Operation Smile

Global Surgery Bootcamp Module 6 – Infrastructure

Learning Objectives

1. Explain how the distribution of health care infrastructure affects surgical care provision
2. Name the key infrastructure components needed to provide surgical care
3. Explore the impact a National Surgical Plan can have

Materials

Listen

1. NPR Podcast, Planet Money, episode from 31 March 2020 "The Race to Make Ventilators"
    a. Episode has been uploaded as a step in Engage
    b. Transcript
2. NPR Podcast, Planet Money, episode from 17 April 2020 "The Mask Mover"
    a. Episode has been uploaded as a step in Engage
    b. Transcript

Read

1. Unite for Sight Global Health University: "Learning from Coca Cola: The Science of Healthcare Delivery"
2. Rajbhandari, "The Neglected Hospital –The District Hospital's Central Role in Global Health Care Delivery" (pages 2-4)
3. Hsia, "Access to Emergency and Surgical Care in sub-Saharan Africa: the infrastructure gap" (pages 5-15)
4. Funk, "Global operating theatre distribution and pulse oximetry supply: an estimation from reported data" (pages 16-30)
5. Chawla, "Water availability at hospitals in low-and middle-income countries: implications for improving access to safe surgical care" (pages 31-40)
6. Chawla, "Electricity and generator availability in LMIC hospitals: improving access to safe surgery" (pages 41-46)
7. Meara, "Global Surgery 2030", read only the **National Surgical Plan** section. (pages 47-49)
8. There are also supplementary readings available for a deeper dive.

**Make sure to watch the Infrastructure Module Summary video after working through these materials.

Things to Think About

- What do you think health care infrastructure consists of? Do the readings pose a different definition, and if so, how is it different?
- What forces are at work that affect availability and placement of health care infrastructure?
- How do we deliver high quality healthcare in areas with minimal infrastructure, or poor-quality infrastructure?
- The COVID-19 pandemic has presented a unique challenge to supply chains for health equipment and supplies.
    - What are some of the challenges that have arisen?
    - Have there been any innovative solutions to these problems?
    - Should we have to resort to these innovative solutions? How do we apply these lessons moving forwards?

The NEW ENGLAND JOURNAL of MEDICINE

Perspective

JANUARY 30, 2020

The Neglected Hospital — The District Hospital's Central Role in Global Health Care Delivery

Ruma Rajbhandari, M.D., M.P.H., Devon E. McMahon, B.A., Joseph J. Rhatigan, M.D., and Paul E. Farmer, M.D., Ph.D.

Although HIV remains an important contributor to the global disease burden, during the past decade great strides have been made in addressing this epidemic. The global health agenda has now begun to include improving delivery of surgical and noncommunicable-disease services in low- and lower-middle-income countries (LLMICs). In addition, renewed calls to implement and extend universal health coverage in these settings have raised the issue of quality improvement, as policymakers strive to increase the value of covered services. Advancing emerging surgery, noncommunicable-disease, and quality agendas will be possible only if investments are aimed at strengthening a perennially undervalued component of health systems in LLMICs: the district hospital.

For people living in these countries, particularly in rural communities, the district hospital is a central hub for higher-level clinical care. District hospitals are often located in a district's capital and can be a central location for medical referrals; training of health workers, including clinical assistants and nurses; supervision of peripheral facilities; and public health surveillance. Such hospitals are generally 50- to 200-bed institutions that provide care for a district's 100,000 to 1 million people (see photo). According to the World Health Organization, district hospitals should offer primary health care, emergency obstetrical care, general surgery, orthopedic surgery, and advanced medical specialty care, including laboratory services and diagnostic imaging.

Although the district hospital plays an essential role in health care delivery, it has often been neglected by the global health community. The 1978 Declaration of Alma-Ata promoted health as a human right and focused on strengthening primary care. Over the past several decades, however, the vast majority of development assistance for health has gone toward vertical, disease-specific interventions targeting conditions such as HIV/AIDS, tuberculosis, and malaria. External funding for these initiatives seldom supports hospital-level health services or overall health system strengthening. For example, an analysis of investments by the Global Fund found that only 37% (U.S. $362 million) of allocated funds went toward strengthening health sys-

Patients at Okhaldhunga Community Hospital in Siddhicharan Municipality, Nepal.

Photograph courtesy of Alex Treadway and the Nick Simons Institute.

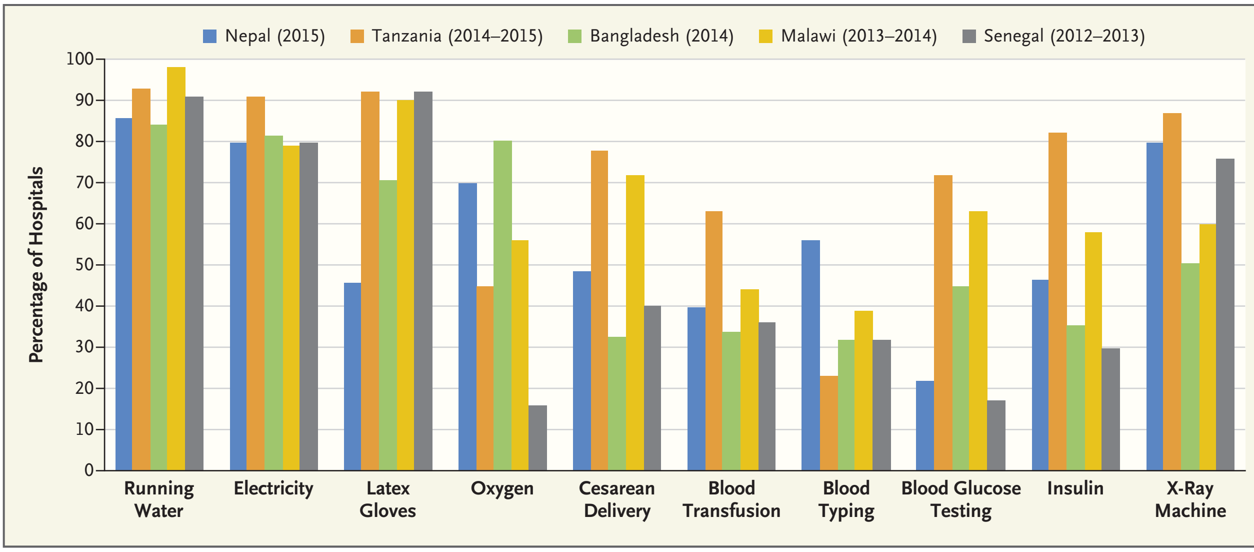
tems, of which more than 60% targeted disease-specific systems.[1] Hospitals, particularly large urban referral hospitals, have been seen as consuming excessive amounts of national health spending and providing little in the way of population health benefits. In addition, policies to increase investment in programs that ensure more equitable health care delivery, such as community-based health interventions, have unwisely constrained investments in district-hospital services.

This lack of support for district hospitals leaves patients with acute illnesses, such as pneumonia and sepsis, and those with acute exacerbations of chronic conditions, such as chronic obstructive pulmonary disease and heart failure, without effective care. We believe that high-functioning district hospitals will be required if global health efforts to offer high-quality surgical services and treatment for noncommunicable diseases are to succeed.

The limited capacity for surgical and anesthetic care in many LLMICs is one manifestation of the neglect of the district hospital among global health priorities. Such hospitals often lack the most basic resources and supplies necessary for performing an operation. Data from the Demographic and Health Surveys show that a large percentage of hospitals in LLMICs lack electricity, running water, latex gloves, and oxygen (see graph).

A hospital's ability to perform so-called bellwether procedures, which include laparotomy, cesarean section, and open-fracture repair, has been used as a marker for the availability of other services, such as obstetrical, general, basic, emergency, and orthopedic surgery. Only 58% of district hospitals in LLMICs can perform a laparotomy, 64% can perform a cesarean section, and 40% are capable of repairing an open fracture.[2] Lack of capacity to carry out these essential operations indicates that other basic services are probably lacking. Physicians are also in short supply at these hospitals; the poorest half of the world's population is served by only one fifth of the world's surgeons and one sixth of the world's anesthesiologists.[2] Although surgical services have been underfunded, they are remarkably cost-effective. In Zambia, the cost-effectiveness ratio for essential surgeries at district hospitals has been estimated at $10.70 per disability-adjusted life-year (DALY), as compared with $12.88 to $362 per DALY for surgical missions, $350 to $500 per DALY for HIV antiretroviral therapy, and $14.20 per DALY for bed nets for malaria prevention.[3]

Many district hospitals in LLMICs also struggle to provide care for noncommunicable diseases. The neglect of such diseases is particularly alarming because in the next 20 years, the burden of cancer, cardiovascular disease, and road-traffic injuries (based on number of deaths and reductions in DALYs) will surpass the burden of communicable diseases in LLMICs.[2] Over the past several decades, much attention has been paid to expanding the reach of medical care by supporting lower-level facilities and community health workers. Although this strategy can help improve long-term management of noncommunicable diseases such as hypertension and diabetes, patients with acute complications of chronic problems must still be referred to hospitals. When these patients arrive at hospitals for higher-level care, however, many of the necessary diagnostics, imaging technologies, and medications are unavailable or nonfunctional. According to data from the Demographic and Health Surveys, for example, x-ray machines, laboratories capable of measuring blood glucose levels, and medications such as insulin are frequently unavailable (see graph).



Availability of Resources and Ability to Perform Certain Procedures among Hospitals in a Sample of Low- and Lower-Middle-Income Countries.

Data are from service provision assessment surveys supported by the Demographic and Health Surveys Program (http://dhsprogram.com/What-We-Do/survey-search.cfm). Hospital data are from an aggregate sample of zonal, district, and private hospitals and were collected according to country-specific sampling procedures.

Finally, as health systems increasingly seek to assess the amount of value they deliver, quality and outcomes will need to be monitored and improved. The perceived lack of high-quality care at government hospitals in LLMICs leads higher-income people to seek care in the private sector. In extreme cases, lack of trust in the quality of care at government hospitals can contribute to the worsening of epidemics, as was seen during the Ebola outbreak in western Africa.

Hospitals in LLMICs underperform on several quality metrics. The number of DALYs lost because of unsafe medical care in hospitals is twice as high in LLMICs (15.5 million) as in high-income countries (7.2 million), with the primary source of lost DALYs being premature death due to adverse events.[4] Most adverse events in LLMICs are caused by therapeutic, diagnostic, operative, obstetrical, and neonatal-related errors. Such errors are most often attributed to defective or unavailable equipment, inadequate training or communication, lack of protocols, and service delays.[5]

An audio interview with Dr. Rajbhandari is available at NEJM.org

Within the past decade, the global health landscape has expanded to encompass broader aspects of hospital-based care. These new global health agendas have often been funded and managed separately, as has historically been the case with vertical disease-control programs targeting HIV, tuberculosis, and malaria. Many health systems in LLMICs struggle to integrate vertical programs into horizontal platforms to deliver a range of services to meet the needs of the communities they serve. By focusing on investments that create highly functional district hospitals, these systems can make progress toward integrating diverse agendas.

District hospitals should be recognized as a crucial piece of the primary health care puzzle, serving both as a platform for treatment programs for various diseases and as the hub of a robust referral network of community health workers and lower-level facilities. We believe that increased investment in hospital-based care is a necessary and cost-effective step toward advancing universal health coverage and strengthening health systems in LLMICs. The improvement of district hospitals is a prerequisite for any advancement of the global agendas for noncommunicable diseases, surgery, and quality of care.

Disclosure forms provided by the authors are available at NEJM.org.

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1. Warren AE, Wyss K, Shakarishvili G, Atun R, de Savigny D. Global health initiative investments and health systems strengthen-

Published by Oxford University Press in association with The London School of Hygiene and Tropical Medicine *Health Policy and Planning* 2012;**27**:234–244

Advance Access publication 26 March 2011 doi:10.1093/heapol/czr023

Access to emergency and surgical care in sub-Saharan Africa: the infrastructure gap

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Accepted 21 January 2011

Background The effort to increase access to emergency and surgical care in low-income countries has received global attention. While most of the literature on this issue focuses on workforce challenges, it is critical to recognize infrastructure gaps that hinder the ability of health systems to make emergency and surgical care a reality.

Methods This study reviews key barriers to the provision of emergency and surgical care in sub-Saharan Africa using aggregate data from the Service Provision Assessments and Demographic and Health Surveys of five countries: Ghana, Kenya, Rwanda, Tanzania and Uganda. For hospitals and health centres, competency was assessed in six areas: basic infrastructure, equipment, medicine storage, infection control, education and quality control. Percentage of compliant facilities in each country was calculated for each of the six areas to facilitate comparison of hospitals and health centres across the five countries.

Results The percentage of hospitals with dependable running water and electricity ranged from 22% to 46%. In countries analysed, only 19–50% of hospitals had the ability to provide 24-hour emergency care. For storage of medication, only 18% to 41% of facilities had unexpired drugs and current inventories. Availability of supplies to control infection and safely dispose of hazardous waste was generally poor (less than 50%) across all facilities. As few as 14% of hospitals (and as high as 76%) among those surveyed had training and supervision in place.

Conclusions No surveyed hospital had enough infrastructure to follow minimum standards and practices that the World Health Organization has deemed essential for the provision of emergency and surgical care. The countries where these hospitals are located may be representative of other low-income countries in sub-Saharan Africa. Thus, the results suggest that increased attention to building up the infrastructure within struggling health systems is necessary for improvements in global access to medical care.

Keywords Infrastructure, developing countries, access, emergency care, surgical care

KEY MESSAGES

- Increasing attention is being placed on making access to emergency and surgical care more available to low-income countries, particularly sub-Saharan Africa, but there is a paucity of data showing the infrastructure needs in these areas.
- No hospital in this five-country study had sufficient infrastructure (within six categories) to carry out what is deemed essential by the World Health Organization for the provision of emergency and essential surgical care.

Introduction

The lack of access to emergency and surgical care in developing countries has been identified as a critical gap in the development of health systems. Since the historic 1978 World Health Organization (WHO) conference at Alma Ata, primary health facilities have been prioritized as the main delivery mechanism for achieving good health outcomes, with an emphasis on immunization services. Increasing resources have also been placed at the hands of individuals and organizations doing work with infectious diseases, particularly HIV, tuberculosis and malaria. Yet even experts in those fields have recognized the paucity of services available for those afflicted with surgical conditions, calling surgery the 'neglected stepchild of global public health' (Farmer and Kim 2008).

While traditionally, primary health centres have delivered preventive care (e.g. vaccinations) and hospitals have delivered more labour and cost-intensive curative care, surgical care can be integrated at all levels in a tiered way, with early referral from primary health centres to higher levels of care for more complex cases. This is consistent with the overall goal of developing a health system to improve health, and strengthening the system's ability to respond to the needs of its population.

The need to develop adequate emergency and surgical services is increasingly evident as surgically treatable diseases, such as hernia repair, become a greater public health burden (Spiegel and Gosselin 2007; Galukande *et al*. 2010). The WHO acknowledged the need to provide essential surgical services when it began the Emergency and Essential Surgical Care project. As part of this project, a guide was developed in 2003 outlining minimum district hospital standards in the area of surgical care: personnel with appropriate education and training, practical continuing education programmes, appropriate physical facilities, suitable equipment and instruments, a reliable system for supply of drugs and medications, and a quality system including standard operating procedures and clinical guidelines (WHO 2003).

If the minimum standards outlined by WHO are to be met, facility-level needs must be considered. This study evaluates the capabilities of the health care facilities in several sub-Saharan African countries in order to provide a baseline understanding of the infrastructure gaps that must be overcome to expand access to emergency and surgical care in the context of developing countries.

Methods

We based our study on the Demographic and Health Surveys (DHS), which is a worldwide project funded by the United States Agency for International Development (USAID), in conjunction with local governments (ministries of health and bureaus of statistics). Service Provision Assessments (SPA) are submodules available for some DHS surveys that provide information based on surveys conducted in health facilities and communities regarding their quality, infrastructure, utilization and availability. SPA data are derived from four main types of collection tools: (1) facility resources questionnaires, in which interviewers collect information on resources, support systems and facility infrastructure elements needed to meet international health standards; (2) observation protocols, in which observers assessed adherence to standards of care for specific medical services; (3) provider interviews; and (4) exit interviews with clients who had been observed receiving a medical service. Surveys are conducted consistently across different countries. Additional details on the methods of SPA data collection are available on the DHS website under the SPA Final Reports for each country (Ghana Statistical Service *et al*. 2003; National Coordinating Agency for Population and Development [Kenya] 2005; National Bureau of Statistics [Tanzania] and Macro International Inc. 2006; Tanzania National Bureau of Statistics 2007; Uganda Ministry of Health 2007; National Institute of Statistics [Rwanda] and 2008; Ministry of Health [Uganda] and Macro International Inc. 2008).

Below we describe the variables chosen and their methods of measurement, as well as data sources (including data collection and processing). The infrastructural elements chosen are based on both structure and process in the classic Donabedian 'structure-process-outcome' framework (Donabedian 1966; Qu *et al*. 2010) for assessing the effectiveness of health care delivery.

Variables and methods of measurement

Based on our experience, recommendations by the WHO (WHO 2003), and availability from recent DHS country surveys, we chose to evaluate six key components (aside from personnel) required for a functioning district surgical service: basic infrastructure, equipment, medicine storage capability, infection control, quality systems, and education. Details of the specific components for each of these inputs are shown in Table 1, as defined by the DHS. Below we outline the role these elements play in supporting surgery and emergency care.

Basic infrastructure is a measure that encompassed elements of physical infrastructure, such as running water and electricity, and overall capacity to support 24-hour emergency services. It is important to note here that it was the *capacity* to provide 24-hour emergency care, rather than the actual availability of this service, that was assessed. Not all health facilities (such as clinics) are expected to provide 24-hour emergency care, but because emergency care can be life-saving, it is important to

Table 1 Definitions of infrastructure elements for survey

Infrastructure element	Definition
Basic infrastructure	
Physical infrastructure	• Functioning latrine • Protected waiting area • Basic level of cleanliness • Year-round water supplied in facility by tap or available within 500 metres of facility • Routinely available electricity during service hours or backup generator with fuel
Components to support 24-hour emergency services	• Adequate physical infrastructure (as described above) • On-site emergency treatment • Capacity to monitor a seriously ill patient overnight until transfer • Two qualified providers • 24-hour duty or on call schedule • Available overnight bed • 24-hour emergency communication
Equipment	
Building or infrastructure repair	• System for maintenance and repair of building or infrastructure
Equipment processing	• Staff knowledge of processing time for at least one method of equipment processing (e.g. autoclave, dr heat sterilization, boiling/steaming, or chemical disinfection) • Passive timer
Medicine storage capability	
Good storage conditions	• Medicines stored in dry location, off the ground and protected from sun, water, pests and rodents
Adequate stock monitoring	• No expired items • Items stored by expiration date • Up-to-date inventory available
Infection control	
Availability of infection control items	• Availability of soap, running water, sharp box, latex gloves and disinfectant in assessed areas
Adequate disposal system for infectious waste	• Collection and disposal of infectious waste, either externally, incinerated, burned in a protected area or pit, or dumped in a protected area or covered pit • No unprotected infectious waste observed in any service site or waste disposal area on day of survey
Education	
Training	• At least 50% of interviewed providers report having received pre- or in-service training within past 12 months
Personal supervision	• At least 50% of interviewed providers report personal supervision within past 6 months
Quality systems	
Management capability	• Management committee meetings at least every 6 months • Documentation of recent management committee meeting
Quality assurance	• Report of quality assurance activities • Documentation of at least one quality assurance activity
Referral systems	• Observation of referral notes or patient records routinely given to patients for referral

assess the ability to provide this care (Kobusingye *et al*. 2005; Jagim 2007; Kruk 2008).

