Timing and cost of scaling up surgical services in low-income and middle-income countries from 2012 to 2030: a modelling study

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Summary

Background Given the large burden of surgical conditions and the crosscutting nature of surgery, scale-up of basic surgical services is crucial to health-system strengthening. The *Lancet* Commission on Global Surgery proposed that, to meet populations' needs, countries should achieve 5000 major operations per 100 000 population per year. We modelled the possible scale-up of surgical services in 88 low-income and middle-income countries with a population greater than 1 million from 2012 to 2030 at various rates and quantified the associated costs.

Methods Major surgery includes any intervention within an operating room involving tissue manipulation and anaesthesia. We used estimates for the number of major operations achieved per country annually and the number of operating rooms per region, and data from Mongolia and Mexico for trends in the number of operations. Unit costs included a cost per operation, proxied by caesarean section cost estimates; hospital construction data were used to estimate cost per operating room construction. We determined the year by which each country would achieve the Commission's target. We modelled three scenarios for the scale-up rate: actual rates (5·1% per year) and two "aspirational" rates, the rates achieved by Mongolia (8·9% annual) and Mexico (22·5% annual). We subsequently estimated the associated costs.

Findings About half of the 88 countries would achieve the target by 2030 at actual rates of improvements, with up to two-thirds if the rate were increased to Mongolian rates. We estimate the total costs of achieving scale-up at US$300–420 billion (95% UI 190–600 billion) over 2012–30, which represents 4–8% of total annual health expenditures among low-income and lower middle-income countries and 1% among upper middle-income countries.

Interpretation Scale-up of surgical services will not reach the target of 5000 operations per 100 000 by 2030 in about half of low-income and middle-income countries without increased funding, which countries and the international community must seek to achieve expansion of quality surgical services.

Funding None.

Introduction

At least 5% of the Global Burden of Disease[1] in low-income and middle-income countries is estimated to be potentially avertable by scaling up a basic surgical package.[2,3] A large proportion of this substantial burden of surgical disorders is due to an extreme scarcity of, and unequal distribution in, surgical services and operating theatres.[4,5] The Disease Control Priorities in Developing Countries, second edition (DCP2), showed the key role that surgical platforms and hospitals could play in the highly resource-constrained settings of sub-Saharan Africa and south Asia.[6] The DCP2 referred to four types of surgically significant interventions: competent, initial surgical care to injury victims; handling of obstetrical complications; timely and competent surgical management of various abdominal and extra-abdominal emergent and life threatening conditions; and elective care of simple surgical conditions such as hernias, clubfoot, cataract, hydroceles, and otitis.[6] In particular, it pointed to the high cost-effectiveness of surgical interventions, further confirmed recently by economic evaluation reviews.[7–9]

Given the large size of the burden of surgical conditions and the demonstrated cost-effectiveness of surgical interventions, scale-up of basic surgical services in low-income and middle-income countries is an essential component of health system development and the movement toward universal health coverage (UHC).[10,11] The *Lancet* Commission on Global Surgery[12] proposes that, for surgical services to meet the needs of populations, countries should aim for a surgical rate of 5000 major surgical operations per 100 000 population. This number derives from estimates that assess the relation between surgical rates and life expectancy, as well as estimates of needed capacity to meet disease burden.[13] Major surgery is defined as any intervention occurring in a hospital operating theatre involving incision, excision, manipulation, or suturing of tissue, usually requiring anaesthesia or sedation.[4] Expanding surgical services is also a key strategy for achieving broader development goals, especially poverty reduction, improving child and maternal survival, controlling HIV/AIDS,[14] and reducing complications from injuries.[15] For example, cataract surgery can help alleviate household poverty by allowing patients to return to work;[16] emergency trauma care and obstetric surgery have a crucial role to play in reducing child and maternal deaths;[17,18] adult male circumcision significantly reduces the risk of heterosexual transmission of HIV;[19] and skilled treatment of injury victims could help reduce the substantial burden of road traffic injuries in low-income and middle-income countries.[15]

Furthermore, the need to measure progress in health, as in assessing whether countries are on track to achieve the Millennium Development Goals (MDGs), will be essential in determining whether countries can achieve the next set of post-2015 Sustainable Development Goals (SDGs), which have a 2030 target date.[20] Studying historical rates of change of mortality and intervention coverage across countries over recent decades[21,22] can be helpful in testing the feasibility of future health targets, such as those proposed for the SDGs.[23–25] Many of these proposals include highly ambitious targets that would require high rates of change. For example, child and maternal mortality would need to decline in all low-income and middle-income countries at rates observed among "best performer" countries of about 6–7% per year (best performers are those that have achieved the fastest historical declines in mortality).[22] Such targets can be "reality tested" by examining whether such high rates have actually been achieved in the past by any low-income and middle-income country. Efforts to reduce surgery-related mortality and morbidity have been undertaken by the WHO,[26] and measurement of surgical capacity in a standardised fashion is a key component to ensure progress in improving safety of surgery. In this context, and given the value of testing the feasibility of proposed post-2015 health goals related to non-communicable diseases and UHC, we aimed to model what volume of surgical services could potentially be achieved in low-income and middle-income countries by the year 2030, at various rates of scale-up, and to estimate the associated costs.

