum_{d \in D} \sum_{t=2015}^{2030} Y_{cf,d,t} - Y_{sq,t}$

where *d* = disease, *cf* = counterfactual scenario, *sq* = status quo, *VLO* = value of lost output.

Labor Supply

The labor force is defined as the employed population greater than 14 years old. To estimate changes in the labor force, EPIC first estimates changes in the total population by age, sex, and year.

Status quo population and labor projections are provided by WHO in the EPIC model (see data sources below). The marginal addition to the population for each year in the absence of disease is first adjusted by the baseline survival rate, and then this addition to the population is adjusted by age- and sex-specific employment rates. In addition, EPIC adjusts for age (a) using an experience factor as suggested by Cuddington,[10] where:

$$(3)\quad EF_a = 0{\cdot}8 + 0{\cdot}02(a-15) - 0{\cdot}0002(a-15)^2$$

Data Sources

The EPIC model was used as provided by WHO apart from the variables discussed below. Mortality rates for the neurosurgical conditions included in this study were not available in the model. To create mortality rate projections, we extracted mortality rate estimates for each disease by country, age group, and sex for the years 2005 and 2015 from GBD2015.[25] For each disease (*d*), we estimated the annualized rate of change (*rc*) from 2005 to 2015 by country, age-group , and sex (s) with the following formula:

$$(4)\quad rc_{a,i,d,s} = \frac{\ln\left[\frac{MR_{2015,a,d,i,s}}{MR_{2005,ad,i,s}}\right]}{10}$$

where *MR* = mortality rate. Mortality rate projections were then calculated as follows:

$$(5)\quad MR_{a,d,i,t,s} = MR_{2015,a,i,s} \cdot e^{rc_{a,i,s}(t-2015)}$$

Further adjustments to the EPIC model include the use of GDP per capita projections with estimates from the International Futures modeling system[14] and updated estimates of capital stock and total factor productivity from the latest edition of Penn World Tables.[12] Labor projections were obtained from the International Labor Organization,[15] while capital depreciation was updated using the latest data form the world development indicators.[27] The original EPIC model contained an error, now corrected, in the experience factor formula (equation 3) in which the last term was positive as opposed to negative.[10]

Population projections, the output elasticity with respect to capital stock and labor, and the savings rate were used as supplied by the WHO.[2,7] The status quo GDP projections to which the model was calibrated were formed by multiplying the GDP per capita projections from the International Futures modeling system times the population projections from the WHO.

Annual Total Economic Welfare Losses

We assess total economic welfare losses secondary to disease with the use of a concept known as the value of a statistical life (VSL). We adopt a similar approach to others[7,16,17,26] in modifying a country's VSL to value disability-adjusted life-years (DALY) secondary to each of the five neurosurgical diseases studied at the country level. The DALY is a health metric that combines morbidity and mortality secondary to disease.

Disability-Adjusted Life-Years

The formula for calculating the number of DALYs in country *i* during time period *t* in a population secondary to a disease is:

(1) $$DALY_{d,i,t} = YLL_{d,i,t} + YLD_{d,i,t}$$

where *YLD* = years lived with disability (morbidity) and *YLL* = years of life lost (mortality). Discounting is a common practice in economic analyses and determines the present value of monetary benefits that will be realized in the future. Due to positive interest rates in capital markets, "a dollar today is worth more than a dollar tomorrow." As we wish to convert future DALYs to economic burden in present value terms, we utilize discounting in our DALY calculations. This differs from the current IHME practice, which starting in GBD2010 stopped discounting. We do not use the global burden of disease YLL estimates as they are not discounted and use a standardized life-table as opposed to country or region specific life-tables.