Of the variety of DHS measures under the equipment category, we selected two indicators that are particularly relevant to emergency and surgical care. First, did the health facility have a system in place to repair buildings or other infrastructure? Second, did the facility have the ability to process equipment for reuse either through sterilization or disinfection? The second measure was judged by availability of resources necessary for processing equipment for reuse and staff's basic knowledge of equipment maintenance procedures (e.g. protocols for appropriate sterilization techniques) (Cheng 1995).

Medicine storage capability, which is vital to the ability of a health facility and health system to provide safe and timely care, was assessed by evaluating supply and monitoring of medication (Froese 1991; United Kingdom Department for International Development 2005). Facilities were checked to determine the percentage of assessed items that were stored in dry locations off the ground and protected from water, sun, rodents and pests. The percentage of medications that were up-to-date and categorized by expiration date was also established.

Functional health facilities of all levels of care should have basic infection control materials (e.g. soap, gloves) available, as well as a system for infectious waste disposal (Nettleman 1993; Shears 2007; Pittet *et al*. 2008). The availability of soap, running water, sharps boxes, disinfectant and latex gloves was assessed in all facilities (except the immunization area and sick child areas). Facilities were also checked for safe methods of infectious waste disposal and absence of unprotected infectious waste on the day of the survey. Accepted methods of disposal were external disposal and incineration or dumping in a protected area or pit.

The fifth element assessed was systems of quality control (Walker 1983; Reerink 1989; Veldhuyzen van Zanten 1996). Is there a system in place—with management, quality assurance and referral systems—to carry out the complicated co-ordination and delivery of care to patients, and self-monitoring for improvement? While a great deal of emphasis has been placed on the importance of collecting data on quality, rather than simply having this data available, personnel should be allocated to ensure that hospital processes and quality measures are evaluated in a systematic fashion, with a mechanism for feedback to improved patient care.

The last element assessed was that of education for health workers in health facilities. Continuing education and training for health care providers is crucial to the development of programmes geared towards improved access to surgical and emergency care (Wallerstein and Weinger 1992; Becker and Morawetz 2004; Dovlo 2004a; Basri *et al*. 2009). We assessed education with two variables: (1) did at least 50% of interviewed providers report having received pre- or in-service training within the past 12 months; and (2) did at least half of interviewed providers report personal supervision of their work within the past 6 months?

Study setting and data sources

We chose to study hospitals and health centres in the five countries of Ghana, Kenya, Rwanda, Tanzania and Uganda due to availability of DHS data for the variables of interest. We abstracted data on facility-level needs from the SPA of each country which are available in PDF format online. No data used in this study were obtained by authors on site. Each SPA survey is based on a nationally representative sample of at least 400 health service sites, ranging from dispensaries to hospitals, covering both public and private (including non-governmental and faith-based) facilities. All hospitals (national referral, regional and district or district-designated hospitals) were purposely included in the sample, and the rest of the facilities were sampled to obtain both national and zonal estimates. The sampling strategy was intended to provide nationally and regionally (sub-nationally) representative data. While the number of eligible functioning facilities depended on the country (e.g. 5633 for Tanzania; 3000 for Uganda), the final sample of facilities in each country covered approximately 10–15% of all facilities in the country. Data were then weighted to represent the actual distribution of facilities in each country.

A rigorous data-verification process was used in the survey process, where all questionnaires were checked after data entry. A sample of questionnaires was also compared with the sample design. The data were then entered twice, and then re-verified. Any discrepancies or missing data were resolved through a strict editing or imputation process standardized by the DHS. Paper data were entered electronically using CSPro, a software package designed and implemented by Macro, the US Census Bureau and others (US Census Bureau 2010). The following countries were studied (year of study in parenthesis): Ghana (2002), Kenya (2004), Rwanda (2001), Tanzania (2006) and Uganda (2007). We used the most recent data available for each country at the time of analysis. When data were not available from the SPAs, supplemental information from other sources such as WHO were used.

Data analysis

After data from each country's SPA were compiled, results from hospitals and health centres were compared as well as results across the five countries. Descriptive analyses were conducted and we calculated the percentage of hospitals and health centres that have met minimum standards for surgical care in six different categories described by WHO (WHO 2003). For each of the six areas of analysis—basic infrastructure, equipment, medicine storage capability, infection control, managing quality control, and education—the minimum standards set according to WHO recommendations are detailed in Table 1.

Results

More than 2000 facilities were surveyed by DHS in total across the five countries, but specialist facilities (e.g. private maternity homes) or those with particular target client populations (e.g. stand-alone HIV voluntary and counselling centres) were excluded. Mobile units and health offices that did not provide clinical care were also excluded from the study. In the final sample, there were 691 facilities, comprised of 21.6% hospitals and 78.6% health centres. Details about specific methodologies in each country have been described in the respective SPA reports of each country (Ghana Statistical Service *et al*. 2003; National Coordinating Agency for Population and Development [Kenya] 2005; National Bureau of Statistics [Tanzania] and Macro International Inc. 2006; Tanzania National Bureau of Statistics 2007; Uganda Ministry of Health 2007; Ministry of Health [Uganda] and Macro International Inc. 2008; National Institute of Statistics [Rwanda] 2008).

Table 2 illustrates the number and distribution of facilities sampled across the surveyed countries. Facilities surveyed ranged from those that were governed wholly by the government, wholly by the private sector (or faith-based organizations), or a combination of public–private management.

Figure 1 shows the wide variation of availability of basic physical infrastructure across countries and facilities. It might be expected that a smaller percentage of health centres have dependable electricity, for example, but even a significant

Table 2 Basic health statistics of selected countries and characteristics of surveyed health facilities

	Ghana	Kenya	Rwanda	Tanzania	Uganda
Health statistics*					
Gross national income per capita (in PPP international)	$1240	$1470	$1300	$980	$880
Life expectancy at birth (male/female)	56/58	52/55	44/47	50/51	49/51
Probability of dying under 5 years (per 1000 live births)	120	121	203	118	134
Total expenditure on health per capita (in international dollars)	$100	$105	$32	$45	$143
Total expenditure on health as % of GDP	6.2%	4.6%	3.7%	5.5%	7.2%
Health facilities surveyed					
Hospital	43	28	34	25	19
Health centre	166	125	170	55	27
Total	209	153	203	80	46

*All data in health statistics taken from World Health Statistics 2008 except for data for Rwanda, which were only available from World Health Statistics 2006.

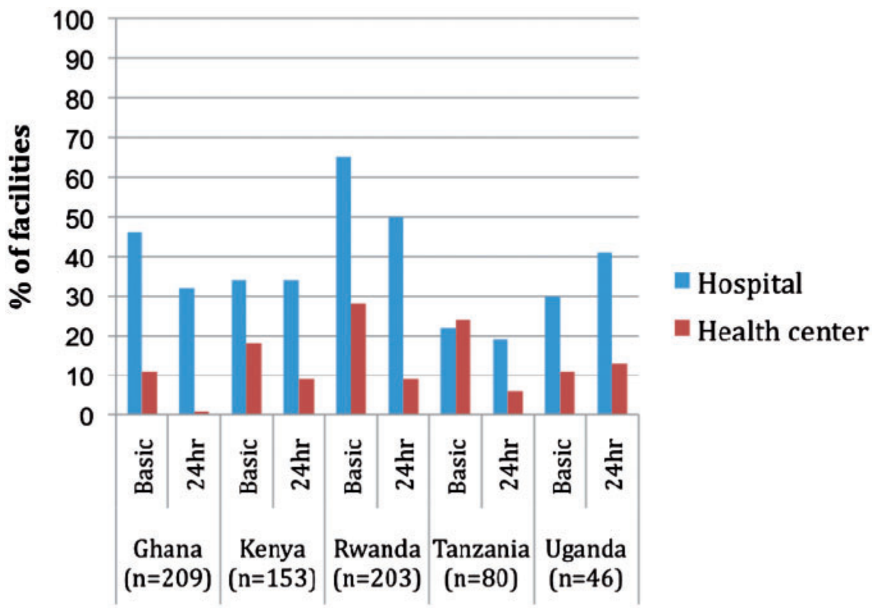

Figure 1 Basic physical infrastructure and capacity to provide 24-hour emergency care across health facilities. Key: Basic = basic physical infrastructure. 24 hr = capacity to provide 24-hour emergency care (please see Table 1 for further definitions)

number of hospitals (as many as 78% in Tanzania) are not equipped with basic building resources. When we evaluated existing capabilities to provide 24-hour emergency care, even the country with the highest percentage of hospitals (Rwanda) has only 50% of hospitals with the components necessary for provision of acute 24-hour care.

Figure 2 illustrates that while a majority of hospitals have a system established to help repair large infrastructure or building problems, fewer facilities had equipment and staff who could competently utilize the equipment at their facility. In hospitals, this ranged from 41% in Tanzania to 61% in Kenya.

Figure 3 shows that while in each country all facilities have a similar proportion that can store medicines away from heat, water, rodents and pests (46–59% in Uganda to 89–91% in Kenya), when the inventory was actually checked for accuracy and expired medication by an observer, a significantly lower proportion of health facilities had adequate monitoring: as low as 14% in health centres and 18% in hospitals in Tanzania.

Figure 4 shows that the proportion of facilities with adequate infection control materials was dramatically low, even in hospitals (0% of hospitals in Tanzania had these materials available in assessed areas). Uganda had the highest coverage of facilities with the availability of these materials as well as proper disposal (verified by observation) of infectious waste.

Figure 5 shows the results of health facilities in the countries we studied in the areas of management practices, quality assurance activities and referral systems. Management committee meetings and documentation of these meeting seemed present in the majority of countries at least on the hospital level, but were less prominent in health centres across countries (except in Rwanda, where health centres outperformed

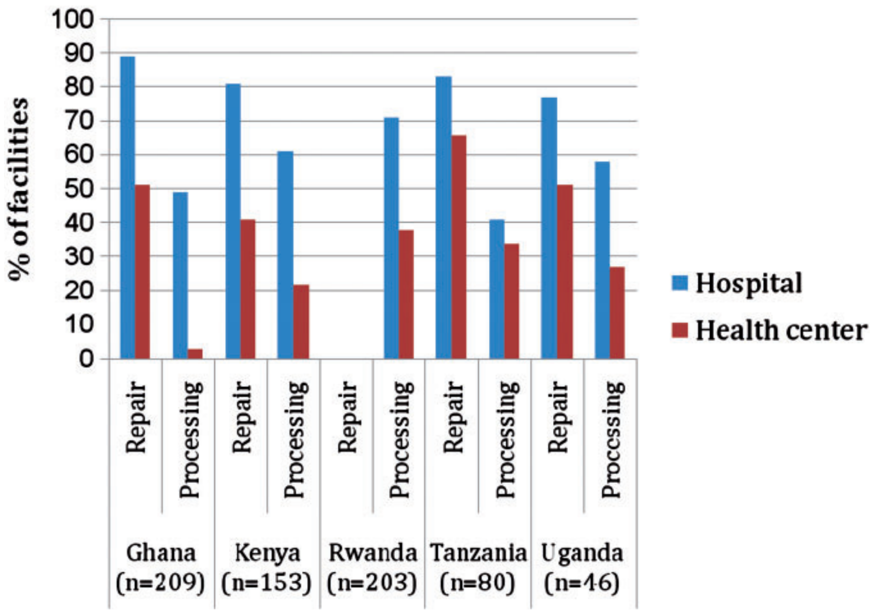

Figure 2 Equipment (repair and processing) systems available in health facilities. Key: Repair = system in place to repair building or infrastructure. Processing = processing area with functioning equipment and power source for methods used, and staff knowledge of equipment processing protocol (please see Table 1 for further definitions). Rwanda missing data for repair

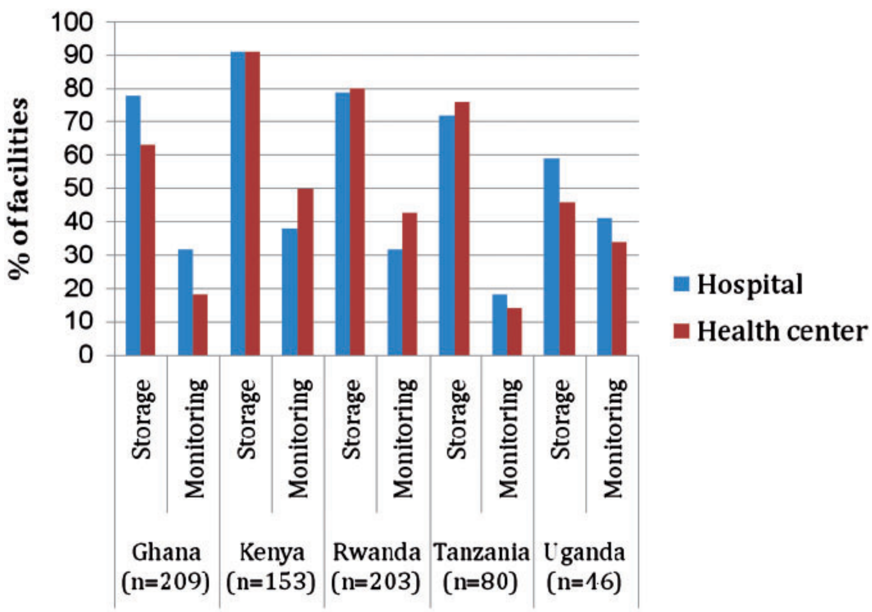

Figure 3 Medicine storage capabilities across health facilities. Key: Storage = system for storing medicines away from water, sun, pests and rodents. Monitoring = inspection of stock for no expired items and available up-to-date inventory (please see Table 1 for further definitions)

hospitals in this area). This pattern was similar in the area of quality assurance as well as referral systems (except referral systems in Uganda, where 39% of clinics had observation of the existence of a referral system and only 5% of hospitals).

Figure 6 shows the results of the percentages of facilities, by type and across countries, which have some type of education programme in place for their health workers.

Discussion

Our results revealed dramatic deficiencies in infrastructure and health worker training in all countries studied. Shortfalls in all six categories—basic infrastructure, equipment, medication storage, infection control, quality control and education—are evident. Most literature in emergency and surgical access in

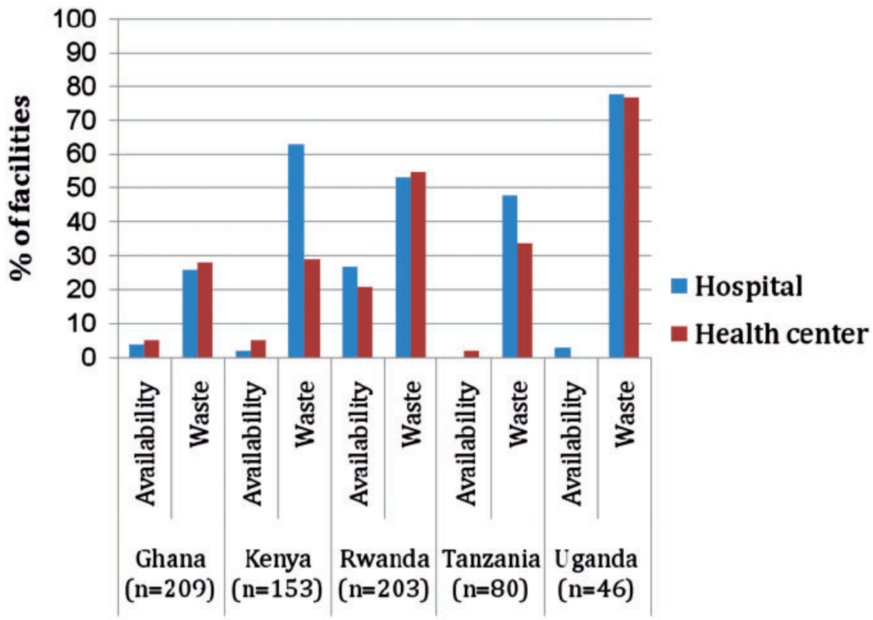

Figure 4 Availability of infection control materials and disposal of infectious waste across health facilities. Key: Availability = availability of soap, running water, sharp box, latex gloves and disinfectant in assessed areas. Waste = appropriate collection and disposal of infectious waste and no observed unprotected infectious waste (please see Table 1 for further definitions). Hospital-level data for Tanzania and health centre-level data for Uganda is '0%', not missing data

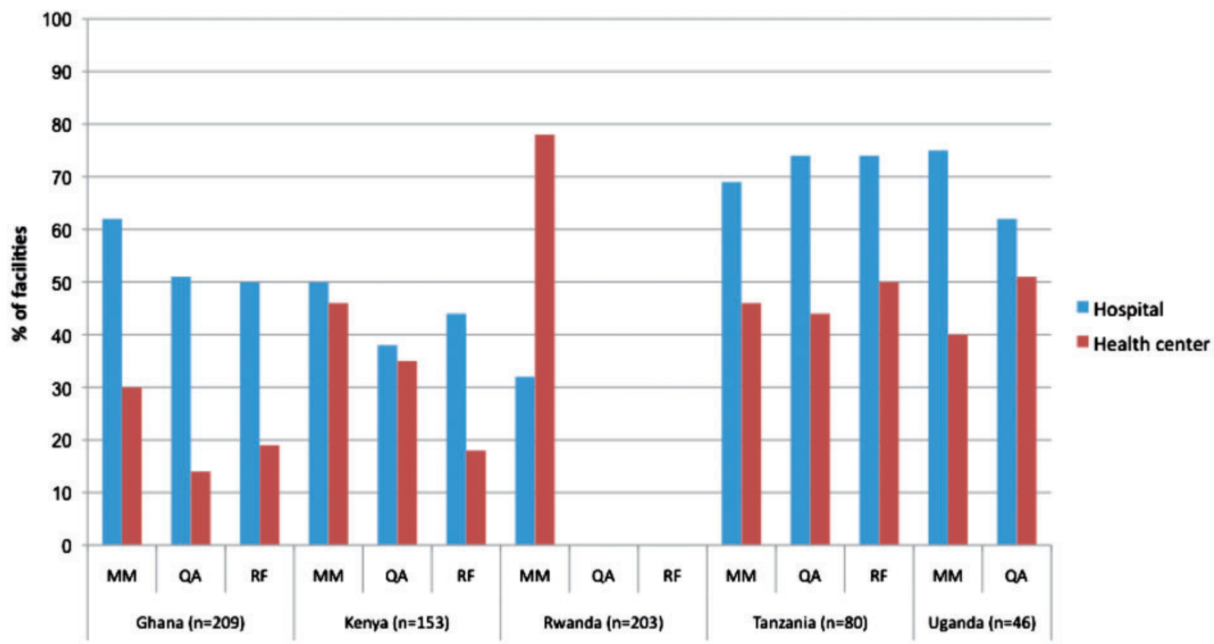

Figure 5 Health care management systems (management committees, quality assurance and referral systems) across health facilities. Key: MM = management committee meetings at least every 6 months and documentation of a recent meeting. QA = quality assurance activities in place and documentation of at least one QA activity. RF = referral system in place, where patients are sent with records or referral note (please see Table 1 for further definitions). No data available for Rwanda in QA and RF sub-elements

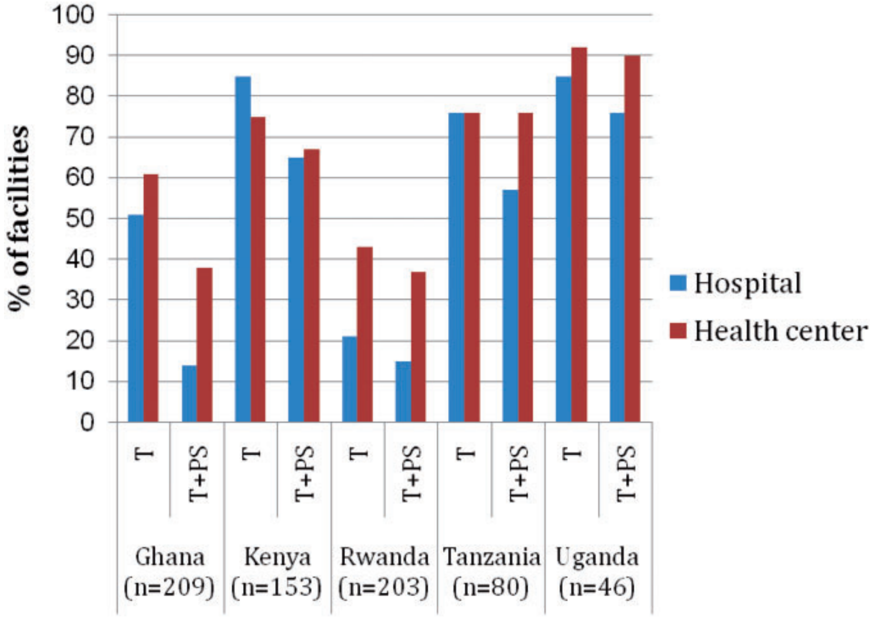

Figure 6 Education (training and supervision) programmes existing across health facilities. Key: T = Facility provided in-service training during past 12 months of at least half of interviewed service providers. PS = Facility provided personal supervision during past 6 months of at least half of interviewed service providers (please see Table 1 for further definitions)

sub-Saharan Africa is focused on shortages of health workers (Hagopian *et al*. 2004; Dovlo 2004a; Dovlo 2004b; Bergstrom 2005; Hagopian *et al*. 2005), following the Donabedian 'structure-process-outcome' model (Qu *et al*. 2010) for assessing health care delivery on which the conceptual framework of this study is based. However, in this study we concentrate on facility infrastructure and training gaps.