Methods

Data

We used levels of surgical volume (number of major surgical procedures conducted per 100 000 population in a given country per year) from 51 countries with a population greater than 1 million[27] on the basis of estimates for major operations as given by Weiser and colleagues.[4] We also used trends in surgical volume limited, due to lack of data, to two specific countries: Mongolia with a time series on laparoscopic surgery and total number of cholecystectomy cases realised over 2000–09,[28] and Mexico with a time series for the total number of major operations realised over 2011–13 (obtained from Ministry of Health, Mexico[29]). We also sourced data on distribution of functional operating rooms per population by world region.[5] As in Weiser and colleagues,[4] we considered major surgery to be any intervention occurring in a hospital operating room involving incision, excision, manipulation, or suturing of tissue, and that usually requires anaesthesia or sedation to control pain.

We used a gross national income (GNI) per capita time series as given by the World Bank[30] for low-income and middle-income countries with a population greater than 1 million.[27] As classified by the World Bank, low-income and middle-income countries include the following three income country groupings, based on GNI per capita: low-income countries (LICs), lower middle-income countries (LMICs), and upper middle-income countries (UMICs). As a result, a total of 103 low-income and middle-income countries with a population greater than 1 million were retained and modelled (appendix).

See Online for appendix

We drew cost estimates for surgical delivery as well as infrastructural building and development from a range of sources. For the cost per major operation, we used, as a proxy, the unit cost for caesarean section as provided for a range of countries by Gibbons and colleagues.[31] Such unit costs capture the recurrent costs of running a surgical service including human resources time (salaries), utilities, equipment, and medicines for the procedure itself, along with the preoperative and postoperative hospitalisation. For the construction cost per functional operating room, we relied on several different sources to determine mean cost of construction per hospital bed (Jim Ansara, Derek Johnson, Archie Ayeh, Edgar Rodas, personal communication).[32–41] We then used data on the cost of construction of a modern operating room in a low-income and middle-income country (Jim Ansara, personal communication), which included outfitting with all the necessary equipment, to estimate a scaling factor such that the cost per hospital bed could be used to estimate the cost of construction of an operating room for each income grouping (further detail is given in the appendix). Estimating the operating room construction cost using the cost per hospital bed is suboptimal, yet there are very few estimates of the construction cost of hospitals in low-income and middle-income countries, and no estimates for the construction cost of operating rooms in the literature. Because we had more data regarding the cost of hospital construction, we relied on the admittedly strong assumption that the labour and capital required to construct a standard district hospital per bed is related to the labour and capital required to construct a standard operating room. We then assumed that costs would follow a similar relation, and used the cost per hospital bed as the basis for estimating the cost per operating room construction. All costs were subsequently adjusted to 2012 US$ using country consumer price index.[30] The unit costs per surgical procedure and per operating room are given in table 1.

	Low-income countries	Lower middle-income countries	Upper middle-income countries
Mean (SD) unit cost per surgical procedure (2012 US$)	179 (31)	219 (45)	332 (130)
Mean (SD) construction cost per operating room (2012 US$)	319 002 (94 276)	412 488 (235 271)	1 906 064 (857 638)

Consistently with Gibbons and colleagues,[31] the unit cost per surgical procedure includes human resources time (salaries), utilities, equipment, and medicines for the procedure itself, along with the preoperative and postoperative hospitalisation.

Table 1: **Cost inputs for analysis of scale-up of surgical services in 88 low-income and middle-income countries, 2012–30**

Modelling of the scale-up

Using surgical volume data and GNI per capita time series, we estimated what level of surgical volume countries would be expected to achieve by 2030, given their income. We estimated the relation between surgical volume (per 100 000 population) in country C (S_C) and country GNI per capita (in 2002 US$) ($Inc_C$):

$$\ln(S_C) = \beta_0 + \beta_1 \ln(Inc_C) + \varepsilon \quad (1)$$

Then, using (1), we estimated country surgical volume in 2012 by imputing country GNI per capita in 2012.[30] Subsequently, using average growth rates (γ) over 2002–12, we derived "actual" (current) surgical growth rates (R_S) among the three income groupings, as given by $R_S = \beta_1 * \gamma$, to estimate the level of surgical volume achieved at current coverage in 2030 by each country. A log-linear model was retained for simplicity and because it presented a sufficiently high goodness of fit (R^2=0·84). Log-linear models are power laws that represent a good, flexible specification for growth models of complex systems, and are general approximating functions for a wide range of complex behaviours.[42]

We also did additional projections using alternative, highly aspirational surgical growth rates based on an 8·9% increase in cholecystectomies per year in Mongolia from 1900 per 100 000 in 2000 to 4250 per 100 000 in 2009,[28] and a 22·5% per year increase in Mexico (based on data from Ministry of Health).