The inclusion of discounting results in the following years of life lost (YLL) formula:

(2) $$YLL_{d,a,t} = \int_a^{LE_{a,t}} e^{-r(x-a)} dx$$

where *a* = age of death, *LE* = country and age-specific life-expectancy, *x* = age integrated over years of life lost (YLLs), *r* = discount rate. Years lived with disability (YLDs) are provided by IHME from a prevalence perspective – only the morbidity incurred during the reference year is considered. Note that the prevalence perspective precludes the need to discount YLDs. Therefore:

(3) $$YLD_{d,a,t} = P_{d,a,t} \cdot DW_d$$

where *P* = prevalence and *DW* = disability weight. Disability weights are used to account for morbidity due to a disease, with 0 = perfect health and 1 = death. It should be noted that as traumatic brain injury (TBI) is an IHME cause, and only mortality estimates were made for this study, YLDs due to TBI are not included in this study.

The Value of a Statistical Life

The value of a statistical life (VSL), which has been developed over the past 40 years,[13] is most easily conceptualized as the maximum amount an individual would be willing to pay to avert their risk of death. As an example, an individual who accepts $2,000 in decreased wages to transfer to a safer occupation where the fatality risk is 0.001 lower is implicitly revealing that she values her risk reduction at $2 million (= $2,000 / 0.001). In this example, the VSL is $2 million. Comparing the wages of occupations with different risk profiles is a subtype of the revealed preference approach to estimating VSL, and has historically been considered to be more robust than the competing survey-based approaches, which form the basis of the so-called stated preference approach.[14,15] More recently, however, stated-preference studies have gained traction in the literature as the methodology has been further refined.[9]

As formal VSL studies have not been performed in the vast majority of developing countries, economists have devised a method for estimating the VSL in a country in which empirical studies have not been performed.[15] Using the ratio of gross national income per capita (GNI per capita) as a conversion factor, one can transfer VSL estimates from a country in which empirical studies have been performed to countries in which they have not. Assumptions regarding the "income elasticity of VSL" (IE-VSL), which dictates how VSL changes in proportion to the relative income of the two considered countries, play an important role in determining the final VSL estimates. Increasing the IE-VSL results in decreased VSL estimates when transferring estimates from high- to low-income countries. Although IE-VSL's of 0.5-1.0 are traditionally used when transferring estimates from high-income countries to LMICs, recent evidence suggests that an IE-VSL of 1.5 may be more appropriate.[16] In addition, while an IE-VSL of 0.55 is commonly used in transferring estimates between high-income countries, there is some debate as to whether this is too low; therefore, we use an IE-VSL of 1.0 as our base case to remain conservative.[21,24]

We adopt a similar approach to others[7,16,17,26] in modifying VSL to value disability-adjusted life-years (DALY) secondary to each of the neurosurgical diseases studied at the country level. To use VSL to place an economic value on a DALY, it is converted to the value of a statistical life-year (VSLY). Assumptions regarding VSLY and how it varies with age, country-specific income, and country- and age-specific life-expectancy are incorporated into the model, and are described below.

Converting DALYs averted to Economic Benefit

The total welfare losses due to disease are given by:

(4) $$VWL_d = VSLY \cdot DALYS_d$$

where *VWL* = total welfare losses. VSL varies with age,[3] and we first estimated the peak value of a statistical life year (VSL_p):

(5) $$VSL_{p,i} = VSL_{p,U.S.} \cdot \left[\frac{YC_i}{YC_{U.S.}}\right]^{IE-VSL}$$

where VSL_p = the peak value of a statistical life, and *YC* = GNI per capita in 2015. We used GNI per capita estimates based on the purchasing power parity (PPP) approach to be consistent with the economic literature.[24]

Empirical evidence indicates that VSL (and VSLY) are not constant over an individual's lifetime, and that they do not monotonically decrease with age as intuition might suggest. Instead, both VSL and VSLY follow an inverted U shape – initially rising with age before falling.[3] We incorporate this concept into our model along with assumptions regarding income, time-preferences for money, and country and age-specific life-expectancy. To calculate age-specific VSLs (VSL_a), we adjust a country's peak VSL to VSL_a

based on the proportion of life lived based on Aldy and Viscusi's 2008 study, "Adjusting the Value of a Statistical Life for Age and Cohort Effects."[3] There is uncertainty regarding the VSL for children; however there is general consensus that the VSL of a child is at least that of an adult.[20] To account for this, we included a data point such that the VSL at birth is equal to the VSL at 1/5 of life-expectancy.