Fewer than half of all hospitals in the five countries have the capacity to provide 24-hour emergency care, and less than 65% of all hospitals have even basic infrastructure components such as reliable sources of water and electricity. In clinics, the availability of basic infrastructure is even lower, ranging from 7% to 35% of facilities. As mentioned in the WHO Safe Surgery Saves Lives Initiative, operating theatres must be adequate in size and lighting, and be sourced with dependable electricity and water (Van Vonderen 2008). For any facility such as a district hospital that is expected to provide anything more than minor surgery, there should be a back-up electrical generator. These results indicate a lack of basic infrastructure that prevents availability of adequate emergency services.

While more than half of hospitals across countries have building repair systems, less than half have equipment repair and maintenance services. Promoting awareness of the importance of equipment may be necessary to spur health centres and hospitals that provide surgery to consider investing in equipment maintenance. For example, incorporating mechanisms of delivering oxygen, either via cylinders or centrally through pipelines, at the initial phase of facility construction is necessary to ensure the availability of essential equipment. Peripheral rural health centres would benefit from mobile equipment, such as mobile oxygen concentrators.

Ensuring the availability of functioning equipment and supplies relies on a planning and procurement process that is essential to proper functioning of a health care system. Beyond the physical infrastructure and equipment, the systems designed to *support* these structures are essential. Funders and managers must consider the need for maintenance personnel and funds for maintenance, repair and replacement of machines or their parts. While each site (e.g. health centre, district hospital) will not necessarily need to hire its own team of engineers, plans must be made for periodic equipment maintenance and routine checks for impending failure/technology updates which may be conducted by outside teams. We show that these support systems—whether they are repair, medicine inventories, infection control or quality systems—are grossly lacking in hospitals and health centres in the five countries.

In addition to equipment, provision of emergency and surgical procedures also requires basic infection control measures. It is striking that so few facilities (from health centres to hospitals) have basic materials to control infection (e.g. soap, running water, sharps box, gloves and disinfectant). Any services offered in a facility beyond the most basic of surgical procedures warrant equipment, for example, that types and screens blood to ensure safe blood transfusion. The WHO Global Strategic Plan for Universal Access to Safe Blood Transfusion has presented a goal that more than 75% of hospitals have an operational transfusion committee (Krug 2008). In order to meet this goal, the severe lack of infection control material in developing countries shown in this study must be addressed. As emergency and surgical equipment needs to be sterilized before each patient use, it is important to consider how the facility plans to sterilize its equipment: should an autoclave be built, or will chemicals (e.g. hydrogen peroxide plasma, formaldehyde) be used?

In the same vein, health care management systems—which we evaluate by assessing the presence of management committees, quality assurance and referral systems—are critical to helping health facilities provide better care. Not only are records and health information systems crucial to providing safe surgical care, but systems must also be established that allow administrators to assess the care they currently provide and to track their progress in delivering good care. Given our findings of the wide range of components of management systems (a referral system as low as 5% in hospitals in Uganda), this is a critical area where investment must be made to strengthen the health care system's ability to deliver surgical care.

Finally, professional development for practitioners is often lacking in resource-limited settings, as we show in our survey. Yet continuous education is important not only for the safety of patients, but also for motivating providers in more rural areas, who often complain of professional (and social) isolation. Continuous education can take different forms including periodic visits to or from referral hospitals. In Uganda, for example, some surgeons working in regional or national hospitals are expected to make 2–3 day visits to district hospitals to provide supervision and real-time feedback of the surgical skills of the providers in the district hospital. Other options exist, such as telemedicine consultations (increasingly common in middle-income countries but less so in low-income countries) or even the mailing or distribution of educational materials. There should be a mechanism to make or encourage health care workers to actively seek continuous medical education (CME); one possibility is to introduce re-registration (which exists in many countries) and make proof of CME attendance a prerequisite for re-registration.

The significant infrastructure gaps in sub-Saharan Africa found in this study are consistent with results from recent literature on surgical and emergency services in other developing countries (Kushner *et al*. 2010a). To conceptualize these health system needs holistically, one can compare the results of this study to the well-publicized idea of the 'surgical safety checklist', intended to reduce medical errors during surgery (Haynes *et al*. 2009). We propose that a similar basic checklist should be made for health facilities in developing countries to ensure that facility deficiencies on a systems level can be reduced. While the surgical checklist requires minimal resources, it has been shown to increase the provision of basic surgical safety and can be deployed incrementally. In the same fashion, we propose that we can increase the ability of health systems to deliver emergency and surgical care in incremental ways by ensuring health facilities meet a checklist of minimum facility standards.

Improvement in any of the six areas that are evaluated in this study is desirable and has potential to lead to substantial improvements. Because the foundational elements of quality medical services are interconnected, deficiencies in one area can undermine adequacy in numerous other aspects of care. One could imagine, for example, that not having a reliable source of electricity or water could threaten the ability to deliver quality health care because it directly affects competency in at least four measures of competency that were considered in this study: ability to provide 24-hour care, equipment use, storage of medication and infection control. While this means it is important to prevent shortages of the vital resources analysed in this study, it also means advancements in one area can lead to widespread progress. Investing in resources and projects that lead to improvements across several areas is possible and cost-effective. For example, measures such as maintaining essential hospital equipment (Cheng 1995) and training health care workers (Cheng 1995; Bickler and Spiegel 2010; Kushner *et al*. 2010b) have already shown that small investments in developing nations can lead in the short-term to minor systemic changes that in the long-term result in widespread improvements in health care functionality.

Limitations

One of the limitations of this study is that the health facilities surveyed are not homogenous, and even within categories of 'hospital', 'health centre' and 'clinic', there are likely widespread variations in ownership, funding, providers, staffing, urban/rural settings and availability of services. All hospitals (national referral, regional and district) are included in the sample, which makes our hospital estimates conservative in the sense that the WHO recommendations for the capabilities of district-level hospitals require that all hospitals have basic facilities. On the other end of the spectrum with the clinics, however, some of these smaller health centres in our sample, particularly in Rwanda and Tanzania, were dispensaries or health posts that may not need certain elements (such as basic physical infrastructure, medicine storage capability) that we assessed.

Another limitation is that these data were collected at different points in time (as early as 2001 in Rwanda, and as late as 2007 in Uganda) and therefore may not be comparable since availability of these support structures could have changed. Nevertheless, we believe that given the lack of knowledge in these areas, the fact that these data are generated from the same survey questions, trained personnel and sample methodology suggests that our methods provide adequate evidence of resource gaps.

Furthermore, we did not conduct analyses at the individual clinic or hospital level. For example, the number of clinics that were consistently able to meet minimum standards of preparedness is unknown. Facilities that met the minimum standards described in Table 1 for each of the six categories we analysed could be considered capable of providing adequate emergency and surgical medical services. Because our analysis was conducted at the country level, we only looked at aggregate data from SPA on the number of facilities reporting certain activities and characteristics. Our study did not identify hospitals that were able to provide quality care in all six areas of analysis. Further research with additional geographical or individual facility levels of analysis are necessary to more narrowly define areas with significant shortfalls in infrastructure. Comparing private and public facilities may also help in designating areas with the most significant resource gaps. Value can still be found, however, in considering the overall quality of surgical and emergency services, and identifying the health service deficiencies in the five African countries we chose to compare.

The DHS data enables assessment of national health care resources and their ability to perform the basic function of providing notes or patient records for patients who are referred to a higher-level of care. For this critical metric, only at two facilities did half of the patients receive a note or record. Referral systems in Africa are known to function poorly, not only because actual referrals do not occur (as our findings show) but because patients bypass the system (Low *et al*. 2001). It could be, however, that patients bypass the system because the existing systems are poorly managed. More research and action in this area is necessary to improve patient transport, both pre-hospital and inter-hospital.

Overall, documentation of these structural barriers is essential to the accumulation of knowledge and action for emergency and surgical care in sub-Saharan Africa. The establishment of systematic methods to evaluate emergency and surgical facilities is needed to improve the quality of medical services. Additionally, incorporating the results of evaluations into national vital statistics and considering them in the context of infrastructure gaps within health systems is critical to improving health outcomes in sub-Saharan Africa.

Conclusions

Just as in any health initiative, the basic infrastructure required for surgery and emergency care must be in place before those services can be scaled up. While human resource challenges receive most attention from governments, efforts to address these should be implemented in tandem with systems-level changes like investment in facilities, establishment of quality systems and determination of processes of care (e.g. equipment repair and maintenance; storage of medicines; infection control).

While there is growing acknowledgement of the emergency and surgical needs of populations, and the striking ability to decrease morbidity and mortality from addressing these needs with increased resources, our findings highlight gross deficiencies in current infrastructure to provide these services. Previous literature has shown the importance of each of the components we studied in relation to improving access, but our study highlights the spectrum of areas (from physical infrastructure to quality systems such as referrals and education) that are required for scale-up (or even start-up) of interventions that can begin to address the emergency and surgical needs of people in the developing world.

The findings in this study do not imply that care of patients needs to wait until optimal infrastructure is established. Not long ago, donors, bilateral and multilateral organizations and other technical bodies realized that to stem the tide of HIV/AIDS, for example, an enormous initial investment was required—and was, in the long-term, more cost-effective—in the fight to stem the tide of the rapidly spreading virus. A sizeable proportion of these funds was precisely for strengthening infrastructure support, ranging from blood supply adequacy and laboratory infrastructure (Centers for Disease Control and Prevention 2008; Abimiku 2009). Rather than sitting idly by, awareness of the lack of infrastructure to provide a wider array of services such as surgery as well as more definitive care should be a call to action to build and rebuild infrastructure and systems as emergency and surgical care is scaled up across sub-Saharan Africa (Farmer 2005).

Acknowledgements

The authors would like to thank Tiffany Wang, BS, for her help in editing this manuscript.

All authors (RH, NM, SM, and MK) conceived the study. RH and MK obtained data sets. RH drafted the manuscript, and all authors contributed substantially to its revision. RH takes responsibility for the paper as a whole.

Funding

No funding received.

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Global operating theatre distribution and pulse oximetry supply: an estimation from reported data

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Summary

Background Surgery is an essential part of health care, but resources to ensure the availability of surgical services are often inadequate. We estimated the global distribution of operating theatres and quantified the availability of pulse oximetry, which is an essential monitoring device during surgery and a potential measure of operating theatre resources.

Methods We calculated ratios of the number of operating theatres to hospital beds in seven geographical regions worldwide on the basis of profiles from 769 hospitals in 92 countries that participated in WHO's safe surgery saves lives initiative. We used hospital bed figures from 190 WHO member states to estimate the number of operating theatres per 100 000 people in 21 subregions throughout the world. To estimate availability of pulse oximetry, we sent surveys to anaesthesia providers in 72 countries selected to ensure a geographically and demographically diverse sample. A predictive regression model was used to estimate the pulse oximetry need for countries that did not provide data.

Findings The estimated number of operating theatres ranged from 1·0 (95% CI 0·9–1·2) per 100 000 people in west sub-Saharan Africa to 25·1 (20·9–30·1) per 100 000 in eastern Europe. High-income subregions all averaged more than 14 per 100 000 people, whereas all low-income subregions, representing 2·2 billion people, had fewer than two theatres per 100 000. Pulse oximetry data from 54 countries suggested that around 77 700 (63 195–95 533) theatres worldwide (19·2% [15·2–23·9]) were not equipped with pulse oximeters.

Interpretation Improvements in public-health strategies and monitoring are needed to reduce disparities for more than 2 billion people without adequate access to surgical care.

Funding WHO.

Lancet 2010; 376: 1055–61

Published Online July 1, 2010 DOI:10.1016/S0140-6736(10)60392-3

See **Editorial** page 1025

See **Comment** page 1027

See **Perspectives** page 1045

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Introduction

Illnesses that need surgical treatment account for a substantial amount of the global burden of disease. Conservative estimates suggest that 11% of the world's disability-adjusted life years are attributable to diseases that are often treated with surgery.[1] Heart and cerebrovascular diseases are the top two causes of death worldwide, cancer is one of the five principal causes of mortality, and injuries from road traffic accidents are among the top ten causes of death.[2] Other surgically treatable disorders such as obstructed labour,[3] obstetric fistulas,[4] and congenital birth defects[1] are major causes of morbidity and mortality in the developing world. As health-care systems in developing regions confront an ageing population with an increased frequency of non-communicable diseases,[5,6] the extent of surgical need will increase substantially. Africa and southeast Asia are already estimated to have higher surgical disease burdens per head than do North and South America and Europe, mainly attributable to injuries and obstetric complications.[1]

This large burden of surgically treated disease has been especially hard to address in low-income settings. Of an estimated 234 million surgical procedures done every year, the wealthiest third of the global population has 75% of the operations, whereas the poorest third undergoes only 4%.[7] Furthermore, many analyses at district and local levels in sub-Saharan Africa and south Asia suggest substantial shortages in anaesthesia and surgical resources.[8–10] However, we know little about these shortages, especially with respect to availability of functioning surgical facilities or staff and equipment levels. Therefore, we aimed to estimate and compare the regional densities and distributions of operating theatres worldwide.

We also sought a simple indicator of availability of anaesthesia and surgical equipment within surgical facilities. We identified pulse oximetry as a component of safe anaesthesia and surgery that is internationally recognised to be essential,[11,12] yet is often unavailable in low-income settings.[13,14] Therefore, availability of pulse oximetry was used as a proxy for adequacy of operating theatre equipment supply because of this scarcity in low-income settings,[13] and because international organisations such as the World Federation of Societies of Anaesthesiologists (WFSA) and WHO regard it as essential for safe anaesthesia and surgery.[11,12]

Methods

Operating theatre data

We obtained profiles of operating theatres from 769 hospitals in 92 countries participating in WHO's safe surgery saves lives programme, and calculated the ratios of functional operating theatres per hospital bed. Every profile was stratified into one of seven geographical

	Hospital profile data			Pulse oximetry data		
	Countries with (n=92)	Countries without (n=100)	p value	Countries with (n=54)	Countries without (n=138)	p value
Life expectancy (years)	67·9 (0·6)	66·5 (0·6)	0·109	66·5 (1·2)	67·5 (0·8)	0·491
Age >59 years	10·6 (0·4)	9·8 (0·2)	0·090	10·7 (0·8)	10·0 (0·3)	0·436
Urban dwellers	56·5 (2·1)	53·3 (2·0)	0·274	55·9 (2·8)	54·4 (1·7)	0·635
Literacy rate	77·3 (1·9)	78·6 (2·5)	0·682	78·4 (3·0)	77·7 (2·3)	0·838
Physician density*	1·6 (0·1)	1·7 (0·4)	0·702	1·6 (0·2)	1·7 (0·2)	0·676
Nurse density*	3·7 (0·3)	3·8 (0·2)	0·791	3·7 (0·3)	3·7 (0·2)	0·902
Hospital beds†	19·4 (1·6)	23·8 (2·1)	0·100	19·6 (2·4)	23·1 (1·7)	0·260
Per head GDP in 2007 (US$)	3850 (458)	3658 (435)	0·767	3301 (470)	3947 (370)	0·296
Per head GNI in 2008 (US$)	3521 (421)	3027 (350)	0·378	2900 (415)	3447 (324)	0·313
Per head health expenditure in 2005 (US$)	368 (37)	295 (26)	0·116	339 (65)‡	324 (40)‡	0·850

Data are adjusted means or medians (SE) unless otherwise stated. Hospital profile data are adjusted for region; pulse oximetry data are adjusted for per head health expenditure. Since hospital beds and per head GDP, GNI, and health expenditure are right-skewed, we log-transformed them; we then obtained adjusted medians by use of these log-transformed variables as outcomes in a linear regression model with region or per head health expenditure as covariates. GDP=gross domestic product. GNI=gross national income. *Number per 1000 population. †Number per 10 000 population. ‡Unadjusted.

Table 1: **Countries with and without hospital profiles or pulse oximetry data**

	Countries (n=190)	Countries with hospital profiles (n=92)	Hospital profiles (n=769)	Maximum hospital profiles from one country	Operating theatres per 100 hospital beds (95% CI)
Sub-Saharan Africa	45	17	39	7	1·3 (1·0–1·7)
Asia	48	17	86	29	2·0 (1·8–2·1)
Middle East, North Africa	18	13	39	8	2·2 (1·9–2·6)
Europe	42	24	123	31	2·6 (2·0–3·3)
Australia, New Zealand	2	2	22	18	3·3 (1·3–5·2)
Latin America	33	17	60	9	3·9 (2·8–5·1)
Canada, USA	2	2	400	362	4·5 (3·9–5·0)

See webappendix p 7 for details of countries in the regions.

Table 2: **Estimated number of operating theatres per 100 hospital beds, by region***

See Online for webappendix

regions—Asia, Australia and New Zealand, Canada and USA, Europe, Latin America, Middle East and North Africa, and sub-Saharan Africa (webappendix p 7).

Pulse oximetry data

We obtained pulse oximetry data from representatives of the WFSA, who sent surveys about availability of this measure to 334 anaesthesia providers in 72 countries chosen to represent a geographically and demographically diverse sample. 172 respondents (51%) replied with the number of operating theatres in their hospitals and the number that had functional pulse oximeters available at all times. Respondents also estimated the percentage of urban and rural hospital operating theatres in their country that had a functioning pulse oximeter (termed urban and rural pulse oximetry penetrance rates). To obtain the overall pulse oximetry penetrance for every country, urban and rural penetrance rates were weighted by the proportion of the population who lived in these areas.

A minimum anaesthesia monitoring standards survey was also sent to all 122 national secretaries of WFSA member societies, who responded about whether their country had national anaesthesia monitoring standards and whether pulse oximetry use during surgery was one of those minimum standards.