The scale-up of surgical services must be accompanied by the development and construction of functional operating rooms. Hence, we estimated the number of new operating rooms that would need to be constructed through the scale-up. For this purpose, using surgical volume estimates[4] and the number of functional operating rooms per 100 000 population per region,[5] we estimated the relation between surgical volume and the number of operating rooms (OR_C) in a given country:

$$\ln(OR_C) = \alpha_0 + \alpha_1 \ln(S_C) + \varepsilon \quad (2)$$

The log-linear form was retained for simplicity and consistency with model (1); it was preferred over the linear model as its goodness of fit was substantially larger (R^2=0·71 against R^2=0·33 only for the linear model). Using (2), we derived the number of functional operating rooms needed per country by 2030 depending on whether actual or aspirational rates of improvements for surgical volume were assumed.

For each country C, we then estimated the year by which the target T (5000 surgical operations per 100 000 population per year) would be achieved, depending on country actual and aspirational rates of scale-up (as defined above). The year by which country C would have achieved T (ie, Y_C) was calculated as

$$Y_C = \frac{1}{R_S} \ln\left(\frac{T}{I_C}\right)$$

where I_C is the level of surgical volume in country C in 2012 and R_S is either actual or aspirational rate. In what follows, we estimated Y_C for the target of 5000 per 100 000.[12]

Costs

Based on the number of functional operating rooms to be built between 2012 and 2030 per country, and the annual increase of surgical cases from 2012 to 2030, we estimated the total costs of surgical scale-up per country, in the following:

$$TC_C = N_{OR} * C_{OR_C} + C_{S_C}\left[\sum_{k=1}^{18} S_C(t_0+k) - S_C(t_0)\right]$$

with $S_C(t_0+k) = Min(T, S_C(t_0)e^{R_S k})$ and where k discretely counts the 18 years included from 2012 through 2030. C_{OR_C} is the unit cost per operating room construction, C_{S_C} is the unit cost per surgical procedure as given per income grouping (table 1), and N_{OR} is the number of operating rooms to be built. T is the target (5000 surgical operations per 100 000) and t_0 is the starting date (2012). Consistently with Gibbons and colleagues,[31] C_{S_C} includes human resources time (salaries), utilities, equipment, and medicines. We then compared these total scale-up costs with the total annual health expenditures[30] at the income grouping level. National health accounts do not provide publicly available information on the breakdown of these annual health expenditures into programmatic costs versus health systems or infrastructure costs, but in low-income countries most of these expenditures are likely to be on health systems or infrastructure. For example, the Taskforce on Innovative International Financing for Health Systems estimated the costs of scaling up health interventions across low-income countries from 2009 to 2015 to be 60–70% constituted from health systems or infrastructure.[43]

Uncertainty analysis

We assessed the robustness of our findings using probabilistic sensitivity analysis. For this purpose, for each scenario (actual rates of scale-up, Mongolian rates, Mexican rates) and each grouping (LIC, LMIC, UMIC), we did Monte Carlo simulations (n=100 000 trials) capturing both parameter uncertainty in the cost inputs (table 1) and estimation uncertainty in the log-linear models (1) and (2). Parameter uncertainty was included through sampling n values for each cost parameter (unit cost per surgical procedure, construction cost per operating room) to which was assigned a gamma distribution built on each cost input's mean and SD[44] (table 1). Estimation uncertainty was included through sampling n values for each pair of coefficients (β_0, β_1) and (α_0, α_1) extracted each from a multivariate Gaussian distribution using mean and variance-covariance matrices from the fitted models (1) and (2). Both parameter uncertainty and estimation uncertainty were varied simultaneously, resulting in n samples for each country for the cost of surgical procedures, cost of operating rooms, and total cost. Through aggregation by summing country results within each grouping, we again obtained n samples for the costs. Finally, extracting the 2·5 and 97·5 percentiles allowed the determination of 95% uncertainty intervals (UIs) (prediction intervals).

Caesarean section unit cost was chosen as a proxy for surgical procedure unit cost as this was the only surgical procedure with robust cost information on a global scale.[31] Given this limitation, we did a sensitivity analysis on the unit cost per procedure. We also did a sensitivity analysis where costs for medical education and training for the needed health workforce were included.

All analyses were conducted with R statistical software.

For **R statistical software** see http://www.r-project.org

Role of the funding source

The funding source had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. All authors had full access to all data in the study. SV had final responsibility to submit for publication.

Results

The estimation of (1) (appendix p 4) means that a 10·0% increase in GNI per capita leads to a 7·6% increase in surgical volume. Income growth rates from 2002 to 2012 for the three country groupings were respectively: 6·6% per year for LICs, 7·0% per year for LMICs, and 6·7% per year for UMICs, with an average of 6·8% per year. This increase in income led to surgical volume growth rate of 5·0% per year for LICs, 5·3% per year for LMICs, and 5·1% per year for UMICs, with an average of 5·1% per year. Given the small variation in surgical volume growth rates between country groupings, we decided to use the average of 5·1% per year in our actual (current) projections.