One can calculate the VSLY by treating VSL as the present value of an annuity, where the VSLY is the payment over the remaining discounted years of life.[13] Consequently, $VSLY_a$ can be estimated by setting the VSL_a equal to $VSLY_a$ multiplied by discounted remaining years of life,

(6) $$VSL_{a,i,t} = VSLY_{a,i,t} \int_a^{LE_{a,i,t}} e^{-r(x-a)}\, dx$$

and then solving for $VSLY_a$. This is the value which is subsequently multiplied by total DALYs to arrive at total welfare losses.

Appendix tables

Appendix table 1. List of countries included in the value of lost output (VLO) and value of lost welfare (VLW) analyses.

Countries	VLO	VLW
Afghanistan		☐
Albania		☐
Algeria	☐	☐
Angola		☐
Argentina	☐	
Armenia	☐	☐
Azerbaijan		☐
Bangladesh	☐	☐
Belarus		☐
Belize		☐
Benin	☐	☐
Bhutan		☐
Bolivia, Plurinational State of	☐	☐
Bosnia and Herzegovina		☐
Botswana	☐	☐
Brazil	☐	☐
Bulgaria	☐	☐
Burkina Faso	☐	☐
Burundi	☐	☐

Cambodia	☐	☐
Cameroon	☐	☐
Cape Verde		☐
Central African Republic	☐	☐
Chad	☐	☐
China	☐	☐
Colombia	☐	☐
Comoros		☐
Congo	☐	☐
Congo, the Democratic Republic of the	☐	☐
Costa Rica	☐	☐
Côte d'Ivoire	☐	☐
Dominica		☐
Dominican Republic	☐	☐
Ecuador	☐	☐
Egypt	☐	☐
El Salvador	☐	☐
Equatorial Guinea	☐	☐
Ethiopia	☐	☐
Fiji	☐	☐
Gabon	☐	☐
Gambia	☐	☐
Georgia		☐
Ghana	☐	☐
Grenada		☐
Guatemala	☐	☐
Guinea	☐	☐
Guinea-Bissau	☐	☐
Guyana		☐
Haiti	☐	☐
Honduras	☐	☐
India	☐	☐
Indonesia	☐	☐
Iran, Islamic Republic of	☐	☐
Iraq	☐	☐
Jamaica	☐	☐
Jordan	☐	☐
Kazakhstan	☐	☐
Kenya	☐	☐
Kiribati		☐

Kyrgyzstan	☐	☐
Lao People's Democratic Republic		☐
Lebanon		☐
Lesotho	☐	☐
Liberia		☐
Libya		☐
Macedonia, The Former Yugoslav Republic of		☐
Madagascar	☐	☐
Malawi	☐	☐
Malaysia	☐	☐
Maldives		☐
Mali	☐	☐
Marshall Islands		☐
Mauritania	☐	☐
Mauritius	☐	☐
Mexico	☐	☐
Micronesia, Federated States of		☐
Moldova, Republic of	☐	☐
Mongolia	☐	☐
Montenegro		☐
Morocco	☐	☐
Mozambique	☐	☐
Namibia	☐	☐
Nepal	☐	☐
Nicaragua	☐	☐
Niger	☐	☐
Nigeria	☐	☐
Pakistan	☐	☐
Palestine, State of		☐
Panama	☐	☐
Papua New Guinea		☐
Paraguay	☐	☐
Peru	☐	☐
Philippines	☐	☐
Romania	☐	☐
Russian Federation	☐	☐
Rwanda	☐	☐
Saint Lucia		☐
Saint Vincent and the Grenadines		☐
Samoa		☐