Economic, population, health, and surgical volume data

Per head gross domestic product for 2007 was obtained from the Statistics Division of the United Nations Secretariat.[15] Data for life expectancy, population, literacy rates, infant, maternal, and HIV mortality rates, physician and nurse densities, and per head health expenditure were obtained for all countries from WHO's world health statistics 2008.[16] We gathered economic data from the World Bank about gross national income (GNI) per head for 2007. Every subregion was classified as high, high-middle, low-middle, or low income according to the mean GNI per head for the countries within it. Definitions of countries with low (≤US$935), low-middle ($936–3705), high-middle ($3706–11 455), and high (≥$11 456) incomes were based on World Bank income groups.[17] We weighted the mean GNI per head calculations by country population to prevent less populous countries from disproportionately affecting the mean GNI per head for every subregion. We calculated surgical volume for every subregion on the basis of our previously established

	Countries	Population (millions)	Economic wealth (GNI per head [US$])	Estimated number of operating theatres (95% CI)	Estimated number of operating theatres per 100 000 population (95% CI)
Europe (eastern)	7	210·4	High middle (6258)	52 777 (43 952–63 373)	25·1 (20·9–30·1)
Asia-Pacific (high income)	4	180·8	High (32 834)	43 958 (38 995–49 554)	24·3 (21·6–27·4)
Europe (central)	12	119·1	High middle (8830)	18 747 (16 342–21 505)	15·7 (13·7–18·1)
Europe (western)	23	409·0	High (38 010)	60 196 (53 478–67 757)	14·7 (13·1–16·6)
North America (high income)	2	335·4	High (45 419)	48 037 (41 024–56 250)	14·3 (12·2–16·8)
Australasia	2	24·7	High (34 303)	3532 (2095–5954)	14·3 (8·5–24·1)
Latin America (southern)	3	58·9	High middle (6660)	8058 (5980–10 859)	13·7 (10·1–18·4)
Asia (central)	9	77·5	Low middle (2006)	9036 (7938–10 286)	11·7 (10·2–13·3)
Caribbean	16	37·0	Low middle (2984)	3870 (3129–4785)	10·4 (8·4–12·9)
Latin America (tropical)	2	195·3	High middle (5732)	19 675 (14 306–27 058)	10·1 (7·3–13·9)
Asia (east)	2	1352·2	Low middle (2370)	63 339 (55 758–71 951)	4·7 (4·1–5·3)
Latin America (Andean)	3	50·1	Low middle (2930)	2263 (1662–3080)	4·5 (3·3–6·1)
Middle East, North Africa	18	413·6	High middle (4889)	17 592 (15 702–19 708)	4·3 (3·8–4·8)
Latin America (central)	9	218·1	High middle (6844)	8729 (7105–10 725)	4·0 (3·3–4·9)
Sub-Saharan Africa (southern)	6	68·5	High middle (4436)	2104 (1566–2827)	3·1 (2·3–4·1)
Asia (southeast)	13	581·2	Low middle (1912)	15 122 (13 578–16 842)	2·6 (2·3–2·9)
Oceania	14	8·3	Low middle (1279)	162 (119–221)	1·9 (1·4–2·7)
Asia (south)	6	1523·1	Low (880)	20 540 (17 944–23 512)	1·3 (1·2–1·5)
Sub-Saharan Africa (central)	6	87·0	Low (844)	1008 (743–1368)	1·2 (0·9–1·6)
Sub-Saharan Africa (east)	14	314·0	Low (434)	3472 (2930–4115)	1·1 (0·9–1·3)
Sub-Saharan Africa (west)	19	308·1	Low (755)	3172 (2662–3780)	1·0 (0·9–1·2)
Total	190	6572·3		405 389 (385 405–426 408)	6·2 (5·9–6·5)

GNI=gross national income. See webappendix p 1 for details of countries in the subregions.

Table 3: **Estimated number of operating theatres per head, ranked by estimated number per 100 000 population**

	Region*	Estimated number of operating theatres (95% CI)	
		Our prediction model	Direct reports and surveys†
Afghanistan	Asia	209 (187–219)	273 (209–356)
Jordan, Lebanon, and Morocco	Middle East, North Africa	1178 (993–1362)	1291 (1142–1459)
Togo and Zambia	Sub-Saharan Africa	379 (297–487)	225 (168–302)
USA	Canada, USA	43 179 (38 040–48 317)	41 061 (40 168–41 954)

* See webappendix p 7 for details of countries in the regions. †Operating theatre data were obtained from health ministry representatives for all countries except the USA. US data were obtained from the 2007 American Hospital Association survey.

Table 4: **Estimates of the number of operating theatres from our model compared with direct reports**

surgical volume prediction model, in which the logarithm of national surgical rates as the outcome and the logarithm of per head health expenditure rates was the sole covariate.[7]

Statistical analysis

The total number of operating theatres is not publicly reported by country. Thus, we estimated the total number in 21 epidemiologically alike subregions identified in the global burden of disease classification scheme[18] by fitting a linear regression model using the 769 hospital profiles. Our a-priori assumptions were that the number of operating theatres in a hospital (and subregion) would be strongly associated with the number of hospital beds and would vary according to the region. Our predictive model, which was stratified by region, used the number of hospital beds as the sole covariate. Generalised estimating equations were used to predict the model slopes, which represented the ratio of theatres to hospital beds for every region. The intercept (ie, the number of theatres when there were no hospital beds) was zero. To obtain 95% CI for the slopes the generalised estimating equations accounted for clustering of hospital profiles in individual countries.

From our predictive model, the estimated number of operating theatres for a hospital, country, or subregion equalled the regional ratio multiplied by the respective number of hospital beds. Since the number of beds for every country is published,[19] we were able to estimate the total number of operating theatres for every country and subregion. To obtain 95% CIs for the predicted number of theatres in subregions, we modelled the error variance of

	Number (95% CI)	Percentage (95% CI)
Australasia	<25	<0·1%
North America (high income)	<25	<0·1%
Europe (western)	<25	<0·1%
Asia-Pacific (high income)	106 (16–688)	0·2% (0·04–1·6)
Latin America (southern)	198 (29–1356)	2·5% (0·4–15·4)
Latin America (tropical)	1511 (1163–1963)	7·7% (3·7–15·1)
Europe (central)	1763 (994–3125)	9·4% (5·3–16·2)
Sub-Saharan Africa (southern)	333 (147–753)	15·8% (6·7–32·8)
Latin America (central)	1648 (1133–2399)	19·2% (13·1–27·1)
Middle East, North Africa	4174 (2954–5897)	23·7% (16·6–32·6)
Caribbean	1228 (949–1588)	31·6% (25·5–38·5)
Asia (east)	21 445 (11 727–39 215)	33·8% (17·0–55·8)
Europe (eastern)	19 223 (12 015–30 754)	36·7% (22·2–54·0)
Asia (southeast)	5703 (4629–7027)	37·7% (30·5–45·5)
Latin America (Andean)	936 (733–1196)	41·4% (36·8–46·2)
Asia (central)	4248 (3664–4925)	47·0% (40·6–53·5)
Asia (south)	10 064 (8586–11 795)	49·0% (42·4–55·6)
Oceania	92 (74–114)	56·9% (46·9–66·4)
Sub-Saharan Africa (west)	1853 (1612–2130)	58·4% (52·9–63·8)
Sub-Saharan Africa (central)	682 (538–865)	67·0% (59·3–73·9)
Sub-Saharan Africa (east)	2461 (2164–2799)	70·4% (65·8–74·7)
Total	77 700 (63 195–95 533)	19·2% (15·2–23·90)

See webappendix p 1 for details of countries in the subregions.

Table 5: **Estimated number of operating theatres without pulse oximetry, by subregion, ranked by percentage without pulse oximetry**

the number of operating theatres. Since the error variance for a count (number of operating theatres) typically increases as the mean of the count increases, we used the Akaike information criterion,[20] a commonly used goodness-of-fit statistic, to find the best model of error variance. The criterion identified the Tweedie distribution[21]—in which the variance of the number of operating theatres equals the mean raised to the 1·5 power—as the best-fit model (webappendix p 2). We calculated an R^2 for clustered data to assess the accuracy of the actual versus predicted number of operating theatres for every hospital.

For the 136 countries without pulse oximetry penetrance data, we built a predictive model with data from the 54 countries for which we received surveys. Our a-priori set of candidate covariates consisted of per head health expenditure, gross domestic product, life expectancy, maternal mortality rate, and physician and nurse densities. With the log-odds of pulse oximetry penetrance as the outcome, we used weighted least-squares to estimate a linear regression model, with country data weighted by population. We used a cross-validation R^2 for all countries in the dataset to further assess the accuracy of the model's predictions. This cross-validation compared the recorded and predicted pulse oximetry penetrance rates for every country after sequentially excluding every country with known penetrance data from the model. From the predictive model, pulse oximetry penetrance rates for countries without oximetry data were estimated with multiple imputation.[22] 100 imputed datasets were created for the analysis.

We did additional sensitivity analyses using regression diagnostics, various transformations, and alternative regression models to find out how sensitive the results were to the assumptions made in our predictive models. For the operating theatre estimation sensitivity analyses, we added the number of hospital beds as a quadratic term to the linear model. The model with the quadratic term worsened the Akaike information criterion. Furthermore, because hospitals were not randomly selected in our sample, we did a sensitivity analysis to see whether oversampling of hospitals with low or high theatre to bed ratios could have biased the results. These analyses showed little evidence of such bias (webappendix p 3). We also did a cross-validation analysis through sequential removal of every hospital profile to establish whether one hospital contributed substantially to influence the regional theatre to bed ratio (webappendix p 4).

For the pulse oximetry analyses, we compared the log-odds, probit, and folded power (which chooses the best transformation of a variable between 0 and 1) transformations of the pulse oximetry penetrance data. The folded power transformation reduced to the log-odds transformation (webappendix p 5). We also compared various imputation models for missing pulse oximetry penetrance data by use of different covariate combinations with adjusted R^2 values over 90% (webappendix p 6). The operating theatre and pulse oximetry penetrance estimations were alike across all of these sensitivity analyses. We also compared key characteristics of countries with and without hospital profiles and pulse oximetry data, adjusting for region and per head health expenditure, respectively, to establish whether these data were missing at random.

All statistical analyses were done with SAS version 9.2.

Role of the funding source

This study was supported by WHO's patient safety programme as part of the safe surgery saves lives initiative. WHO had no role in survey dissemination, data gathering, data analysis, or the decision to submit for publication. The corresponding author had full access to all the data in the study and had final responsibility for decision to submit for publication.

Results

Table 1 shows characteristics of countries with and without operating theatre and pulse oximetry data. No differences were noted in any of the measured variables, suggesting that data were representative of the full population. The linear regression model for operating theatres had a good fit with an R^2 of 0·88. Table 2 shows the ratio of operating theatres to hospital beds, which varied from about one per 100 hospital beds in sub-Saharan Africa to more than four in Canada and the USA.

	Percentage of operating theatres without pulse oximetry	Population (millions)	Number of operations (millions; 95% CI)	Operations without pulse oximetry (millions; 95% CI)
Australasia, North America (high income), Europe (western), and Asia-Pacific (high income)	<1%	949·9	131·6 (127·0–136·5)	0·1 (0·06–0·2)
Latin America (southern), Latin America (tropical), and Europe (central)	1–10%	373·3	14·2 (10·5–19·2)	1·1 (0·6–1·8)
Sub-Saharan Africa (southern), Latin America (central), and Middle East, North Africa	11–30%	700·2	22·8 (16·7–31·3)	4·9 (3·3–7·4)
Caribbean, Asia (east), Europe (eastern), Asia (southeast), Latin America (Andean), Asia (central), and Asia (south)	31–50%	3831·5	63·3 (33·4–120·0)	23·5 (11·4–48·4)
Oceania, sub-Saharan Africa (west), sub-Saharan Africa (central), and sub-Saharan Africa (east)	51–70%	717·4	2·9 (2·5–3·4)	1·9 (1·6–2·2)
Total	··	6572·3	234·9 (191·7–278·0)	31·5 (18·3–54·3)

See webappendix p 1 for details of countries in the subregions. ··=not applicable.

***Table 6:* Estimated number of operations without pulse oximetry**

From these ratios we estimated the number of operating theatres in the 21 subregions. Our analyses suggest that there are more than 400 000 operating theatres worldwide, or about six per 100 000 people (table 3). The number of theatres per head varied more than 20-fold between the subregions. Eastern Europe and high-income Asia-Pacific had the highest number of operating theatres per head, whereas central, east, and west sub-Saharan Africa had the lowest (table 3). All high-income subregions had more than 14 operating theatres per 100 000 people, whereas all low-income subregions had fewer than two. More than 2 billion people live in subregions with fewer than two operating theatres per 100 000 people. Table 4 shows that our operating theatre model estimates are similar to the direct report estimates from seven countries in four regions.

172 anaesthesia providers from 54 countries responded to our pulse oximetry survey. A model with per head health expenditure (both linear and quadratic terms) as the sole covariate was the most parsimonious model with the largest adjusted R^2 (0·93), and thus was used in all subsequent analyses. Cross-validation analysis of this model showed that the imputation accurately predicted the pulse oximetry penetrance when the penetrance of any country with known data was sequentially removed from the model (R^2=0·90). We estimated that about 19% of operating theatres did not have pulse oximeters, which corresponds to about 77 700 operating theatres worldwide (table 5). In low-income subregions, we estimated that 23·6% (18·1–30·2) of theatres in urban areas and 66·5% (56·1–75·5) in rural areas were without pulse oximetry. Conversely, high-income subregions had pulse oximeters in more than 99% of their operating theatres. We estimate that around 32 million operations are undertaken every year without pulse oximetry (table 6).

Table 7 shows the results of our survey of minimum anaesthesia monitoring standards. 68 of the 122 (56%) WFSA member nations responded. 58 countries (85%) have established national anaesthesia monitoring standards, and all these countries confirmed that pulse oximetry use during surgery was a minimum standard. The mean regional GNI per head for countries that mandated pulse oximetry ranged from about $1100 in Asia to more than $45 000 in North America.

Discussion

There is a measurable disparity in the availability of operating theatres and essential surgical equipment worldwide. All high-income subregions had at least 14 operating theatres per 100 000 people. By contrast, all low-income subregions—more than 2 billion people—had fewer than two operating theatres per 100 000 people, despite having a higher burden of surgically treated diseases per head than do high-income regions.[1] People in such regions are effectively without access to surgical care. Furthermore, essential equipment is unavailable in many operating theatres. Pulse oximetry—an essential monitoring device for safe surgery and our measure of operating theatre resource adequacy—was absent more than half of the time in low-income regions.

Although this unmet surgical need has been known about for several decades,[23] it has not been quantified in a way that can guide public health leaders and ministries toward effective solutions. Weiser and colleagues' analysis[7] of the global volume of surgery showed that there are nearly twice as many surgical procedures as there are births every year.[24] Their study emphasised the disproportionately low volume of surgery in low-income settings compared with high-income settings, although the main cause of this disparity (ie, poor access to operating theatres, scarcity of equipment, insufficient workforce and training, or inadequate infrastructure) was not examined.

Our analysis begins to address the causes of the disparity in surgical care between high-income and low-income countries. Some unmet surgical need might be related to their being too few operating theatres. For example, low-income western sub-Saharan Africa—a

	Country responses/invitations	Countries with established minimum monitoring standards	Countries that include pulse oximetry as a minimum monitoring standard	GNI per head for countries that mandate oximetry (US$)
Asia	12/28	8	8	1142
Australasia	2/2	2	2	34 303
Europe	21/36	20	20	24 339
Latin America	14/22	12	12	6649
Middle East, North Africa	8/14	8	8	5342
Canada, USA	2/2	2	2	45 419
Sub-Saharan Africa	9/18	6	6	1929
Total	68/122	58	58	9065

Data are number unless otherwise stated. GNI=mean gross national income. *See webappendix p 7 for details of countries in the regions. The pulse oximetry data in tables 5 and 6 are based on the pulse oximetry availability survey, not the minimum anaesthesia monitoring standards survey used in this table. Mean gross national income per head calculations are weighted by country population.

Table 7:* Minimum anaesthesia monitoring standards survey, by region

region with a higher surgical disease burden than high-income areas[1]—has substantially fewer operating theatres per head than high-income subregions such as North America, western Europe, and Australasia. One functioning operating theatre for 100 000 people is very unlikely to meet the surgical needs of this subregion.

Many resource-limited settings also have restricted anaesthesia resources or surgical equipment.[10,13] Our survey of minimum anaesthesia monitoring standards showed that all countries with anaesthesia standards regard pulse oximetry as mandatory for surgery. Most anaesthetists in developed settings do not give anaesthesia without pulse oximetry. Thus, the absence of this monitoring device suggests resource limitations that prevent anaesthesia providers from using equipment that is highly valued and essential.

The absence of pulse oximetry in many operating theatres is not only a safety concern for patients, but also increases doubt about availability of other essential equipment such as sutures, surgical instruments, drugs, and autoclaves. Survey results[25] from government hospitals in Sierra Leone showed that only 50% of hospitals had equipment sterilisers, 30% had adequate supplies of suction pumps, and 20% had regular supplies of sterile gloves.[26] However, global estimates are unavailable to quantify these gaps internationally.

Our analyses have important limitations. We used hospital profiles from the safe surgery saves lives programme as the basis for our operating theatre estimates because the total number is not reported by every country. Participation in the programme needs a commitment from every hospital to use the WHO surgical safety checklist, and thus these hospitals might not be a representative sample. However, WHO regards the checklist as essential for safe surgery[12] and has worked with health ministries and professional societies worldwide to promote use in all hospitals that do surgery. Additionally, our sensitivity analysis suggests that the estimated operating theatre to bed ratios had minimum bias (webappendix p 3).

Another limitation arises from the consistency of hospital bed reporting in countries. Although our hospital bed numbers were obtained from WHO's statistical information system (WHOSIS), countries report these numbers differently. For example, Denmark does not report private hospital beds whereas Germany does. Some countries include specialty hospitals, such as psychiatric institutions or rehabilitation hospitals, which have very little (or no) surgical capacity. Free-standing surgical centres are also not accounted for when hospital bed numbers are used to predict the number of operating theatres. Furthermore, since the adequacy of equipment, surgical staffing, and overall efficiency of surgical services can vary between high-income and low-income settings, we cannot postulate about the optimum number of operating theatres for a particular subregion. Poor regions probably have an increased proportion of inefficient surgical care because of resource constraints such as unreliable electricity supply or shortages of surgical equipment.

The pulse oximetry component of our analysis was restricted by the subjective nature of the availability survey and a provider response rate of 51%. Additionally, we used multiple imputation to obtain penetrance estimates for most countries since pulse oximetry data were only available for 54 countries. Although any method that substitutes missing data is imperfect, our model showed robustness on cross-validation and has previously been applied in a global surgical volume prediction model.[7] Our penetrance estimates also align with previous reports that have exemplified the need for pulse oximeters in poor regions. One survey of anaesthesia professionals in 29 Asian countries showed that more than 75% had inadequate access to pulse oximetry,[27] with similar data reported in Africa.[13]

So far the unmet surgical need has not been resolved, but should be addressed. We have quantitative estimates of the regional differences of two crucial parts of this dilemma—operating theatre access and availability of essential surgical equipment (as gauged by pulse oximetry use). The other components (surgical workforce,[28] training,[29] and infrastructure[10]) have been described on a small basis but deserve increased analysis globally.