Using our actual scale-up model (1), 15 of the original 103 countries were predicted to have achieved 5000 surgical procedures per 100 000 by 2012: Botswana, Brazil, Costa Rica, Gabon, Hungary, Kazakhstan, Lebanon, Mexico, Mauritius, Malaysia, Panama, Romania,

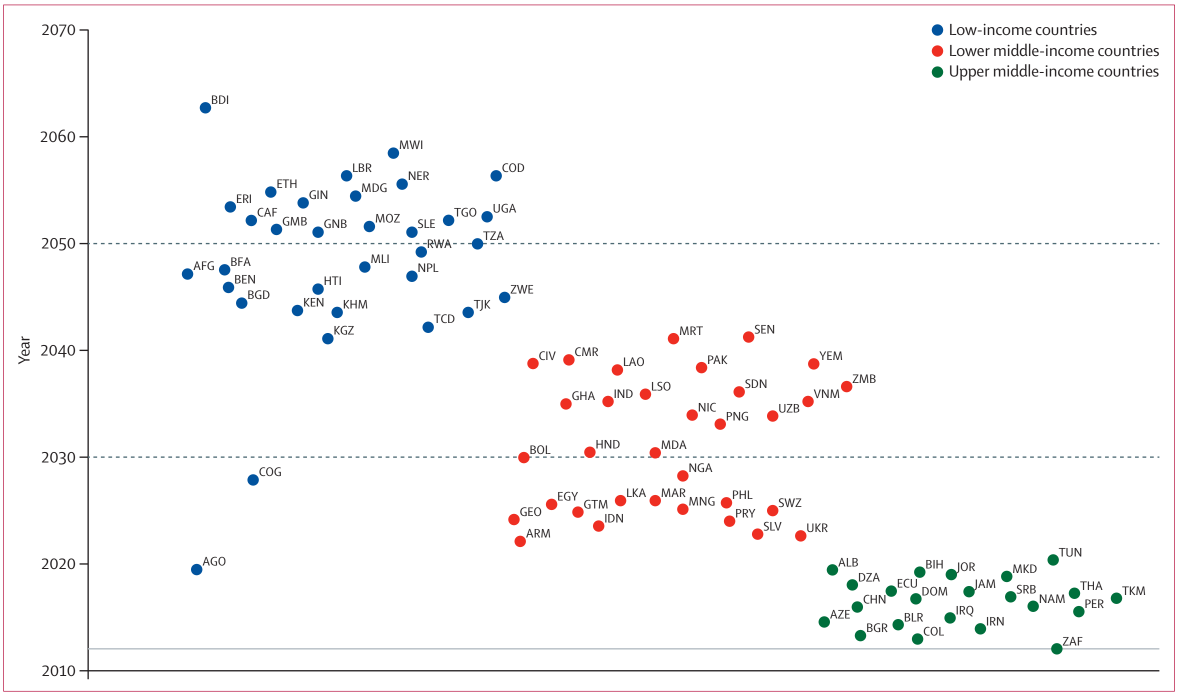

***Figure 1:* Year by which target of 5000 surgical procedures per 100 000 population per year is achieved by 88 low-income and middle-income countries with actual rates of scale-up (5·1% per year)**

X-axis is simply used to display countries by income groupings: low-income countries, lower middle-income countries, and upper middle-income countries. For country abbreviations see appendix.