Sao Tome and Principe		☐
Senegal	☐	☐
Serbia	☐	☐
Sierra Leone	☐	☐
Solomon Islands		☐
South Africa	☐	☐
South Sudan		☐
Sri Lanka	☐	☐
Sudan		☐
Suriname		☐
Swaziland	☐	☐
Syrian Arab Republic	☐	
Tajikistan	☐	☐
Tanzania, United Republic of	☐	☐
Thailand	☐	☐
Timor-Leste		☐
Togo	☐	☐
Tonga		☐
Tunisia	☐	☐
Turkey	☐	☐
Turkmenistan		☐
Uganda	☐	☐
Ukraine	☐	☐
Uzbekistan		☐
Vanuatu		☐
Venezuela, Bolivarian Republic of	☐	☐
Viet Nam		☐
Yemen	☐	☐
Zambia	☐	☐
Zimbabwe	☐	☐
n	90	127

References

1. Global Burden of Disease Study 2015, in. Seattle, United States: Institute for Health Metrics and Evaluation (IHME)
2. Abegunde D, Stanicole A: An estimation of the economic impact of chronic noncommunicable diseases in selected countries, in. Geneva: World Health Organization, 2006

3. Aldy JE, Viscusi WK: Adjusting the value of a statistical life for age and cohort effects. **Review of Economics and Statistics 90:**573-581, 2008
4. Alkire BC, Shrime MG, Dare AJ, Vincent JR, Meara JG: Global economic consequences of selected surgical diseases: a modelling study. **Lancet Glob Health 3 Suppl 2:**S21-27, 2015
5. Asemota AO, George BP, Bowman SM, Haider AH, Schneider EB: Causes and trends in traumatic brain injury for United States adolescents. **J Neurotrauma 30:**67-75, 2013
6. Bloom D, Cafiero E, McGovern M, Prettner K, Stanicole A, Weiss J, et al: The economic impact of non-communicable disease in China and India: estimates, projections, and comparisons, in**.** Boston: Harvard Initiative for Global Health: Program on the Global Demography of Aging, 2013
7. Bloom DE, Cafiero ET, Jané-Llopis E, Abrahams-Gessel S, Bloom LR, Fathima S, et al: The global economic burden of noncommunicable diseases, in**.** Geneva: World Economic Forum, 2011
8. Cobb CW, Douglas PH: A Theory of Production. **American Economic Review 18:**139-165, 1928
9. Cropper ML, Hammitt JK, Robinson LA, National Bureau of Economic Research.: Valuing Mortality Risk Reductions Progress and Challenges, in **NBER working paper series no. w16971.** Cambridge, Mass.: National Bureau of Economic Research, 2011, p Electronic resource.
10. Cuddington JT: Modeling the macroeconomic effects of AIDS, with an application to Tanzania. **World Bank Econ Rev 7:**173-189, 1993
11. Faul M, Xu L, Wald MM, Coronado WG: Traumatic Brain Injury in the United States: Emergency Department Visits, Hospitalizations nad Deaths 2002-2006, in**.** Atlanta (GA): Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, 2010
12. Feenstra RC, Inklaar R, Timmer MP: The next generation of the Penn World Table (Version 9.0). **American Economic Review 105:**3150-3182, 2015
13. Hammitt JK: Valuing changes in mortality risk: lives saved versus life years saved. **Review of Environmental Economics and Policy 1:**228-240, 2007
14. Hughes B: IFs: The international futures modeling system version 7.24, in**.** Denver: Frederick S. Pardee Center for International Futures, Josef Korbel School of International Studies, University of Denver, 2016, Vol 2016
15. International Labor Organization: Economically active population, estimates and projections (6th Edition), in, 2011, Vol 2014
16. Jamison DT, Jha P, Laxminarayan R, Ord T: Infectious disease, injury, and reproductive Health, in **Copenhagan Consensus 2012.** Copenhagan: Copenhagen Consensus Center, 2012
17. John R, Ross H: The global economic cost of cancer: a report summary, in: American Cancer Society, 2010
18. Mauritz W, Brazinova A, Majdan M, Leitgeb J: Hospital admissions for traumatic brain injury of Austrian residents vs. of visitors to Austria. **Brain Inj 28:**1295-1300, 2014
19. Peeters W, van den Brande R, Polinder S, Brazinova A, Steyerberg EW, Lingsma HF, et al: Epidemiology of traumatic brain injury in Europe. **Acta Neurochir (Wien) 157:**1683-1696, 2015
20. Roman HA, Hammitt JK, Walsh TL, Stieb DM: Expert elicitation of the value per statistical life in an air pollution context. **Risk Anal 32:**2133-2151, 2012
21. Suhrcke M: Perspective paper: chronic disease prevention and control, in**.** Copenhagen: Copenhagen Consensus, 2012
22. Tagliaferri F, Compagnone C, Korsic M, Servadei F, Kraus J: A systematic review of brain injury epidemiology in Europe. **Acta Neurochir (Wien) 148:**255-268; discussion 268, 2006
23. Te Ao B, Tobias M, Ameratunga S, McPherson K, Theadom A, Dowell A, et al: Burden of Traumatic Brain Injury in New Zealand: Incidence, Prevalence and Disability-Adjusted Life Years. **Neuroepidemiology 44:**255-261, 2015
24. Viscusi WK, Aldy JE: The value of a statistical Life: a critical review of market estimates throughout the world. **Journal of Risk Uncertainty 27:**5-76, 2003