Our group is investigating the structure of surgical systems in positive outlier communities (ie, those that have succeeded in provision of surgical services in regions with fewer than two operating theatres per 100 000 people), although results have not been published. To address the gap in essential surgical equipment within existing facilities, WHO recently expanded the safe surgery saves lives programme to include the global pulse oximetry project.[30] The project's main aim is to improve pulse oximetry access through increased availability of low-cost pulse oximeters in resource-limited settings. This project's framework could be applicable to other essential equipment, such as sutures or autoclaves.

The disparity in operating theatre and equipment availability between resource rich and poor countries is substantial and its reduction will be very important for public health. We need informed initiatives targeted toward reduction of these barriers to accessible and safe surgical care, which would have a profound effect on global health.

Contributors

LMF, TGW, WRB, and AAG were responsible for study design and conception. LMF, TGW, AFM, ACE, and IHW acquired the data. LMF wrote the article, which was critically revised by all authors. GD is a technical officer within the patient safety programme at WHO, and assisted with review of the report but had no role in the funding of this research. All authors reviewed and approved the final report.

Conflicts of interest

WHO provides grant support to the Harvard School of Public Health to conduct the Safe Surgery Saves Lives project, which this project is related to and several authors participate in (LMF, WRB, SRL, AAG). AM has been a Temporary Consultant for WHO and has Chaired the Safety and Quality Committee for the World Federation of Societies of Anaesthesiologists. AFM was the founder of Safer Sleep LLC, and is director and a shareholder of the company. TGW, ACE, IHW, and GD declare no conflicts of interest.

Acknowledgments

We thank Abdel Breizat (Jordan), Gastao Duval (Brazil), Mohamad Hamandi (Lebanon), Pedro Ibarra (Colombia), Ashish Jha (USA), Mohamed A L Labib (Zambia), Aboudoul-Fatou Ouro-Bang'na Maman (Togo), Amina Sahel (Morocco), Philippe Scherpereel (France), Ahmad Shah Shokohmand (Afghanistan), and Jing Zhao (China) for their help to obtain data for operating theatres and pulse oximetry; and Jeff Blossom (USA) for his assistance in creation of the region map.

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Supplementary webappendix

This webappendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: Funk LM, Weiser TG, Berry WR, et al. Global operating theatre distribution and pulse oximetry supply: an estimation from reported data. *Lancet* 2010; published online July 1, 2010. DOI:10.1016/S0140-6736(10)60392-3.

Appendix 1 – WHO member nations

Sub-region[1]	Region[2]	Countries
Australasia	Australia/ New Zealand	Australia, New Zealand
Asia, Central	Asia	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan
Asia, East	Asia	China, Democratic People's Republic of Korea
Asia Pacific, High Income	Asia	Brunei Darussalam, Japan, Republic of Korea, Singapore
Asia, South	Asia	Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan
Asia, Southeast	Asia	Cambodia, Indonesia, Lao (People's Democratic Republic), Malaysia, Maldives, Mauritius, Myanmar, Philippines, Seychelles, Sri Lanka, Thailand, Timor-Leste, Viet Nam
Caribbean	Latin America	Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Trinidad and Tobago
Europe, Central	Europe	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Serbia and Montenegro, Slovakia, Slovenia, The former Yugoslav Republic of Macedonia
Europe, Eastern	Europe	Belarus, Estonia, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine
Europe, Western	Europe	Andorra, Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino,[α] Spain, Sweden, Switzerland, United Kingdom
Latin America, Andean	Latin America	Bolivia, Ecuador, Peru
Latin America, Central	Latin America	Colombia, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Venezuela
Latin America, Southern	Latin America	Argentina, Chile, Uruguay
Latin America, Tropical	Latin America	Brazil, Paraguay
Middle East / North Africa	Middle East / North Africa	Algeria, Bahrain, Egypt, Iran (Islamic Republic of), Iraq, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Morocco, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, Turkey, United Arab Emirates, Yemen
North America, High Income	Canada/ United States	Canada, United States of America
Oceania	Asia	Cook Islands, Fiji, Kiribati, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu
Sub-Saharan Africa, Central	Sub-Saharan Africa	Angola, Central African Republic, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon
Sub-Saharan Africa, East	Sub-Saharan Africa	Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Somalia,[β] Sudan, Tanzania (United Republic of), Uganda, Zambia
Sub-Saharan Africa, Southern	Sub-Saharan Africa	Botswana, Lesotho, Namibia, South Africa, Swaziland, Zimbabwe
Sub-Saharan Africa, West	Sub-Saharan Africa	Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Sao Tome and Principe, Senegal, Sierra Leone, Togo

[1] based on the Global Burden of Disease classification scheme
[2] based on the classification scheme used to calculate OT to hospital bed ratios (Table 2)
[α] excluded because hospital bed data were unavailable
[β] excluded because per capita health expenditure data were unavailable

Appendix 2 - Goodness of fit for operating theatre estimation models using Akaike Information Criterion (AIC)*

Sub-region	Model 1 AIC	Model 2 AIC (chosen for our analysis)	Model 3 AIC
Europe, Eastern	32.1	3.4	5.1
Asia Pacific, High Income	952.5	122.5	1,240.3
Europe, Central	54.3	4.3	7.7
Europe, Western	2,144.7	511.2	1,737.3
North America, High Income	3.6	2.0	2.0
Australasia	2.4	2.0	2.0
Latin America, Southern	7.6	2.2	2.5
Asia, Central	298.0	14.7	49.1
Caribbean	994.3	220.2	1,489.1
Latin America, Tropical	3.4	2.0	2.6
Asia, East	5.4	2.0	2.0
Latin America, Andean	5.3	2.1	2.5
Middle East / North Africa	1,001.2	94.2	205.9
Latin America, Central	20.0	2.9	7.9
Sub-Saharan Africa, Southern	121.8	17.9	127.9
Asia, Southeast	9,495.5	1,843.9	9,938.2
Oceania	785,165.1	1,030,986	1,493,701
Asia, South	2,635.6	367.6	1,589.8
Sub-Saharan Africa, Central	400.3	72.3	381.4
Sub-Saharan Africa, East	831.3	125.0	475.1
Sub-Saharan Africa, West	2,357.6	541.3	1,954.8

*The AIC is a common goodness of fit statistic that is used to compare alternative models. For a linear regression model, the AIC is similar to the residual sum of squares. Though the actual value of the AIC is not meaningful, the relative values of the AIC for different models suggest which model to choose (the preferred model has the smallest AIC). In this analysis, Model 2 is the best fitting model across the sub-regions.

Model 1 - variance of a sub-region's total number of operating theatres (OTs) = mean number of OTs for that sub-region (Poisson distribution)

Model 2 - variance of a sub-region's total number of OTs = (mean number of OTs for that sub-region)$^{1.5}$ (Tweedie distribution)

Model 3 - variance of a sub-region's total number of OTs = (mean number of OTs for that sub-region)^{2} (approximately equal to a negative binomial distribution)

Appendix 3 – Sensitivity of operating theatre to hospital bed ratios under different sample selection mechanisms

Region	True OT to bed ratios with extreme oversampling[1]	True OT to bed ratios with heavy oversampling[2]	OT to bed ratios based on our sample [95% CI]	True OT to bed ratios with heavy undersampling[3]	True OT to bed ratios with extreme undersampling[4]
Sub-Saharan Africa	1.2	1.3	1.3 [1.0-1.7]	1.4	1.5
Asia	1.7	1.8	2.0 [1.8-2.1]	2.1	2.2
Middle East / North Africa	2.0	2.1	2.2 [1.9-2.6]	2.3	2.5
Europe	2.3	2.4	2.6 [2.0-3.3]	2.8	3.0
Australia / New Zealand	2.9	3.0	3.3 [1.3-5.2]	3.5	3.8
Latin America	3.5	3.6	3.9 [2.8-5.1]	4.3	4.6
Canada / US	4.0	4.1	4.5 [3.9-5.0]	4.7	5.0

[1] Assuming hospitals above the observed OT to bed ratio were oversampled at 10 times the odds of hospitals below
[2] Assuming hospitals above the observed OT to bed ratio were oversampled at 5 times the odds of hospitals below
[3] Assuming hospitals above the observed OT to bed ratio were undersampled at 5 times the odds of hospitals below
[4] Assuming hospitals above the observed OT to bed ratio were undersampled at 10 times the odds of hospitals below

OT = operating theatre

If hospitals with high OT to bed ratios were oversampled in our sample, then the true OT to bed ratios would be lower than the OT to bed ratios estimated from our sample. Similarly, if such hospitals were undersampled, then the true OT to bed ratios would be higher than the OT to bed ratios estimated from our sample. Under “heavy” oversampling and undersampling, the true OT to bed ratios are all within the 95% CIs for the OT to bed ratios estimated from our sample. Even for “extreme” oversampling and undersampling, the OT to bed ratios estimated from our sample are similar to the true OT to bed ratios. This suggests that our estimates of OT to bed ratios are not very sensitive to the selection mechanism that generated our sample and thus have minimal bias.

Appendix 4 – Cross validation of operating theatre to bed ratios*

Region	# of hospital profiles (N=769)	OT to bed ratio [95% CI] (chosen for our analysis)	Range of possible OT to bed ratios when sequentially excluding hospitals
Sub-Saharan Africa	39	1.3 [1.0-1.7]	1.3-1.4
Asia	86	2.0 [1.8-2.1]	1.9-2.0
Middle East / North Africa	39	2.2 [1.9-2.6]	2.1-2.4
Europe	123	2.6 [2.0-3.3]	2.5-2.7
Australia / New Zealand	22	3.3 [1.3-5.2]	2.8-3.5
Latin America	60	3.9 [2.8-5.1]	3.4-4.1
Canada / US	400	4.5 [3.9-5.0]	4.3-4.5

*OT to bed ratio = number of OTs per 100 hospital beds as shown in Table 2. In this cross validation analysis, we sequentially removed each hospital profile to determine whether one profile had a substantial effect on the OT to hospital bed ratio for that region. For a listing of which countries and sub-regions comprise the regions listed above, please refer to Appendix 1; OT = operating theatre

Appendix 5 - Estimated number of operating theatres without pulse oximetry according to type of pulse oximetry penetrance transformation

Sub-region	Log-odds/folded power transformation* (chosen for our analysis)	Probit transformation
	Point estimate (95% CI)	**Point estimate (95% CI)**
Australasia	<25	<25
North America, High Income	<25	<25
Europe, Western	24 (13-48)	27 (13-53)
Asia Pacific, High Income	106 (16-688)	251 (37-1,697)
Latin America, Southern	198 (29-1,356)	327 (58-1,842)
Latin America, Tropical	1,511 (1,163-1,963)	2,566 (1,624-4,053)
Europe, Central	1,763 (994-3,125)	2,332 (1,469-3,701)
Sub-Saharan Africa, Southern	333 (147-753)	329 (148-734)
Latin America, Central	1,648 (1,133-2,399)	1,662 (1,167-2,368)
Middle East / North Africa	4,174 (2,954-5,897)	4,439 (3,383-5,825)
Caribbean	1,228 (949-1,588)	1,210 (969-1,512)
Asia, East	21,445 (11,727-39,215)	20,756 (13,476-31,970)
Europe, Eastern	19,223 (12,015-30,754)	19,371 (12,208-30,736)
Asia, Southeast	5,703 (4,629-7,027)	5,384 (4,480-6,470)
Latin America, Andean	936 (733-1,196)	887 (704-1,116)
Asia, Central	4,248 (3,664-4,925)	3,865 (3,466-4,310)
Asia, South	10,064 (8,586-11,795)	10,037 (8,593-11,724)
Oceania	92 (74-114)	90 (73-112)
Sub-Saharan Africa, West	1,853 (1,612-2,130)	1,658 (1,451-1,894)
Sub-Saharan Africa, Central	682 (538-865)	567 (454-713)
Sub-Saharan Africa, East	2,461 (2,164-2,799)	2,354 (2,036-2,720)
Totals	**77,700 (63,195-95,533)**	**78,121 (66,139-92,274)**

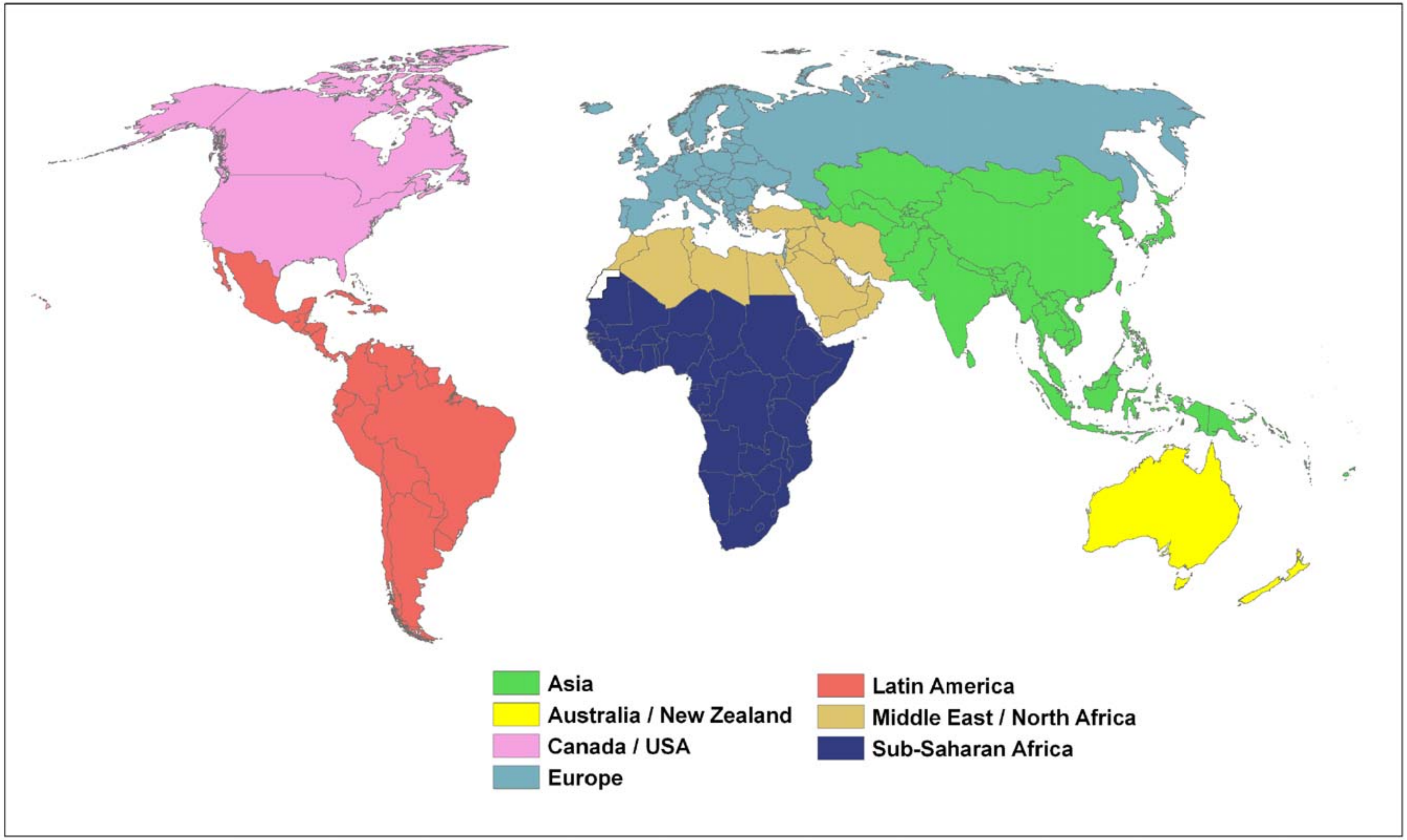
*The folded power transformation reduced to the log-odds transformation

Appendix 6 - Estimated number of operating theatres without pulse oximetry using models with the highest adjusted-R^2

	Model 1 (chosen for our analysis)	**Model 2**
Covariates	PCHE + $(PCHE)^2$	PCHE + $(PCHE)^2$ + RN density
Adjusted-R^2	0.93	0.94
Sub-region	**Point estimate (95% CI)**	**Point estimate (95% CI)**
Australasia	<25	<25
North America, High Income	<25	<25
Europe, Western	24 (13-48)	25 (13-49)
Asia Pacific, High Income	106 (16-688)	61 (10-392)
Latin America, Southern	198 (29-1,356)	119 (15-920)
Latin America, Tropical	1,511 (1,163-1,963)	1,361 (1,044-1,773)
Europe, Central	1,763 (994-3,125)	1,818 (1,045-3,162)
Sub-Saharan Africa, Southern	333 (147-753)	332 (148-745)
Latin America, Central	1,648 (1,133-2,399)	1,614 (1,095-2,380)
Middle East / North Africa	4,174 (2,954-5,897)	3,823 (2,599-5,623)
Caribbean	1,228 (949-1,588)	1,151 (895-1,480)
Asia, East	21,445 (11,727-39,215)	21,828 (10,866-43,847)
Europe, Eastern	19,223 (12,015-30,754)	20,005 (12,814-31,232)
Asia, Southeast	5,703 (4,629-7,027)	5,196 (4,301-6,278)
Latin America, Andean	936 (733-1,196)	821 (588-1,148)
Asia, Central	4,248 (3,664-4,925)	5,754 (4,892-6,768)
Asia, South	10,064 (8,586-11,795)	10,048 (8,594-11,747)
Oceania	92 (74-114)	92 (74-114)
Sub-Saharan Africa, West	1,853 (1,612-2,130)	1,745 (1,522-2,000)
Sub-Saharan Africa, Central	682 (538-865)	639 (512-796)
Sub-Saharan Africa, East	2,461 (2,164-2,799)	2,421 (2,120-2,765)
Totals	**77,700 (63,195-95,533)**	**78,861 (62,863-98,931)**

PCHE = per capita health expenditure; RN = nurse

The log-odds of pulse oximetry penetrance were the outcome for both models.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Water availability at hospitals in low- and middle-income countries: implications for improving access to safe surgical care

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ARTICLE INFO

Article history:
Received 4 February 2016
Received in revised form 5 June 2016
Accepted 10 June 2016
Available online 18 June 2016

Keywords:
Essential surgery
Surgical capacity
Water availability
Low- and middle-income countries

ABSTRACT

Introduction: Although two billion people now have access to clean water, many hospitals in low- and middle-income countries (LMICs) do not. Lack of water availability at hospitals hinders safe surgical care. We aimed to review the surgical capacity literature and document the availability of water at health facilities and develop a predictive model of water availability at health facilities globally to inform targeted capacity improvements.

Methods: Using Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, a systematic search for surgical capacity assessments in LMICs in MEDLINE, PubMed, and World Health Organization Global Health Library was performed. Data regarding water availability were extracted. Data from these assessments and national indicator data from the World Bank (e.g., gross domestic product, total health expenditure, and percent of population with improved access to water) were used to create a predictive model for water availability in LMICs globally.

Results: Of the 72 records identified, 19 reported water availability representing 430 hospitals. A total of 66% of hospitals assessed had water availability (283 of 430 hospitals). Using these data, estimated percent of water availability in LMICs more broadly ranged from under 20% (Liberia) to over 90% (Bangladesh, Ghana).

Conclusions: Less than two-thirds of hospitals providing surgical care in 19 LMICs had a reliable water source. Governments and nongovernmental organizations should increase efforts to improve water infrastructure at hospitals, which might aid in the provision of

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0022-4804/$ – see front matter
http://dx.doi.org/10.1016/j.jss.2016.06.040

safe essential surgical care. Future research is needed to measure the effect of water availability on surgical care and patient outcomes.