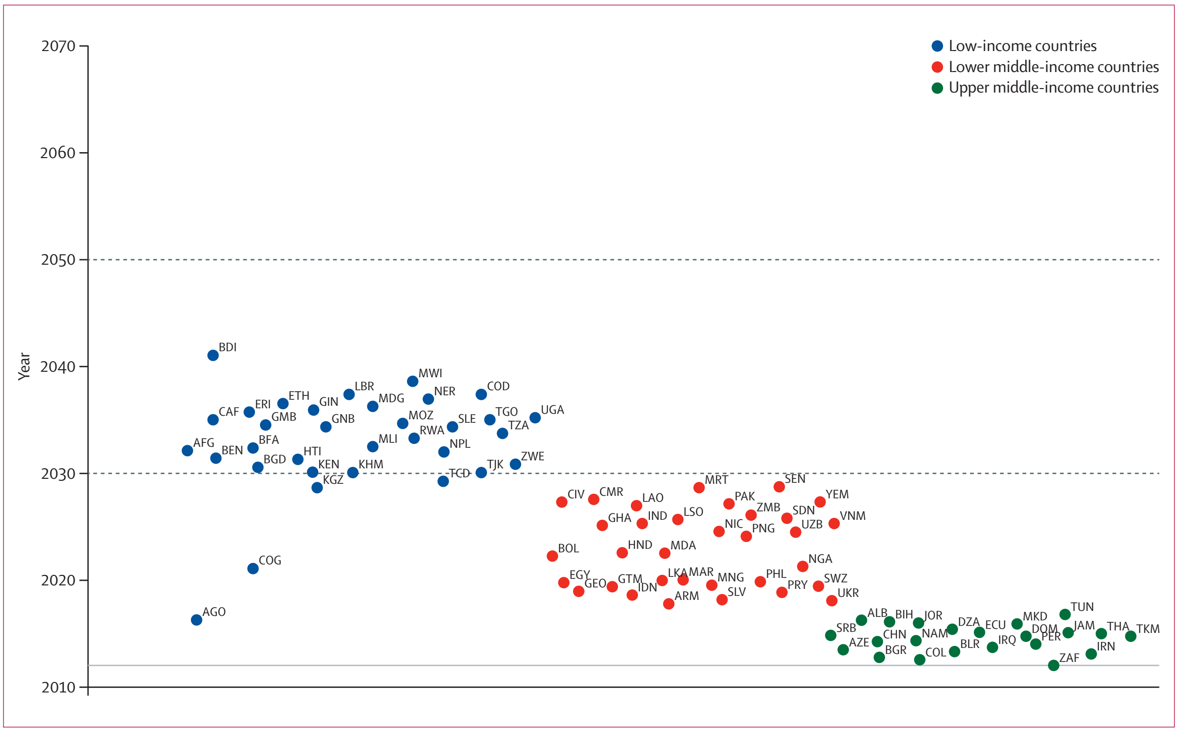

***Figure 2*: Year by which target of 5000 surgical procedures per 100 000 population per year is achieved by 88 low-income and middle-income countries with Mongolian rates of scale-up (8·9% per year)**
X-axis is simply used to display countries by income groupings: low-income countries, lower middle-income countries, and upper middle-income countries. For country abbreviations see appendix.

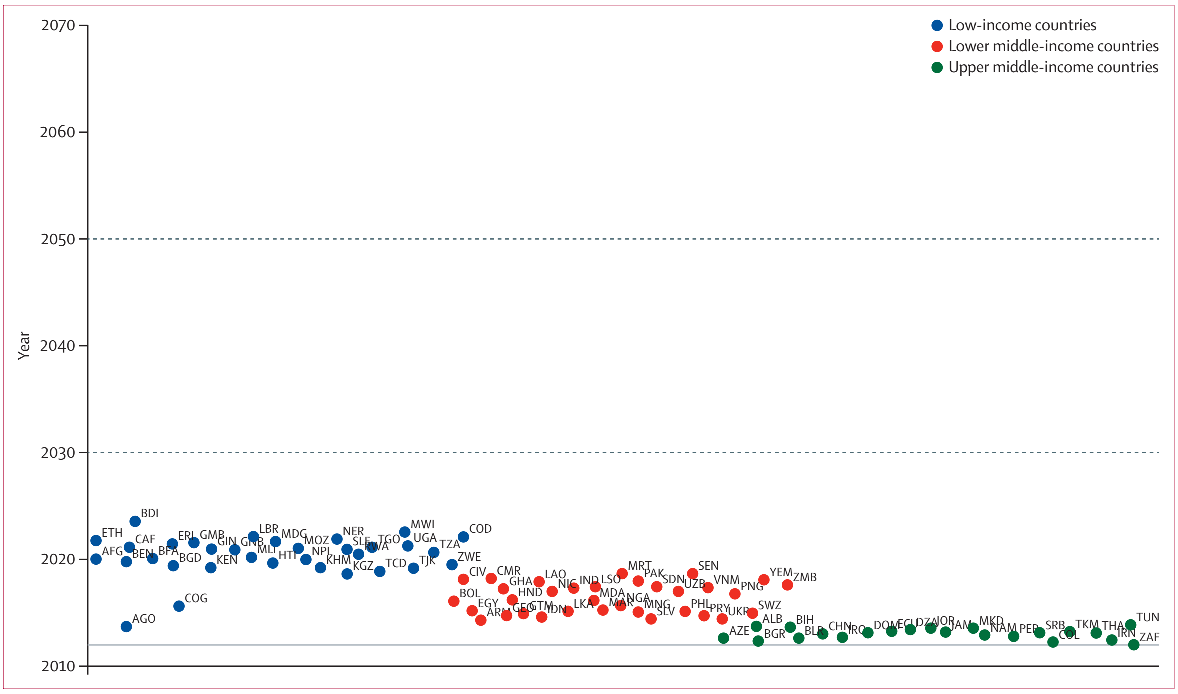

***Figure 3*: Year by which target of 5000 surgical procedures per 100 000 population per year is achieved by by 88 low-income and middle-income countries with Mexican rates of scale-up (22·5% per year)**
X-axis is simply used to display countries by income groupings: low-income countries, lower middle-income countries, and upper middle-income countries. For country abbreviations see appendix.

Suriname, Turkey, and Venezuela. These results are consistent with recent 2012 estimates on expected number of surgical operations for WHO member countries (Thomas Weiser, personal communication). These 15 countries were subsequently removed from our analysis; we therefore focused on the 88 countries that did not meet target rates of surgery. For these remaining 88 countries, the mean estimated surgical volume in 2012 was 2060 cases per 100 000 and varied from 370 per 100 000 in Burundi to 4980 per 100 000 in South Africa. In 2030, with actual rates of scale-up, this estimated average would be 5190 cases per 100 000, with a variation from 940 per 100 000 in Burundi up to 12 530 per 100 000 in South Africa (appendix p 6).