25. Wang H, Naghavi M, Allen C, Barber RM, Bhutta ZA, Carter A, et al: Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. **The Lancet 388:**1459-1544
26. WHO: **Macroeconomics and health: investing in health for economic development.** Geneva: WHO, 2001
27. World Bank: The World Bank: open data (world development indicators), in, 2016, Vol 2016

Study VII

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Research Letter

Modelling why 70 per cent of the world's population lack access to surgery

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Dear Editor

The Lancet Commission on Global Surgery[1] showed that at least 140 million additional surgical procedures are needed to prevent loss of life or significant disability worldwide, and that implementing surgical, obstetric and anaesthesia care is a cost-effective solution for global public health. The commission set out to estimate the proportion of the global population that lack access to such care and, as a first step, the meaning of the word access needed to be clearly defined.

Previous research[2] had used operating theatre density as a proxy for surgical capacity and found that 2 billion people lacked access to surgery. It is however well known in the sustainable development goals era, infrastructure to deliver healthcare is not sufficient to achieve universal healthcare coverage. As research in high-income settings has consistently shown, there is a critical window of time between onset of symptoms and receiving treatment for many surgical conditions. If patients are unable to access surgical care during this time frame, they are much more likely to suffer from a poor outcome (or even death). Globally, more people are estimated to die as a result of inadequate quality of care rather than availability[3], i.e. care must be safe. Finally, as healthcare expenses are one of the leading causes of impoverishment[4], wreaking havoc upon entire households, surgical care must also be affordable. Any definition of meaningful access consequently needs to address not only capacity but also the timeliness, safety, and affordability of the care provided.

Using the above four axes of access, Alkire *et al.*[5] estimated the proportion of each country's population that did have access to surgical care (a function of the joint probability of having access to each of the axes of access), ultimately determining that up to 70 per cent of the world's population lacks full access to surgical care.

For this letter, the methodology is revisited but applied to every possible combination of joint probabilities, and by doing so the relative scale of the issues that need to be solved in order to achieve universal healthcare in surgery is determined (*Fig. 1* and *Table S1*). The global population that lacks access to surgery owing to a combination of one or more factors is presented as a set of area-proportional ellipses in an Euler diagram.