Background

Since 1990, nearly two billion people have gained access to improved sources of water, one of the success of the United Nations Millennium Development Goals.[1] Despite this success, 700 million people still live without access to water; half of those without water live in sub-Saharan Africa.[2] Lack of access to water, sanitation, and hygiene (WASH) infrastructure has a significant and negative impact on both health and healthcare provision, including surgical care.[1,3,4]

Much of the increased access to water has been achieved by providing piped water on-site (i.e., running water), building public taps, drilling boreholes, and supporting rainwater capture methods.[1] However, public taps, boreholes, and rainwater capture are poorly suited for providing a constant supply of large volumes of water.[2] Furthermore, water availability at hospitals has not been systematically addressed.[2] In low- and middle-income countries (LMICs) with a funded institutional framework for achieving improved WASH targets, water coverage in hospitals is 85% or greater. To date, few LMICs have assessed or reported the availability of water in hospitals.

The World Health Assembly 68.15 underlined the importance of strengthening emergency and essential surgical care as a component of universal health coverage; in particular, it specifies the concern that inadequate investment in infrastructure, such as water availability, limits progress in improving delivery of surgical care.[3] The need to better defining the critical aspects of providing essential surgical care lead to the launch of the WHO Global Initiative for Emergency and Essential Surgical Care in 2005, an alliance of international organizations, civil and professional societies, nongovernmental organizations, and those representing disciplines of surgery, orthopedics, anesthesia, emergency medicine, and obstetrics.[4] Recognizing the availability of water at hospitals providing surgery as a limiting factor is important for this mission and surgeons operating in LMICs. Reliable water availability is essential for providing safe surgical care.[1,5,6] Water is required for washing instruments, steam sterilization, wound irrigation, and surgical hand scrub (SHS). SHS is an essential surgical safety measure[4]; it is also the most water-intensive part of surgical care, ranging from 15 to 20 L per SHS.[5-7] In 1 y, a tertiary hospital in Nigeria used 200,283 L of water for SHS alone.[6] Lack of reliable water availability can lead to delays in treatment and poor surgical outcomes.[6,8-14]

Surgery is an indivisible and indispensable part of healthcare.[15] However, surgical care is under funded, which has led to critical capacity deficiencies and a significant burden of avertable death and disability.[16-18] Although a number of surgical capacity assessments have reported a lack of equipment and supplies, water availability at hospitals remains poorly characterized.[1,19,20] These assessments provide a unique opportunity to examine the water availability at hospitals in LMICs. Thus, we aimed to systematically review the surgical capacity literature and describe the availability of water at hospitals in LMICs where they were performed. In addition, we used data from these assessments to model water availability at hospitals in LMICs more broadly. By doing so, the findings might identify fundamental limitations in surgical capacity and inform targeted capacity development strategies.

Material and methods

Systematic review

We designed a systematic search strategy to identify all published surgical capacity assessments that reported the water availability at hospitals in LMICs (see Supplementary material). The search strategy included terms for each of the following surgical care capacity assessments:

(i) WHO's Tool for Situational Analysis to Assess Emergency and Essential Surgical Care[21];
(ii) Personnel, Infrastructure, Procedures, Equipment, and Supplies survey[22]; and
(iii) the Harvard Humanitarian Initiative's survey tool.[23]

Other terms were used to identify records that did not use the three tools aforementioned but assessed surgical care capacity, such as "surgical," "surgery," "capacity," "assessment," and "survey" (see Supplementary material). The World Bank World Development Report was used to define LMICs.[24]

Low-income countries are those with a gross national income (GNI) per capita of $1045 or less in 2014; lower-middle-income countries are those with GNI per capita between $1046 and $4125; upper-middle-income countries are those with GNI per capita between $4126 and $12,735.[24]

The titles and abstracts of retrieved records were screened for relevance, and the duplicates were removed. Two reviewers (S.S.C. and S.G.) screened all records; a third reviewer (A.L.K.) resolved disagreements. The remaining full-text reports and their reference lists were reviewed. Reports were included if they described the availability of water at one or more hospitals in a LMIC. If multiple reports from one country were found, the report with the most hospitals assessed was included.

Systematic review data analysis

A binary score was assigned to water availability for each hospital (i.e., water reliably available or not reliably available). For studies that did not provide data for each hospital, the countrywide prevalence of water availability was used. Most reports did not provide description of type or quality of the water source; thus, we were not able to stratify the reports by these important differences.

The percent of hospitals with water availability in each country were pooled using a fixed-effect model with Stata v13 (StataCorp, TX). Weights were applied based on the capacity assessment sample size (i.e., number of hospitals assessed), and a fixed continuity correction was added for countries that had water available at all hospitals assessed to allow the use of non-negative constants. Confidence intervals (CIs) were calculated with a binomial distribution. Estimates of heterogeneity were calculated from the inverse-variance fixed-effect model. Significant intragroup heterogeneity was identified (i.e., I^2 was between 53%-93% with corresponding P values < 0.05).[25]

To explore heterogeneity further, percentages were transformed using the Freeman–Tukey double arcsine method and pooled using a DerSimonian–Laird random-effects model for each income-level subgroup (i.e., low-income, lower-middle-income, and upper-middle-income countries).[26] Despite these attempts to minimize statistical heterogeneity, the I^2 measure continued to be 50%-95%, which suggested substantial intragroup and intergroup heterogeneity. Thus, pooled estimates are not discussed. Instead, we present a narrative synthesis of water availability as recommended by the Cochrane Collaboration.[27] Forest plots are presented to demonstrate both the range and variability of water availability between assessments.

Modeling water availability at hospitals in LMICs globally

National indicator data from the World Bank related to healthcare capacity and water availability were extracted for all LMICs, including the countries that had surgical capacity assessments.[1,24] These indicators included: gross domestic product (GDP), total healthcare expenditure, percent of rural population with improved access to water (rural), and percent of urban population with improved access to water (urban; Table 1).

Model building and validation

We built a multivariable logistic regression model to predict of water availability at hospitals in LMICs more broadly. To do so, we examined bivariate relationships between national indicators and water availability at the hospitals reported by the capacity assessments. We then included all the predictors in the model simultaneously. Each of the national indicator covariates demonstrated evidence for a significant relationship with the percent water availability at hospitals ($P < 0.05$); thus, they were included in the multivariable model:

$$\text{Percent of hospitals with water availability} \sim \beta_{0_i} + \beta_{GDP_i} + \beta_{THE_i} + \beta_{Rural_i} + \beta_{Urban_i}$$

Crude odds ratios and multivariable odds ratios and their respective 95% CIs that describe the relationship between the percent of hospitals with water availability and national predictors were calculated from the logistic model.

Table 1 – Univariate variables used to build the predictive model of water availability.

Coefficient	Variable
β_{GDP_i}	Gross domestic product (GDP)
β_{THE_i}	Total healthcare expenditure as % of GDP
β_{Rural_i}	Percent of rural population with improved access to water
β_{Urban_i}	Percent of urban population with improved access to water

Evaluating the goodness-of-fit and discriminating ability of the model

We assessed model accuracy (i.e., agreement between model-predicted percent of hospitals with water availability and observed percentages) using the Hosmer–Lemeshow goodness-of-fit test and calibration plots (i.e., graphs of predicted percentages *versus* the observed percentages of water availability). We grouped observations based on percentiles of ordered values of model-predicted probabilities such there was about the same number of observations in each group.[28] There was no evidence of poor model fit (Hosmer–Lemeshow chi-square test statistic $P = 0.38$). The calibration plots showed that observed and expected frequencies were very close to each other, which suggested that the logistic model fit the data well.

Next, we assessed the model's ability to discriminate (i.e., correctly classify hospitals with or without water availability from the capacity assessments) by calculating predictive performance indices (i.e., sensitivity and specificity values) for different model-predicted percentage cutoff values (Supplementary material). Using this estimates, we constructed a receiver-operating-characteristic curve to evaluate the accuracy of the model (Supplementary material). The area under the receiver-operating-characteristic curve was 0.73, which suggested that our model had relatively good capability to correctly classify hospitals as with or without water availability. Finally, we used the model to predict percent of hospitals in a LMIC with water availability and the respective 95% CIs.

Results

Search results

The systematic search returned 72 records; 50 records were not relevant to the study; no duplicates were identified. The remaining 22 full-text reports were reviewed. Of these, 19 reports described water availability at hospitals in a LMIC (Fig. 1).[23,29-45]

LMICs with at least one report of water availability spanned five continents: Africa (11 reports; 58% of reports); Asia (4; 21%); South America (2; 11%); North and Central America (1; 5%); and Oceania (1; 5%). Reports from three countries,

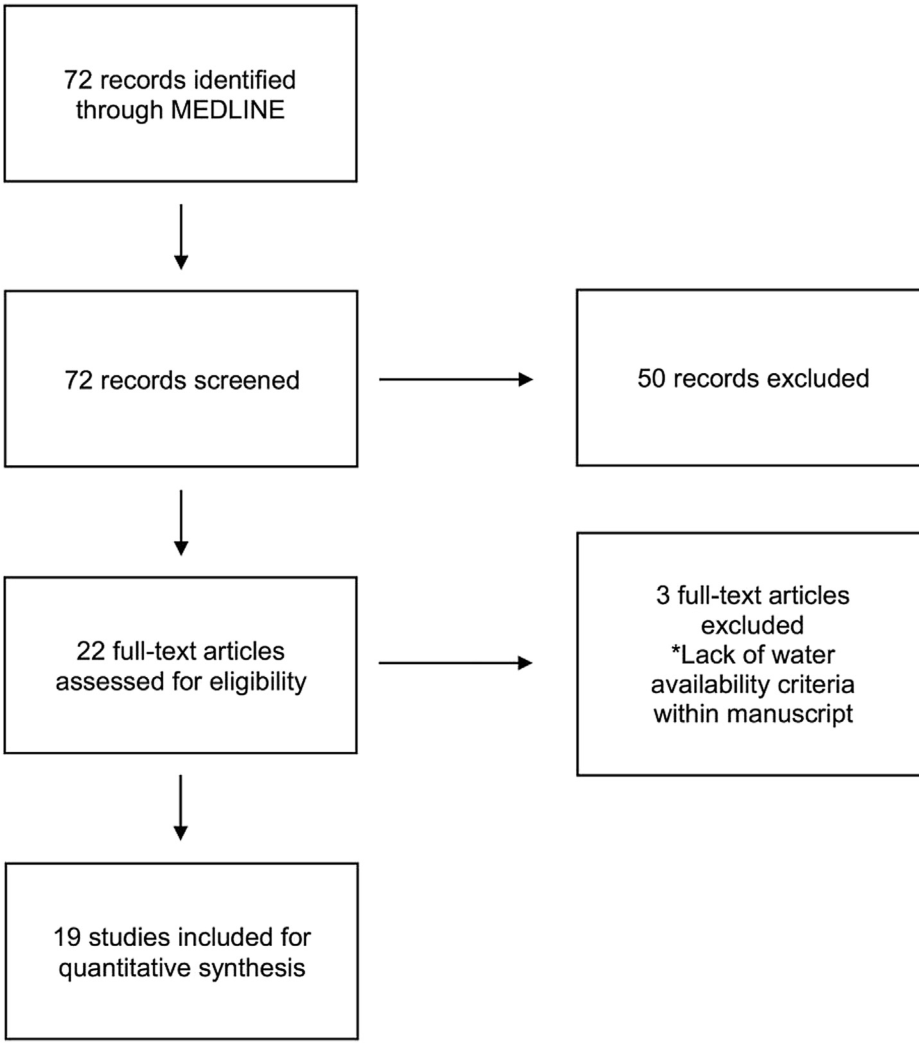

Fig. 1 – Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram for the results form a systematic search for reports of water availability from surgical capacity assessments in low- and middle-income countries.

Afghanistan, Somalia, and Ghana, did not include hospital-specific data regarding water availability. The number of hospitals per country ranged from nine in Guyana and the Solomon Islands to 48 in Tanzania (median number of hospitals 17; interquartile range [IQR] 14-28). In total, the reports described water availability at 430 hospitals in 19 LMICs.

Water availability reported by capacity assessments

Overall, 66% of hospitals assessed had water availability (283 of 430 hospitals). The median percent of hospitals with water availability from published reports was 61% (IQR 47.5%-82%). Only one assessment, from Bangladesh, reported that all of the hospitals assessed had water availability.[39] The percentage of hospitals with water access always available ranged from 22% in Malawi to 100% in Bangladesh (median 61%; IQR 48%-82%). In Malawi, 19 of 23 district hospitals and 2 of 4 central hospitals lacked a source of running water that was always available (Fig. 2).

Modeled water availability in LMICs globally

Countries with moderate to high GDP (i.e., GDP greater than 10 billion nominal USD) were more likely to have a higher percentage of hospitals with water availability than countries with GDP less than five billion nominal USD (Table 2). Total health expenditure was less strongly associated with the percent of hospitals with water availability, particularly in the multivariable model. While percent of rural population with improved access to water was associated with a higher percent of hospitals with water availability in both the bivariate and multivariable model, percent of urban population with improved access to water was not strongly associated with percent of hospitals with water availability in the multivariable model.

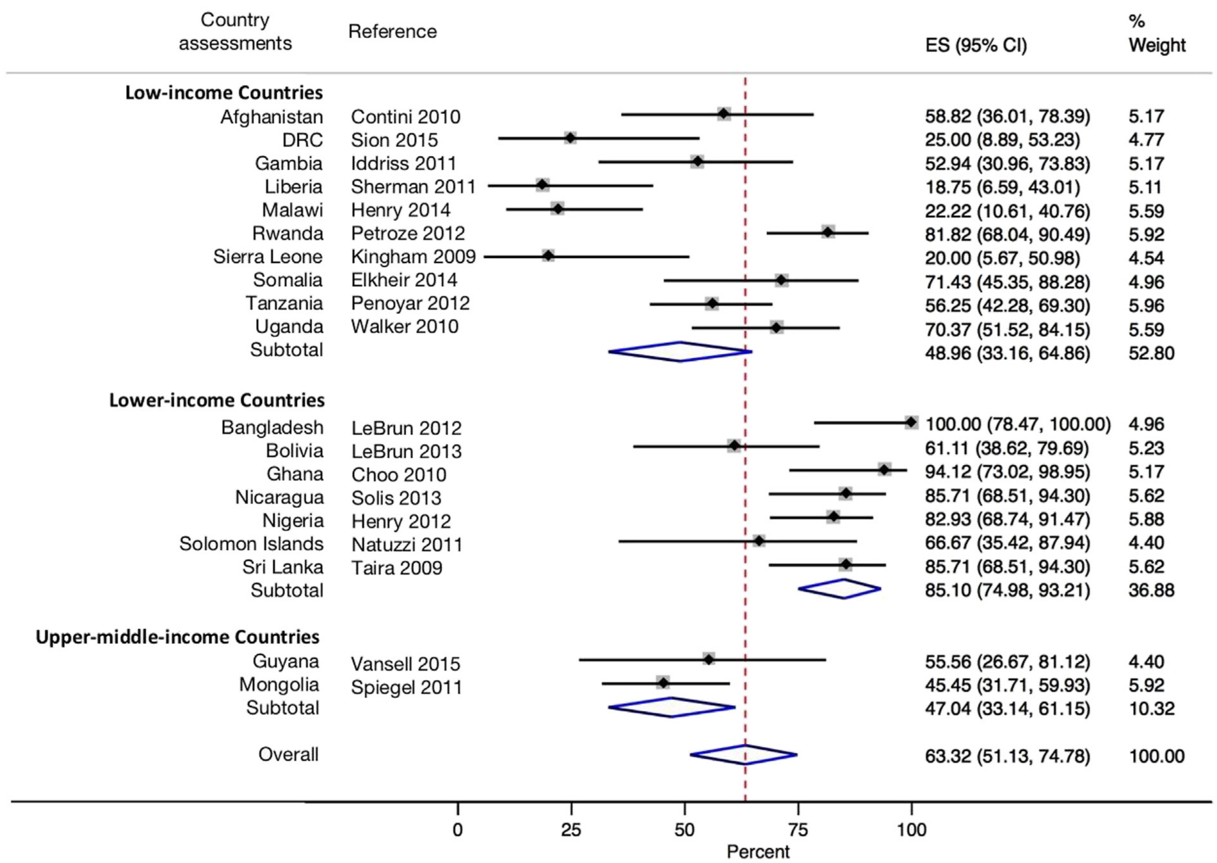

Fig. 2 – Forest plot of water availability for countries included in assessment. (Color version of figure is available online.)

Estimated water availability from our model ranged from less than 20% in Sierra Leone, Liberia, and Togo to more than 90% in India, Malaysia, Thailand, Armenia, and Guinea (Table 3). In general, the sub-Saharan African region had the lowest estimated water availability and South and Southeast Asia regions had the highest estimated availability (Fig. 3).

Table 2 – Predictors of the availability of water at the hospitals.

Covariate	Univariate analysis			Multivariate analysis		
	OR	95% CI	P value	OR	95% CI	P value
GDP (in billions)						
≤5*	1			1		
>5-≤10	7.048	(3.259-15.243)	<0.001	18.513	(5.155-66.487)	<0.001
>10-≤15	2.889	(1.516-5.506)	0.001	5.94	(2.761-12.779)	<0.001
>15	4.539	(2.685-7.674)	<0.001	6.123	(3.275-11.448)	<0.001
Total health expenditure (% of GDP)						
≤5*	1			1		
>5-10	0.364	(0.218-0.607)	<0.001	0.527	(0.283-0.980)	0.043
≥10	0.671	(0.320-1.404)	0.289	0.351	(0.105-1.176)	0.09
% Rural population with improved water	1.112†	(1.007-1.227)	0.036	1.256	(1.044-1.511)	0.016
% Urban population with improved water	1.219‡	(1.017-1.461)	0.032	1.266	(0.918-1.745)	0.15

CI = confidence interval; GDP = gross domestic product; OR = odds ratio.
* Baseline category.
† Odds ratio reported per 10% difference in % of rural population with improved water.
‡ Odds ratio reported per 10% difference in % of urban population with improved water.

Table 3 – Estimated percent of hospitals with a reliable water source in low- and middle-income countries.