Using our operating theatre scale-up model (2) (appendix p 7), among the 88 countries, the estimated number of operating rooms in 2012 was on average 5·5 per 100 000 population and varied from 2·0 per 100 000 in Burundi to 10·1 per 100 000 in South Africa. In 2030, this estimated average would be of 9·8 operating rooms per 100 000, with a variation from 3·6 per 100 000 in Burundi up to 17·9 per 100 000 in South Africa (appendix p 9).

With a target of 5000 surgical operations per 100 000 population, with actual rates of scale-up, 39 of 88 countries would have achieved the target by 2030, an additional 33 would achieve this target between 2030 and 2050, and another 16 after 2050 (figure 1). At an 8·9% annual rate of scale-up as seen in Mongolia, 59 countries would achieve the target by 2030, and the remaining 29 between 2030 and 2050 (figure 2). Using a 22·5% annual increase as seen in Mexico, all 88 countries would achieve the target by 2030 (figure 3).

We estimated the total costs of increasing surgical capacity for each of the three income groupings based on the three scenarios: actual (current), Mongolian, and Mexican rates of scale-up (table 2). With actual rates of increase (5·1% per year), the total costs are $298 billion (95% UI 186–436) for the 88 low-income and middle-income countries evaluated; with Mongolian rates (8·9% per year), the total costs are $422 billion (274–602); and with Mexican rates (22·5% per year), the total costs are $552 billion dollars (370–771).

Among each of the three income groupings, using actual rates of scale-up, the total costs amounted to an annual $1·1 billion (95% UI 0·8–1·5) for 33 LICs (4% of their total annual health expenditures of $30 billion), an annual $8·4 billion (5·3–12·5) for 33 LMICs (4% of their total annual health expenditures of $218 billion), and an annual $7·0 billion (1·2–14·6) for 22 UMICs (1% of their total annual health expenditures of 664 billion dollars). With Mongolian rates, the total costs amounted to an annual $2·4 billion (1·7–3·4) for the LICs (8% of total annual health expenditures), an annual $13·7 billion (8·9–19·7) for the LMICs (6% of total annual health expenditures), and an annual $7·3 billion (1·2–15·6) for the UMICs (1% of total annual health expenditures).

	Low-income countries	Lower middle-income countries	Upper middle-income countries
Actual rates of scale-up (5·1% per year)			
Cost of surgical procedures	14 (9–19)	115 (71–169)	86 (13–191)
Cost of operating rooms	6 (3–10)	37 (7–90)	40 (5–105)
Total cost	20 (14–27)	152 (95–224)	126 (21–262)
Mongolian rates of scale-up (8·9% per year)			
Cost of surgical procedures	31 (20–45)	197 (125–283)	91 (13–209)
Cost of operating rooms	13 (6–23)	50 (10–123)	40 (5–105)
Total cost	44 (30–61)	247 (159–354)	131 (21–280)
Mexican rates of scale-up (22·5% per year)			
Cost of surgical procedures	76 (52–104)	274 (173–396)	95 (13–223)
Cost of operating rooms	17 (8–30)	50 (10–123)	40 (5–105)
Total cost	93 (67–124)	324 (210–462)	135 (21–294)

Note: consistently with Gibbons and colleagues,[31] the cost of surgical procedures includes human resources time (salaries), utilities, equipment, and medicines for the procedure itself, along with the preoperative and postoperative hospitalisation. 95% uncertainty intervals are given in parentheses.

Table 2: **Total costs (billions of 2012 US$) of scaling up surgical services from 2012 to 2030 with: actual (current), Mongolian, or Mexican rates of scale-up**

	Low-income countries	Lower middle-income countries	Upper middle-income countries
Actual rates of scale-up (5·1% per year)			
Cost of surgical procedures	7 to 21	57 to 172	43 to 129
Cost of operating rooms	6	37	40
Total cost	13 to 27	94 to 209	83 to 169
Mongolian rates of scale-up (8·9% per year)			
Cost of surgical procedures	15 to 46	100 to 296	45 to 136
Cost of operating rooms	13	50	40
Total cost	28 to 59	150 to 346	85 to 176
Mexican rates of scale-up (22·5% per year)			
Cost of surgical procedures	38 to 114	137 to 411	47 to 142
Cost of operating rooms	17	50	40
Total cost	53 to 131	187 to 461	87 to 182

Total costs (billions of 2012 US$) of scaling-up surgical services from 2012 to 2030 with: actual (current), Mongolian, or Mexican rates of scale-up; where unit cost per surgical procedure was varied per ±50%.

Table 3: **Sensitivity analysis for the unit cost per surgical procedure**

With Mexican rates of scale-up, the total costs amounted to an annual $5·2 billion (3·7–6·9) for the LICs (17% of total annual health expenditures), an annual $18·0 billion (11·7–25·7) for the LMICs (8% of total annual health expenditures), and an annual $7·5 billion (1·2–16·3) for the UMICs (1% of total annual health expenditures).