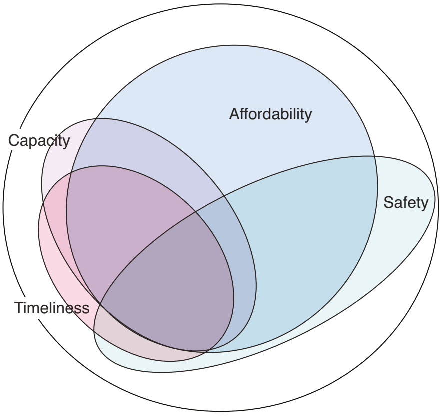

Fig. 1 Area-proportional Euler diagram of the lack of access to surgery

The large circle represents the total global population, and the smaller ellipses represent those who do not have access to surgical care owing to each factor.

What are the lessons to be learnt from such a mathematical exercise? By visualizing data in this way, the multidimensional nature of the problem immediately becomes obvious. Of the billions of people estimated to lack access to surgery, 60 per cent do so because a lack of two or more factors, 27 per cent due to a lack of three or more factors, and 13 per cent owing to all four.

The relative importance of the different factors can thus be understood, in particular the outsized influence of affordability on the number of people who lack full access to surgery. In the authors' experience, much of the foreign aid for surgery is aimed primarily at capacity building, whereas comparatively less attention is given to affordability. Conceivably, when global health programmes are run by teams comprising mainly physicians and other health workers, issues requiring entirely different skill sets, such as insurance schemes or road networks, are not prioritized. Understanding this can aid in moving

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towards universal health coverage as a continuum rather than a binary headcount, where solutions will have to be tailored to the specific hindrance rather than one size fits all.

In light of these lessons, any attempt to mitigate this ongoing public health crisis will need to be focused not solely on operating capacity, but will need to be as multifactorial as the problem it seeks to solve.

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Supplementary material

Supplementary material is available at *BJS* online.

Data availability

Data utilized in the study are available from the corresponding author upon reasonable request.

References

1. Meara JG, Leather AJM, Hagander L, Alkire BC. Global surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *Lancet* 2015;**386**:569–624
2. Funk LM, Weiser TG, Berry WR, Lipsitz SR, Merry AF, Enright AC *et al.* Global operating theatre distribution and pulse oximetry supply: an estimation from reported data. *Lancet* 2010;**376**:1055–1061
3. Kruk ME, Gage AD, Arsenault C, Jordan K, Leslie HH, Roder-DeWan S *et al.* High-quality health systems in the sustainable development goals era: time for a revolution. *Lancet Global Heal* 2018;**6**:e1196–e1252
4. Shrime MG, Dare A, Alkire BC, Meara JG. A global country-level comparison of the financial burden of surgery. *Br J Surg* 2016; **103**:1453–1461
5. Alkire BC, Raykar NP, Shrime MG, Weiser TG, Bickler SW, Rose JA *et al.* Global access to surgical care: a modelling study. *Lancet Glob Health* 2015;**3**:e316–e323

Title*: Why does 70% of the world's population lack access to surgery?*

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Supplementary Materials - Index

Supplementary Figures and Tables

Supplementary Figures and Tables

Table S1. The estimated number of people globally that lack access to surgery due to issues with timeliness (T), capacity (C), affordability (A), safety (S), and the combinations thereof. *

Factor	Million people
T	1,500
C	1,900
S	2,400
A	3,800
$T \cup C$	2,200
$T \cup S$	3,200
$T \cup A$	4,100
$C \cup S$	3,400
$C \cup A$	4,100
$S \cup A$	4,500
$T \cup C \cup S$	3,600
$T \cup C \cup A$	4,300
$T \cup S \cup A$	4,700
$C \cup S \cup A$	4,700
$T \cup C \cup S \cup A$	4,800

*Global population used in these calculations: 7 billion.

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