Country	Lower estimate	Estimate	Upper estimate
East Asia and Pacific			
Kiribati	3.5	14.4	43.5
Solomon Islands	20.4	34.7	52.3
Timor-Leste	16.9	41.9	71.9
Samoa	28.3	49.3	70.5
Mongolia	38.9	52.6	66
Fiji	35.4	61.6	82.5
Tonga	39.5	66.2	85.4
Cambodia	62	76	86
Laos	59	80.7	92.4
China	71.6	83.7	91.3
Myanmar	71.8	85.1	92.8
Vietnam	73.1	85.4	92.7
Indonesia	74.7	86.9	93.7
Philippines	78.2	89.4	95.2
Malaysia	81.2	91.2	96.1
Thailand	81.6	91.7	96.4
Europe and Central Asia			
Montenegro	30	50.7	71.1
Azerbaijan	67	77.3	85.1
Serbia	64.7	80.4	90.2
Albania	68.9	83.2	91.7
Ukraine	70.6	84.6	92.6
Macedonia	71.2	85.8	93.6
Bulgaria	73.6	86.1	93.3
Belarus	73.8	86.2	93.3
Bosnia and Herzegovina	73.7	86.4	93.5
Georgia	73.9	86.5	93.6
Romania	73.9	86.5	93.6
Turkey	73.9	86.5	93.6
Tajikistan	71	88.5	96.1
Moldova	83.5	88.7	92.4
Kazakhstan	78.5	89.6	95.3
Armenia	79.1	92.2	97.4
Kyrgyzstan	76	92.9	98.2
Latin America and the Caribbean			
Grenada	28.5	47.9	67.9
St. Lucia	28.9	48.3	68.4
Guyana	28.6	49.1	69.9
Haiti	42	72	90.1
Peru	62.6	72.2	80.1
Dominican Republic	60.5	75	85.5
Nicaragua	50.2	75.3	90.2
Ecuador	65.8	75.8	83.7
Colombia	65.6	76.6	84.9
Bolivia	66.5	77.3	85.3

(continued)

Table 3 – (continued)

Country	Lower estimate	Estimate	Upper estimate
Honduras	69.8	80.7	88.3
El Salvador	70.5	81.6	89.2
Guatemala	71	82	89.5
Panama	71.1	82.4	89.9
Brazil	71.5	82.7	90
Mexico	71.4	83.4	91
Costa Rica	72.6	84.1	91.3
Paraguay	73.3	85.1	92.2
Middle East and North Africa			
Djibouti	15.8	30.6	50.8
Iraq	63.4	73.7	81.9
Morocco	59.2	73.8	84.5
Algeria	59.2	74.5	85.5
Iran	71.6	83.5	91.1
Jordan	71.7	83.6	91.1
Lebanon	73.2	86	93.2
Egypt	73.8	86.2	93.3
South Asia			
Maldives	20.1	39.7	63.2
Afghanistan	44.6	53.4	61.9
Bhutan	39.9	66.5	85.6
Bhutan	39.9	66.5	85.6
Nepal	66.4	81.1	90.3
Bangladesh	73.1	86.8	94.1
South Asia			
Pakistan	78.2	89.3	95.1
India	80.2	90.6	95.8
Sri Lanka	81.3	91.3	96.2
Sub-Saharan Africa			
Sierra Leone	3.1	13	40.9
Liberia	5.7	18.5	46
Togo	7.9	19.3	40.2
Eritrea	9.9	26.7	54.6
Lesotho	10.2	26.7	53.9
Guinea Bissau	13.7	29.2	51.6
Swaziland	17.4	30.7	48.3
Burundi	18.5	31.8	49
Central African Republic	13.6	35.5	65.8
Gambia	23	39	57.8
Comoros	23.1	40.7	61.1
Malawi	25	42.5	62
Sao Tome and Principe	28	46.9	66.7
Mozambique	35.6	49.1	62.8
Tanzania	43	52	60.7
Cabo Verde	30.7	56.4	79
Angola	30.6	57	79.9
Zambia	49.4	60.1	69.9

(continued)

Table 3 – (*continued*)

Country	Lower estimate	Estimate	Upper estimate
D.R.C.	33.7	61.9	83.8
Ethiopia	44.7	62.8	77.9
Chad	35.8	63.3	84.2
Madagascar	27.4	63.6	89
Cameroon	48.4	65.9	79.9
South Sudan	43.1	66.8	84.3
South Sudan	43.1	66.8	84.3
Mali	46	71.6	88.2
Sub-Saharan Africa			
Cote d'Ivoire	62.6	72.8	81
Republic of Congo	28.9	73.1	94.8
Nigeria	56.9	74.5	86.6
Kenya	56.9	74.6	86.8
Uganda	66.5	76.9	84.8
Burkina Faso	56.7	77.2	89.7
Ghana	67.3	78.9	87.1
South Africa	69.5	80.6	88.4
Namibia	63.4	80.8	91
Senegal	67.4	83	92
Rwanda	77.9	83.2	87.5
Mauritania	56.8	83.8	95.3
Botswana	72.5	84.1	91.4
Gabon	67	84.2	93.3
Niger	65.3	85.7	95
Mauritius	79	92.1	97.3
Benin	84.4	93.2	97.2
Guinea	86.8	93.6	97.1

Data unavailable for: American Samoa, Belize, Cuba, Dominica, Jamaica, North Korea, Kosovo, Libya, Marshal Islands, Micronesia, Palau, Papua New Guinea, Somalia, Sudan, Suriname, Syria, Tunisia, Turkmenistan, Tuvalu, Uzbekistan, Palestine, Yemen, and Zimbabwe.

Discussion

This study aimed to assess water availability at hospitals in LMICs. Water is an essential infrastructure resource for providing safe surgical care. Given that only 66% of hospitals that underwent surgical capacity assessment had water availability, this resource deficiency likely represents a common and significant barrier to the provision of surgical care. Our model highlights this potential deficiency in many LMICs. Thus, specific attention to hospital infrastructure development to facilitate surgical capacity improvements is urgently needed.

Other than the reports described, few data are available to put our results into context. Reports of other infrastructure deficiencies (e.g., electricity) at hospitals in many LMICs suggest that improvements to these essential resources are required. Similarly, there are no data regarding the effect of improving infrastructure on surgical care output. However, water availability within hospitals is essential to not just providing surgical care but also preventing disease. In addition to facilitating safe surgery (e.g., SHS, steam sterilization, and wound irrigation), waterborne nosocomial infections in LMICs can lead to increased patient morbidity, mortality, and hospitalization costs.[46-51] Given these broader benefits, water availability should be prioritized for improving access to safe health care and surgical care provision.

The first step to addressing the challenge of water availability in hospitals in LMICs is to set national policies with appropriate funding and support. Examples of successful implementation of water availability strategies have been reported from Laos and Bangladesh.[1] In 25 hospitals in Laos, the national government provided guidance on environmental standards, integration of standards into national programs, and support for capacity building and personnel training.[1] The success is reflected in our model, which predicts water availability in hospitals in Laos of 81%, well above the median percentage for LMICs in general (66%).[1] Another success story is Bangladesh, which has provided water availability to all hospitals countrywide. This initiative was created given the high incidence of diarrheal disease, which remains a major cause of death among all ages in the country.[52] Although all hospitals surveyed in Bangladesh reported reliable water availability, the sources vary and range from piped water to tube wells.[39] Thus, future capacity assessments might consider assessing the temporal water availability, water quality, and type of water infrastructure so that specific recommendations can be made.[53] An unexpected result of the model was that it suggests that some lower GDP countries were more likely to have hospitals with water availability than relatively high GDP countries. While this may be due to uncontrolled confounding among unmeasured variables, it may also be the result of WASH programs that are under funded and/or under resourced in spite of relative national wealth.

The model might be useful for identifying countries that may benefit from improving hospital water availability. First, the model needs to be validated by assessments of water availability at hospitals in several of the countries reported. Should it be found to be valid, national governments and international organizations might use the data from the model to advocate and plan for improving hospitals' access to reliable and clean water. Given the dearth of data regarding the impact of water availability on healthcare outcomes in LMICs, monitoring and evaluation exercises could also prove beneficial as capacity improvement activities commence. The model may be by countries to better understand their level of water infrastructure, as it relates to surgical capacity. For example, bordering countries may be at opposite ends of water availability; notably Burundi has a predicted availability of 31.8% whereas neighboring Rwanda has a predicted availability of 83.2%. Burundi may possibly gain from the strategies used by Rwanda to build its water and surgical capacity infrastructure.

This study has a number of limitations. While our search identified assessments from 19 countries, the assessments varied in the number of hospitals visited and the reporting of quality. Thus, we were unable to describe water availability with high accuracy or in greater detail. Second, assessments

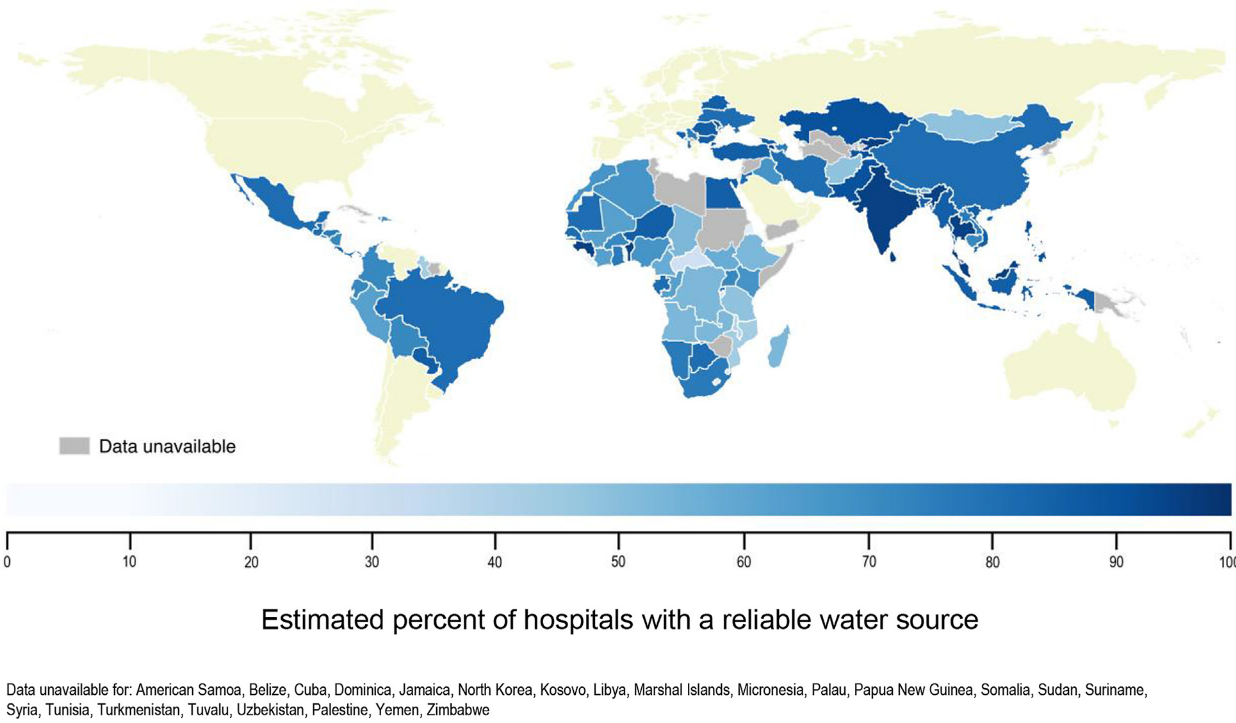

Fig. 3 – Map of estimated percent of hospitals with a reliable water source in low- and middle-income countries. (Color version of figure is available online.)

rarely reported the type of water source or its temporal availability; thus, we were forced to use binary classification of availability: availability or unavailable. This classification might have misclassified hospitals with intermittent water availability making our estimates overly conservative. Third, our model suggested that hospitals in some countries with relatively high GDP were less likely to have water available than hospitals in countries with lower GDP. In addition, we were not able to make a reasonable comparison between water availability at hospitals and surgical care. At last, robust data to validate our model are not available. However, despite these limitations, the findings suggest that water availability at hospitals in LMICs is generally insufficient and requires at least systematic assessment, if not significant improvement.

Conclusions

The availability of water at hospitals in LMICs is likely insufficient globally and may be hindering the provision of safe surgical care. There is wide variation in availability between and within regions that requires specific attention to determine the best courses of action given differences in current availability, demand, infrastructure, and natural resources. The model presented offers a useful starting point for national and international organizations to consider when planning healthcare and surgical capacity improvement initiatives. Securing improved water sources at the household level has been one of the greatest successes of the United Nations Millennium Development Goals; we must extend this success to hospitals. This will require concerted effort by LMICs and implementing partners to assess the current situation, develop appropriate policies, set national targets, and building capacity in this fundamental healthcare resource.

Acknowledgment

This study was funded in part by grant R25-TW009345 from the Fogarty International Center, US National Institutes of Health. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Authors' contributions: All authors had substantial contribution to the manuscript. S.S.C. was responsible for data abstraction, analysis, and manuscript writing. B.T.S. contributed to the manuscript writing and data analysis. F.M.O. contributed to modeling analysis and manuscript writing. S.G., E.B.H., and A.L.K. contributed through project guidance, data analysis, and manuscript writing.

Disclosure

The authors have no real or potential conflict(s) of interest to disclose.

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jss.2016.06.040.

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JOURNAL OF SURGICAL RESEARCH • MARCH 2018 (223) 136–141

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Electricity and generator availability in LMIC hospitals: improving access to safe surgery

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ARTICLE INFO

Article history:
Received 25 July 2017
Received in revised form
19 September 2017
Accepted 12 October 2017
Available online 21 November 2017

Keywords:
Essential surgery
Surgical capacity
Electricity availability
Generator availability
Low- and middle-income countries

ABSTRACT

Background: Access to reliable energy has been identified as a global priority and codified within United Nations Sustainable Goal 7 and the Electrify Africa Act of 2015. Reliable hospital access to electricity is necessary to provide safe surgical care. The current state of electrical availability in hospitals in low- and middle-income countries (LMICs) throughout the world is not well known. This study aimed to review the surgical capacity literature and document the availability of electricity and generators.

Methods: Using Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, a systematic search for surgical capacity assessments in LMICs in MEDLINE, PubMed, and World Health Organization Global Health Library was performed. Data regarding electricity and generator availability were extracted. Estimated percentages for individual countries were calculated.

Results: Of 76 articles identified, 21 reported electricity availability, totaling 528 hospitals. Continuous electricity availability at hospitals providing surgical care was 312/528 (59.1%). Generator availability was 309/427 (72.4%). Estimated continuous electricity availability ranged from 0% (Sierra Leone and Malawi) to 100% (Iran); estimated generator availability was 14% (Somalia) to 97.6% (Iran).

Conclusions: Less than two-thirds of hospitals providing surgical care in 21 LMICs have a continuous electricity source or have an available generator. Efforts are needed to improve electricity infrastructure at hospitals to assure safe surgical care. Future research should look at the effect of energy availability on surgical care and patient outcomes and novel methods of powering surgical equipment.

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0022-4804/$ – see front matter © 2017 Elsevier Inc. All rights reserved.
https://doi.org/10.1016/j.jss.2017.10.016

Introduction

Energy is recognized as a United Nations Sustainable Development Goal and essential prerequisite for achieving the global health and development goals.[1] In addition, the United Nations Secretary-General launched the "Sustainable Energy for All" initiative with the goal to achieve universal energy access by 2030 while doubling the global rate of energy efficiencies and renewable energy.[2] However, 1.2 billion people, 20% of the world population, are without access to electricity. Most of those without access to electricity live in sub-Saharan Africa and Asia. Of those without access to electricity, 85% reside in rural areas. In addition, 2.8 billion people rely on polluting fuels, such as wood, charcoal, dung, and coal for cooking and heating.[3]

Electricity is an essential component of the infrastructure necessary to deliver health services at District Level Hospitals and above.[4] Electricity is used in the basic functioning of hospitals including lighting, the heating and cooling of air, and powering equipment necessary to provide essential and emergency surgery safely. In addition, the World Health Organization's (WHO) highlighted essential medications and health products include those which require electricity to use and deliver care.[5]

The Lancet Commission on Global Surgery defined electricity as one of the 10 needs for the provision of safe surgical and anesthesia care.[6] Surgical care requires sterilization, anesthesia, and recovery services. In low- and middle- income countries (LMICs) this may mean the use of an oxygen concentrator or generators, vital sign monitors, autoclaves, and anesthesia equipment. Other related hospital services, such as imaging and diagnostic laboratory services, also require electricity. Surgical equipment such as electrocautery and suction machine require electricity, as does performing emergency procedures at night.[7] In addition, the Lancet Commission defined electricity and infrastructure broadly, as one of the 10 needs for the provision of safe surgical and anesthesia care globally. Despite the recognition of electricity as central to the work of surgeons in LMICs, there is limited literature on this topic to guide surgeons and policy-makers alike.

Thus, we aimed to systematically review the surgical capacity literature and describe the availability of electricity at hospitals in LMICs where they were performed. In addition, we used data from these assessments to model electricity availability at hospitals in LMICs more broadly. By doing so, the findings might identify fundamental limitations in surgical capacity based on electrical infrastructure and inform targeted capacity development strategies.

Methods

Systematic review

We designed a systematic search strategy to identify all published surgical capacity assessments that reported electricity and generator availability at hospitals in LMICs (see supplementary material). The methods used for the systematic review and data analysis are similar to the one employed in a previous study on water and surgical capacity (Figure).[8] The search strategy included terms for each of the following surgical care capacity assessments:

i. Tool for Situational Analysis to Assess Emergency and Essential Surgical Care of WHO[9]
ii. Personnel, Infrastructure, Procedures, Equipment and Supplies survey[10]; and
iii. the Harvard Humanitarian Initiative's survey tool.[11]

Other terms were used to identify records that did not use these three tools but assessed surgical care capacity, such as "surgical," "surgery," "capacity," "assessment," and "survey" (see supplementary material). The World Bank World Development Report was used to define LMICs.[12]

The titles and abstracts of retrieved records were screened for relevance, and duplicates were removed. Two reviewers (SSC and SG) screened all records; a third reviewer (ALK) resolved disagreements. The remaining full-text reports and their reference lists were reviewed. Reports were included if they described the availability of electricity and generator at one or more hospitals in an LMIC. If multiple reports from one country were found, the report with the most recent study was included.

Systematic review data analysis

A binary score was assigned to electricity availability for each hospital (i.e. electricity reliably available or not reliably

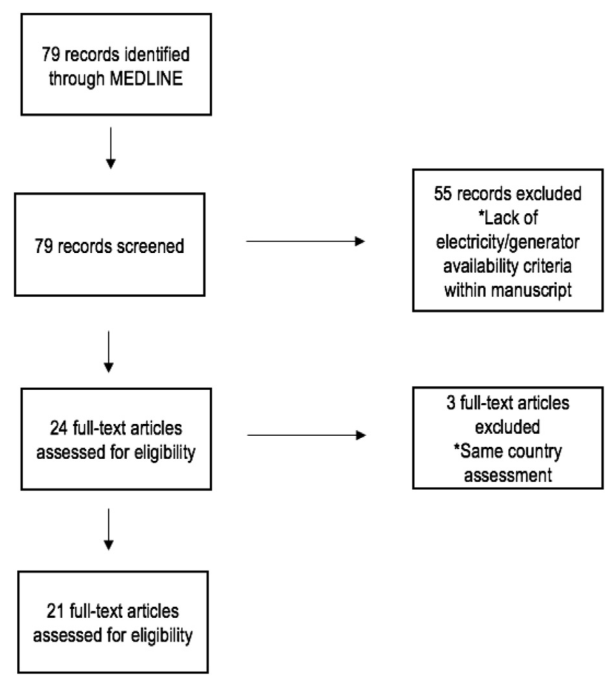

Figure – PRISMA flow diagram for the results forms a systematic search for reports of electricity and generator availability from surgical capacity assessments in low- and middle-income countries. PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

available). A binary score was assigned to generator availability for each hospital. For studies that did not provide data for each hospital, the countrywide prevalence of electricity and/or generator availability was used. Most reports did not provide description of type or quality of the electricity source; thus, we were not able to stratify the reports by these important differences.

Results

Search results

The systematic search returned 79 articles, of which 21 reported electricity availability, totaling 503 hospitals. Of the 21 countries covered five WHO regions, including Africa (10), South-East Asia (2), Western Pacific (2), Eastern Mediterranean (3), Americas (4). This includes 11 low-income countries, 8 LMICs, and 2 upper-middle income countries (Table 1).[11,13-32]

Continuous electricity

All 21 countries reported the availability of electricity in hospitals assessed. The mean availability of reliable electricity is 58.1% (292 of 503 hospitals assessed). Hospitals that reported as having reliable electricity availability ranged from 0% (Malawi, Sierra Leone, and Uganda) to 100% (Iran). Twelve countries, spanning five WHO regions, were reported as having ≥50% of hospitals with reliable electricity. African region had seven of the nine countries with less than 50% of hospitals with reliable electricity with a regional average of 39.1% (Table 2).