Finally, the costs of surgical procedures accounted for a large proportion of the total costs (table 2), and as such changes in the unit cost per procedure substantially affected our findings (table 3). If caesarean section unit cost, the best available estimated proxy for surgical procedure unit cost globally,[31] underestimates or overestimates the actual cost per procedure, total scale-up costs could be significantly altered. Likewise, costs could

	Low-income countries	Lower middle-income countries	Upper middle-income countries
Medical education costs (billions of 2012 US$)	1·7–3·4	5·0–10·0	3·0–6·1
Share of total cost, actual rates of scale-up (%)	8·5–17·0	3·3–6·6	2·4–4·8
Share of total cost, Mongolian rates of scale-up (%)	3·9–7·8	2·0–4·0	2·3–4·6
Share of total cost, Mexican rates of scale-up (%)	1·8–3·6	1·5–3·0	2·2–4·4

Based on inputs from Kruk and colleagues[46] and Holmer and colleagues,[45] where cost per surgical personnel education is varied from $75 000 to $150 000.

Table 4: **Estimation of medical education costs for surgeons, anaesthesiologists, and obstetricians, and shares those costs represent with respect to the total cost estimated for three different scenarios: actual rates of scale-up (5·1% per year), Mongolian rates of scale-up (8·9% per year), and Mexican rates of scale-up (22·5% per year)**

be altered substantially with the inclusion of additional medical education or training costs for the surgical workforce needs (table 4).[45,46]

Discussion

Using a scale-up target of 5000 surgical procedures per 100 000 population per year, we estimate that about half of low-income and middle-income countries in our study would achieve such levels of surgical delivery by 2030 based on actual (current) rates of scale-up (5·1% per year). At Mongolian rates of improvements (8·9% per year), two-thirds of countries would achieve the target, while at Mexican rates (22·5% per year), all countries will attain at least 5000 operations per 100 000 by 2030. It is very unlikely that all 88 countries could emulate Mexican rates of scale-up; these are too ambitious to have as a baseline to set future targets. However, with actual rates (5·1% per year) or aspirational Mongolian rates (8·9% per year), a large number (half to two-thirds) of countries would still achieve the target by 2030. In fact, actual and Mongolian rates are comparable in magnitude with best performer countries' rates of improvements for under-5 and maternal mortality in low-income and middle-income countries in recent years, where best performer countries' rates of mortality decline of 7·1% per year and 6·3% per year, respectively, were observed.[22] However, such large decreases in under-5 and maternal mortality were only made possible by significant international community attention on maternal and child health issues, particularly enhanced with the momentum of the MDGs. There is empirical evidence showing that the adoption of the MDGs in the year 2000 was associated with a rise in financing for the three health-related goals (child health; maternal health; and HIV, tuberculosis, and malaria) and that the rise in financing led to substantial progress.[47,48] Annual financing for global health almost tripled over 2000–11, from about $10 billion to almost $28 billion, dominated by the rise in funding for the three health-related MDGs.[48] Therefore, to achieve similarly ambitious surgical targets, a comparable mobilisation of attention and funding targeted at surgery and health system strengthening will be needed. To date, surgery has not been prioritised on the global health agenda; indeed, Farmer and Kim have argued that "surgery may be thought of as the neglected stepchild of global public health."[49]

Our study found that the total (cumulative) cost of scaling up surgical services over 2012–30 would be substantial: $298 billion for actual rates of scale-up, $422 billion for Mongolian rates, and $552 billion dollars for Mexican rates. However, the annual average costs over the 18-year period—ranging from about $16 billion per year (with actual rates) to $31 billion per year (with Mexican rates)—compare very favourably with estimates of the costs of scaling up services to tackle infectious, maternal, and child deaths. For example, The *Lancet* Commission on Investing in Health[23] estimated that the costs of reducing such deaths down to universally low levels through aggressive scale-up of services would be about $70 billion per year over 2015–35. The Commission used a similar methodological approach to the one we used—that is, in their modelling, the authors assumed that all LICs and LMICs could scale up these services at the rates achieved by recent "best performer" countries. In addition, in each scenario (actual, Mongolian, and Mexican rates of scale-up), the total costs represent only 1% of total annual health expenditures among UMICs, as these countries already spend a larger share on health care and have a better health system infrastructure in place. By contrast, the total costs associated with Mexican rates of scale-up are certainly prohibitive for both LICs and LMICs, as they represent about 17% and 8% of total annual health expenditures, respectively. The total costs with Mongolian rates represent about 4–8% of total annual health expenditures for both LICs and LMICs, while total costs for actual rates still represent about 4% of annual total health expenditures for LICs and LMICs. Therefore, it seems unlikely that scale-up of surgery in LICs and LMICs would occur unless substantial financial commitments are made available to country health budgets, whether through increased domestic resources or international donor funding.

This study develops a simple approach to examine the scale-up of surgical services and its associated costs in a large number of low-income and middle-income countries (panel). The analysis also broadly suggests the kind of financial resources needed to enable surgery scale-up and health system strengthening in those countries, with the objective of mobilising country policymakers and the global health community towards committing such necessary investments. Nevertheless, our approach has several limitations. First, given the extreme lack of data, our analysis relied significantly on several log-linear models. More sophisticated modelling could be used, for example with the inclusion of additional covariates such as population size, percentage of urban population, and caesarean section rates. And rigorous model selection using goodness of fit criteria could be implemented. Given the large uncertainty in the inputs and the significant knowledge gap, our intent was to present simple methods that are readily understandable and replicable; furthermore, we quantified both parameter and modelling uncertainty in the estimation of UIs with our results. Indeed, available data were extremely scarce, and we relied on estimates for levels of surgical volume[4] and solely on two sources (from Mexico and Mongolia) for trends in surgical volume. Thus, there are inherent limitations with use of this restrictive data, most importantly the lack of representation of the unequal distribution of surgical services within countries. Second, our costing exercise did not include medical education or training costs for the additional surgeons, surgical officers, and associated medical personnel for the scale-up, as the surgical personnel needs are difficult to quantify[45] and few data are available on surgical personnel training costs.[46,50] Indeed, the total training costs required to achieve surgical scale-up could be substantial. Holmer and colleagues[45] projected that by 2030 an additional 600 000–1 600 000 surgeons, anaesthesiologists, and obstetricians would be needed in low-income and middle-income countries; the training cost per surgeon has informally been estimated to be as high as $75 000 in Mozambique[46] and $150 000 in Haiti (Bryan Mundy, personal communication). As a sensitivity analysis, we estimated the share that these education costs could represent towards total costs of scale-up (table 4). Third, owing to lack of data, our modelling did not include the heterogeneous nature within countries of health-care delivery (per socioeconomic status, geographical setting), neither did it address the essential issues of surgical care accessibility, availability, affordability, underuse, and quality. Surgical volume does not necessarily imply quality in the outcomes, given the limited operative capacity in many countries; and substantial investments should also be accounted for quality improvement, prioritising essential surgery and safe anaesthesia in the post-2015 agenda.[51] Finally, there are several limitations to any modelling study that uses a "best performer" approach (in which it is assumed that all countries could emulate the performance of "best performer" countries). For example, as highlighted by The *Lancet* Commission on Investing in Health,[23] even if substantial new financing becomes available, it is unclear whether all low-income and middle-income countries would have the institutional and absorptive capacity to achieve the best performer rates of scale-up or to distribute services evenly across the country. And these types of models do not take into account the potential impact on health outcomes of (a) external events, such as political instability or natural disasters, and (b) other development sectors (eg, transport, education). Goal setting in global health has a complex history—many ambitious targets, such as the WHO's goal of "3 by 5" (putting 3 million people on antiretroviral treatment by 2005) were not met.[52] We acknowledge that our paper may be contributing to this trend of setting highly ambitious goals. Nevertheless, there is an empirical basis for our suggested target of 5000 surgical operations per 100 000,[12] and the target date of 2030 refers to the internationally adopted end date for the SDGs.[20]

Our analysis highlights the significant financial investments that scale-up of surgical services represents. Despite these required large investments, improving surgical capacity is a critical component of health system development, especially in the context of UHC. According to our analysis, a large number of low-income and middle-income countries will not be able to reach the target of 5000 surgical operations per 100 000 population per year by 2030 based on current rates of improvements. Hence, increased attention and commitment from the international community is essential for improving surgical services, a critical step for increasing access to basic health-care services.

Panel: Research in context

Systematic review

The endorsement of a target goal of 5000 surgical procedures per 100 000 population is a novel recommendation from *The Lancet*'s Commission on Global Surgery, and an initial search of Medline and Google Scholar failed to identify any studies that addressed the feasibility or costs of scaling up surgical services to reach a target goal for surgical procedures per capita. For these reasons, a systematic review was not done. Prior efforts have been made to identify costs associated with surgical care, but these have been performed at the regional or country level and on the whole have been directed at cost-effectiveness for specific surgical conditions, rather than attempts to capture the cost of scaling up all surgical services for a broad range of countries.[7–9,46] Indeed, identifying the cost of simply building an operating theatre, essential to our exercise, required reaching out to colleagues in low-income and middle-income countries and searching popular media (eg, newspapers). While others have published studies that attempt to identify the cost of scaling up access to health care in low-income and middle-income countries, including the recently published *Lancet*'s Commission on Investing in Health,[23] we could not identify any studies specific to surgical services.

Interpretation

The dearth of surgical services in low-income and middle-income countries plays a central role in the avertable burden of surgical disease, which is inequitably distributed.[2] With current scale-up rates, only half of low-income and middle-income countries will reach the target of 5000 surgical procedures per 100 000 population by 2030. To adequately address the gap in essential surgical services in a timely manner, additional funding must be allocated to build surgical capacity in low-income and middle-income countries.

Contributors

SV initiated the study, coordinated the research, and did the analysis with BCA and MGS. BCA, SWB, JAL, GM, MGS, TUL, and TGW provided data. SV wrote the first draft of the manuscript. BCA, SWB, JAL, GM, MGS, TUL, TGW, and GY reviewed and commented on the manuscript.

Declaration of interests

We declare no competing interests.

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