Generator availability

Sixteen of the 21 hospitals reported the availability of generators in hospitals assessed. The mean availability of generator is 72.4% (309 of 427 hospitals assessed). Hospitals reporting the availability of generators ranged from 14.3% (Somalia) to 100% (Liberia and Uganda). Twelve countries, spanning five WHO regions, reported as having ≥50% of hospitals with available generators. Countries reporting less than 50% of health facilities with generator availability include Malawi, Bangladesh, Mongolia, and Somalia.

Some countries had <50% continuous electricity but ≥50% generator availability: Gambia (44.4%, 52.9%), Liberia (45.5%, 100.0%), Sierra Leone (0%, 50.0%), Tanzania (43.8%, 58.3%), Uganda (0.0%, 100.0%), and Mongolia (66%, 45%). Malawi has the lowest rate of reliable electricity at hospitals (0.0%), lowest

Table 1 – Electricity consumption and access by country.

WHO region	Country	Number of facilities	Pop (thousand, 2015)	World Bank Class	UNDP HDI (2014)	Electric power consumption (kWh per capita, 2013)	Access to electricity (% of population, 2012)
AFRO	Democratic Republic of Congo	12	77,266.81	LIC	0.433	110	16
	Gambia	18	1990.92	LIC	0.441		35
	Ghana	17	27,409.89	LMIC	0.579	382	64
	Liberia	11	4503.44	LIC	0.430		10
	Malawi	27	17,215.23	LIC	0.445		10
	Nigeria	41	182,201.96	LMIC	0.514	142	56
	Rwanda	44	11,609.67	LIC	0.483	157	18
	Sierra Leone	10	6453.18	LIC	0.413		14
	Tanzania	48	53,470.42	LIC	0.512	89	15
	Uganda	14	39,032.38	LIC	0.483		18
SEARO	Bangladesh	7	160,995.64	LMIC	0.57	293	60
	Sri Lanka	28	20,966.00	LMIC	0.757	526	89
WPRO	Mongolia	44	2959.13	LMIC	0.727	1909	90
	Solomon Islands	9	583.59	LMIC	0.506		23
EMRO	Afghanistan	17	32,526.56	LIC	0.465		43
	Iran	42	79,109.27	UMIC	0.766	2899	100
	Somalia	14	10,787.10	LIC			33
PAHO	Bolivia	18	10,724.70	LMIC	0.662	705	91
	Guyana	9	767.07	UMIC	0.636		79
	Haiti	45	10,711.07	LIC	0.483	49	38
	Nicaragua	28	6082.03	LMIC	0.631	598	78

AFRO = African region; SEARO = South-East Asia region; WPRO = Western Pacific region; EMRO = Eastern Mediterranean region; PAHO = Pan-American Health Organization; LIC = low-income country; LMIC = low- and middle- income countries; UMIC = upper-middle income country; UNDP HDI = United Nations Development Programme Human Development Index.

Table 2 – The availability of reliable electricity and generator facilities by country and region.

WHO region	Country	Author	Year	Availability of reliable electricity (% of facilities assessed)	Availability of generator (% of facilities assessed)	Availability of reliable electricity (% of facilities assessed)	Availability of generator (% of facilities assessed)
AFRO	Democratic Republic of Congo	Sion	2015	41.7%	N/A	39.1%	72.0%
	Gambia	Iddriss	2011	44.4%	52.9%		
	Ghana	Choo	2010	82.4%	82.4%		
	Liberia	Knowlton	2013	45.5%	100.0%		
	Malawi	Henry	2014	0.0%	29.6%		
	Nigeria	Henry	2012	51.2%	92.7%		
	Rwanda	Petroze	2012	81.8%	81.8%		
	Sierre Leone	Kingham	2009	0.0%	50.0%		
	Tanzania	Penoyar	2012	43.8%	58.3%		
	Uganda	Linden	2012	0.0%	100.0%		
SEARO	Bangladesh	LeBrun	2012	28.6%	42.9%	41.1%	42.9%
	Sri Lanka	Taira	2009	53.6%	N/A		
WPRO	Mongolia	Spiegel	2011	65.9%	45.5%	60.7%	45.5%
	Solomon Islands	Natuzzi	2011	55.6%	N/A		
EMRO	Afghanistan	Contini	2010	41.2%	N/A	63.7%	63.7%
	Iran	Kalhor	2016	100.0%	97.6%		
	Somalia	Elkheir	2014	50.0%	14.3%		
PAHO	Bolivia	LeBrun	2012	55.6%	61.1%	69.5%	83.6%
	Guyana	Vansell	2015	55.6%	N/A		
	Haiti	Tran	2015	77.8%	93.3%		
	Nicaragua	Solis	2013	89.3%	96.4%		

AFRO = African region; SEARO = South-East Asia region; WPRO = Western Pacific region; EMRO = Eastern Mediterranean region; PAHO = Pan-American Health Organization.

rates of available generator (29.6%), and lowest rate of access to electricity by its population (10%, tied with Liberia) (Table 2).

Discussion

Limited availability of electricity and generators is widely described in LMICs; however, there is a lack of literature on electricity in hospitals providing surgical care. Our findings suggest that these limitations are reflected in the availability of electricity and generator in hospitals providing surgical care. Less than two-thirds of hospitals have reliable electricity available. Less than three-quarters of hospitals in LMICs have an available generator. Our findings suggest that current assessments may overestimate surgical capacity in LMICs unless they consider the limitations from the availability of electricity and generator power.

Our findings reflect those in the literature. A study of 13 health facility in 11 sub-Saharan African countries found mean availability of reliable electricity of 72% at health facilities (compared with 58.1%).[33] Another study of 883 health facilities from 24 LMICs determined that reliable electricity was available at only 64% of the facilities. Other studies have commented on hospital buildings in LMICs with deficits in infrastructure, including lack of electricity.[34-38]

To better understand the challenges that those regions face in providing reliable electricity to hospitals, we can examine sub-Saharan Africa, with a mean regional availability of reliable electricity of 39.1%. Sub-Saharan Africa is the least developed region in the world regarding energy availability and access, with 585 million people with no access to electricity services.[39] Not only does the region have the lowest capacity for generating energy, but it also faces challenges because of unreliable energy supplies, high cost, and limited access to the grid. Per capita electricity in sub-Saharan Africa is one-third as compared with South Asia and one-tenth as compared with Latin America. Energy availability is unreliable with an average of 56 days with power outages per year. To compensate, buildings must maintain an electricity generator as an alternative source of power.[40]

In recognition of the necessity of electricity for health and development, there are efforts to address the global need. The United Nations Secretary-General launched the "Sustainable Energy for All" initiative with a goal to achieve universal access to energy by 2030, while doubling the global rate of energy efficiencies and renewable energy.[2] The Electrify

Africa Act of 2015 by the United States seeks to encourage African countries to provide first-time access to electricity for at least 50 million people in sub-Saharan Africa by 2020.[41] Still surgeons globally must face the additional challenge of creating workarounds to provide electricity for their health systems. Creative workarounds include hand cranks, bicycle generators, cow-go-around generators, incinerator steam generators, solar collectors, and biogas among many others. These also represent opportunities for alternative energy to play a significant role in making the energy infrastructure of hospitals that would otherwise be without reliable electricity.[42]

Although this review has been able to shed light on the pervasive lack of electrical infrastructure, it has several limitations. Unfortunately, the 21 country assessments identified reported of the source of electricity or quality of generator in a variety of ways. Also, many of the assessments lacked details regarding temporal availability requiring us to classify electricity as a binary of "always available" or "not always available." This classification scheme makes our estimates conservative, as some hospitals with intermittent outages would be classified as "not always available." Our findings suggest that availability of reliable electricity and generator at hospitals in LMICs is insufficient and requires further assessment and significant improvement.

Conclusion

The availability of electricity and generators at hospitals in LMICs is lacking and limits the provision of safe surgical care globally. There is variation in availability between and within regions requiring directed action to determine the best remedies to improve current infrastructure. Securing sustainable energy is recognized as a prerequisite to development by the United Nations Sustainable Development Goals; we must recognize hospitals as a key in translating energy access to improve health. LMICs and implementing partners must conduct assessments, set national priorities, develop policies, and build the capacity required to provide safe surgical care.

Acknowledgment

Funding: This study was funded, in part, by grant from the Fogarty International Center, US National Institutes of Health (R25-TW009345).

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Authors' contributions: All authors had substantial contribution to the manuscript. S.C. was responsible for data abstraction, analysis, and manuscript writing. B.S. contributed to the manuscript writing and data analysis. S.K. contributed to manuscript writing. S.M.W, G.B., A.K., and T.M. contributed through project guidance, data analysis, and manuscript writing.

Disclosure

The authors have no real or potential conflict of interest to disclose.

Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jss.2017.10.016.

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Recommendations for research

National and international

- An increase in research capacity, training, funding and output in LMICs should be a priority on both local and global levels.
- Local research should be facilitated with international funding and capacity-building partnerships, and driven by local priorities.
- In addition to further defining the problem, global surgery research focus should also extend to identification of solutions, particularly in the areas of cost and financing, quality, safety, care delivery innovations, and disease determinants.
- Funders, editors, and ethical committees should consider a list of core questions, such as those identified by the Commission, when reviewing global surgery research projects.

National surgical plan

Start here.

The development of resilient surgical systems will need commitment and engagement from various stakeholders at the national and international levels, and from public, private, and charitable sectors. A national strategic plan that specifically addresses surgery is essential for the proper planning of care delivery, education, and research. This plan should be country and context specific, developed and owned by all stakeholders, and rest within a broader strategy of improvement of national health systems.

Here we present a framework for a national surgical plan that addresses five major domains of surgical systems development: infrastructure, workforce, service delivery, information management, and financing. Each domain consists of several components, selected to be representative but not exhaustive elements for systems development within that domain. Accompanying these components are the Commission's relevant recommendations and a proposed system of assessment and evaluation of progress.

Not all aspects of these assessments will be directly relevant to all contexts, and not all aspects of the assessments suggested in this framework will be readily collectible at the outset. Nonetheless, improvement in access to care starts with an acknowledgment of the unknown followed by implementation of a plan to fill those gaps in knowledge.

Surgical systems, despite their differences, share striking similarities across context depending on resource level. The burden of disease varies, however, as do the capabilities of the present system. This suggested framework, then, is meant to serve as a flexible template upon which to build a context-appropriate, comprehensive plan with time-bound targets (table 7).

Conclusions

Surgical and anaesthesia care must become an integral component of health care and health systems in LMICs to realise our vision of universal access to safe, affordable surgical and anaesthesia care when needed. At present, gross global inequity exists in the burden of surgical conditions and in access to surgical and anaesthesia care between high-income countries and LMICs. Surgery has long been overlooked as a health need for the world's poorest people. As a result, untreated surgical conditions have exerted substantial but largely unrecognised negative effects on human health, welfare, and economic development. In this Report, we have shown that the magnitude of human suffering from surgical conditions is large: each year up to 140 million people need surgical procedures to save their lives or to prevent long-term disability, but do not get them. More than 30 million more people are impoverished in the process of seeking surgical and anaesthesia care because of OOP health costs and greater than 70% of the world's population does not have access to timely, safe, and affordable surgical and anaesthesia care should they need it. The economic and development effects are also substantial: up to 2% of potential annual economic growth is lost in LMICs as a result of surgical conditions. Although the present situation in many LMICs is deeply problematic, this Commission has shown that many opportunities exist for substantial, tangible improvements to occur in the next 15 years and beyond.

2015 is a pivotal year for global health, and can be one for global surgery too. New opportunities exist to address health-care inequity and to reset the global health agenda to meet present and new health challenges. These include global commitments to achievement of UHC, greater strategic investments in health, and the launch of a new set of SDGs, which aim to end poverty, promote sustainable economic growth, and ensure health for all at all ages by tackling infectious diseases, non-communicable diseases, and injuries. The full realisation of these promises will only be possible by strengthening of health services and health systems, including strengthening of the delivery of safe, affordable, and timely surgical care.

In 2015, we urge local, national, and global health stakeholders to commit to the provision of better global surgical and anaesthesia care. Not as an additional or competing health and development goal, but as a crucial component of many existing ones. Better global surgical and anaesthesia care will only be realised through increased investment in human and physical resources for surgery and anaesthesia, accompanied by a focus on safety, quality, and efficiency. Our cost estimates for scaling up surgical and anaesthesia care in LMICs are low compared with the economic and human welfare returns imparted through widespread provision of basic surgical services. Early and urgent domestic and external investment in surgical and anaesthesia care is needed to realise these returns. Prompt action is especially important in view of the rising burden of cancer and injuries in LMICs, which need surgical and anaesthesia care in most cases and

	Recommendations	Assessment methods
Infrastructure		
Surgical facilities; facility readiness; blood supply; access and referral systems	• Track number and distribution of surgical facilities • Negotiate centralised framework purchase agreements with decentralised ordering • Equip first-level surgical facilities to be able to do laparotomy, caesarean delivery, and treatment of open fracture (the Bellwether Procedures) • Develop national blood plan • Reduce barriers to access through enhanced connectivity across entire care delivery chain from community to tertiary care • Establish referral systems with community integration, transfer criteria, referral logistics, and protection for first responders and helpful members of the public	• Proportion of population with 2 h access to first-level facility • WHO Hospital Assessment Tool (eg, assessment of structure, electricity, water, oxygen, surgical equipment and supplies, computers and internet) • Proportion of hospitals fulfilling safe surgery criteria • Blood bank distribution, donation rate
Workforce		
Surgical, anaesthetic, and obstetric providers; allied health providers (nursing, operational managers, biomedical engineers, and radiology, pathology, and laboratory technician officers)	• Establish training and education strategy based on population and needs of country • Require rural component of surgical and anaesthetic training programmes • Develop a context-appropriate licensing and credentialling requirement for all surgical workforce • Training and education strategy of ancillary staff based on population and needs of country • Invest in professional health-care manager training • Establish biomedical equipment training programme	• Density and distribution of specialist surgical, anaesthetic, and obstetric providers • Number of surgical, anaesthetic, and obstetric graduates and retirees • Proportion of surgical workforce training programmes accredited • Presence of task sharing or nursing accredited programmes and number of providers • Presence of attraction and retention strategies • Density and distribution of nurses, and ancillary staff including operational managers, biomedical engineers, and radiology, pathology, and laboratory technicians
Service delivery		
Surgical volume; system coordination; quality and safety	• All first-level hospitals should provide laparotomy, caesarean delivery, and open-fracture treatment (Bellwether Procedures) • Integrate public and private NGO providers into common national delivery framework; promote demand-driven partnerships with NGOs to build surgical capacity • Prioritise health-care management training • Prioritise quality improvement processes and outcomes monitoring • Promote telemedicine to build system-wide connectivity • Promote system-wide connectivity for telemedicine applications, clinical support, and education	• Proportion of surgical facilities offering the Bellwether Procedures • Number of surgical procedures done per year • Surgical and anaesthetic related morbidity and mortality (perioperative) • Availability of system-wide communication
Financing		
Health financing and accounting; budget allocation	• Cover basic surgical packages within universal health coverage • Risk pool with a single pool; minimise user fees at the point of care • Track financial flows for surgery through national health accounts • Use value-based purchasing with risk-pooled funds	• Surgical expenditure as a proportion of gross domestic product • Surgical expenditure as a proportion of total national health-care budget • Out-of-pocket expenditures on surgery • Catastrophic and impoverishing expenditures on surgery
Information management		
Information systems; research agenda	• Develop robust information systems to monitor clinical processes, cost, outcomes, and identify deficits • Identify, regulate, and fund surgical research priorities of local relevance	• Presence of data systems that promote monitoring and accountability related to surgical and anaesthesia care • Proportion of hospital facilities with high-speed internet connections

These components addressing surgical care should be incorporated within a broader strategy of improvement of national health systems. NGO=non-governmental organisation.

Table 7: **National surgical plan components and framework**

when untreated are projected to profoundly affect national productivity and welfare.

Alongside scaling up of surgical and anaesthesia care, a further major conclusion is the pressing need for financial risk protection against the costs of surgery for individuals in LMICs. Financial protection is needed to prevent medical impoverishment and to improve access to surgical and anaesthesia care, especially for people with a low income. Essential surgical procedures, packages, and platforms aimed at saving lives and preventing major disability should be included within country-level and international UHC policies, which the Commission believes should be pro-poor and financed through public risk pooling.

Finally, research, monitoring, and assessment play a crucial part in the future of global surgical and anaesthesia care. Inattention to the suffering imposed by surgical conditions, a paucity of scientific rigor around implementation science, and a complete absence of globally accepted surgical metrics are factors that have all contributed to the neglect of surgical and anaesthesia care within global health during the past two decades. A commitment to better understand the problems and solutions should be a priority goal for those dedicated to improvement of surgical and anaesthesia care worldwide.

During the course of this Commission, thousands of contributors from more than 110 different countries across six continents came together in support of global surgery. All contributors have emphasised the global need for better surgical and anaesthesia care, as experienced from within their own communities and the symbiotic association between surgical and anaesthesia care and health systems. Although efforts to improve surgery and anaesthesia in LMICs should be grounded in the reality of those on the frontline and driven by local need, the causes of inadequate and inequitable surgical and anaesthesia care are clearly both a worldwide concern and a worldwide responsibility. Realisation of the vision of this Commission will require further harnessing of this powerful global network. Coordinated and sustained efforts that are solution-orientated are needed at all levels, to generate political priority, mobilise resources, and assure action and meaningful improvements. Using *The Lancet* as an independent forum and mechanism, this Commission will continue to measure progress in global surgical and anaesthesia care and demand accountability at a national and international level for surgical capacity and outcomes in LMICs. We will do so supported by a growing global network and movement committed to better surgical and anaesthesia care for all.

End here.

Contributors
All commissioners and authors contributed to the key messages, conclusions, recommendations, writing, and editing of the Commission. Substantial contributions to the research and data gathering were done by a core research team listed in the acknowledgments section of the appendix. Additional research support, counsel, and advice were supplied by several important individuals and organisations also listed in the appendix (p 176). All research was done under the leadership of the Commission cochairs (JGM, AJML, and LH) and the Working Group Leads (NR, EAA, GLY, and RLG; appendix p 176) with assistance from NPR, JNR, AD, and SLMG respectively.

Declaration of interests
LH reports grants from the Swedish Society for Medical Research and the Swedish Society of Medicine. JD is an editor at the *Lancet* journals. MGS reports personal fees from Ethicon. AG, TGW, and IHW serve on the board of Lifebox. SB is in the process of submitting the required information to the technology transfer office at the University of California, San Diego with regard to patenting a method for estimating the need for surgical care in a population. ER was the founder and President of Cinterandes Foundation. All other authors declare no competing interests.

Acknowledgments
We dedicate this report to Edgar Rodas, who was a commissioner, colleague, and friend. Edgar sadly died on March 2, 2015. The work in this report was enhanced by the generous financial or in-kind support that we received from the following organisations: Association of Anaesthetists of Great Britain and Ireland, Babson College, Bill & Melinda Gates Foundation, Boston Children's Hospital, Dubai Harvard Foundation for Medical Research, FAPESP Fundacao de Amparo a Pesquisa de Sao Paolo, Harvard Business School, Harvard Medical School Center for Global Health Delivery-Dubai, Harvard Medical School Department of Global Health and Social Medicine, Indian Institute of Management Bangalore, King's College London, Lund University, Melbourne Business School, National Cancer Institute, Operation Smile, Pershing Square, Steven C. and Carmella R. Kletjian Foundation, Inc., Royal College of Surgeons in Ireland, The Royal College of Surgeons of Edinburgh, The Rockefeller Foundation, and University of Virgina Darden School of Business. We are grateful to the hundreds of people who contributed to this report. Contributors are listed in the appendix.

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