

# Estimated need for surgery worldwide based on prevalence of diseases: a modelling strategy for the WHO Global Health Estimate

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## Summary

**Background** Surgery is a foundational component of health-care systems. However, previous efforts to integrate surgical services into global health initiatives do not reflect the scope of surgical need and many health systems do not provide essential interventions. We estimate the minimum global volume of surgical need to address prevalent diseases in 21 epidemiological regions from the Global Burden of Disease Study 2010 (GBD).

**Methods** Prevalence data were obtained from GBD 2010 and organised into 119 disease states according to the WHO's Global Health Estimate (GHE). These data, representing 187 countries, were then apportioned into the 21 GBD epidemiological regions. Using previously defined values for the incident need for surgery for each of the 119 GHE disease states, we calculate minimum global need for surgery based on the prevalence of each condition in each region.

**Findings** We estimate that at least 321.5 million surgical procedures would be needed to address the burden of disease for a global population of 6.9 billion in 2010. Minimum rates of surgical need vary across regions, ranging from 3383 operations per 100 000 in central Latin America to 6495 operations per 100 000 in western sub-Saharan Africa. Global surgical need also varied across subcategories of disease, ranging from 131 412 procedures for nutritional deficiencies to 45.8 million procedures for unintentional injuries.

**Interpretation** The estimated need for surgical procedures worldwide is large and addresses a broad spectrum of disease states. Surgical need varies between regions of the world according to disease prevalence and many countries do not meet the basic needs of their populations. These estimates could be useful for policy makers, funders, and ministries of health as they consider how to incorporate surgical capacity into health systems.

**Funding** US National Institutes of Health.

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## Introduction

Surgical care has a role in treating a broad spectrum of diseases in the alleviation of human suffering.<sup>1</sup> It is required at all ages; from neonates with congenital anomalies to elderly people with cataracts. Surgery can be preventative, as in reducing HIV transmission through circumcision, or curative, as in many cancers. It is often a component of acute emergency care, such as bowel perforations and trauma, as well as the treatment of chronic diseases such as osteoarthritis and inflammatory bowel disorders. Additionally, surgical care is important in the diagnosis and supportive care of numerous conditions. For example, patients with renal failure require dialysis access and may eventually be candidates for kidney transplantation. In recognition of these many roles, researchers and economists now acknowledge that surgical care is a fundamental component of health care and contributes to overall social and economic development.<sup>2-4</sup>

Previous efforts to integrate surgical services into global health have failed to recognise the scope of surgical need. Traditionally, surgical initiatives in global health were implemented as disease-specific vertical interventions to meet targeted needs in resource-poor settings of the

world.<sup>5-7</sup> More recent efforts to expand the breadth of such services include the WHO's Emergency and Essential Surgical Care programme<sup>8</sup> and the World Bank's Disease Control Priorities project,<sup>9</sup> both of which promote the implementation of essential packages of interventions at first-level hospitals in low-income and middle-income countries (LMICs). However, research now shows that surgical care is required in the treatment of nearly all disease states of the global burden of disease, strengthening the argument that these services must be integrated into health systems at all levels and for diverse clinical problems.<sup>10</sup> This integration complicates the existing lack of access to surgical care estimated to affect 4.8 billion people worldwide.<sup>11</sup>

Defining the role of surgery in health systems remains a difficult problem in global health. Specifically, there is a need to define its role across a spectrum of diseases and what minimum levels of surgical intervention might be. In this report, we use prevalence data for diseases and conditions described by the Global Burden of Disease, Injuries, and Risk Factors Study 2010 (GBD 2010) to estimate the minimum need for surgery in each of the GBD regions of the world.

*Lancet Glob Health* 2015;  
3 (52): S13-20

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## Methods

### Global prevalence data

We obtained prevalence data from the GBD study from the Institute for Health Metrics and Evaluation (IHME).<sup>12</sup> From its beginnings in 1990, the complexity of GBD has grown to include 291 diseases and injuries organised into 21 disease subcategories, 1160 sequelae of these conditions, and 67 risk factors in 187 countries.<sup>13</sup> It combines data from many sources including vital registration, demographic surveillance systems, household surveys, verbal autopsies, and other sources.<sup>14</sup>

We extracted all-age population prevalences from GBD 2010 and standardised our disease taxonomy according to the WHO Global Health Estimate (GHE).<sup>15</sup> This process was accomplished by disaggregating GBD disease states into coding definitions based on the International Classification of Diseases 10th edition (ICD-10) and reorganising them according to the GHE framework. The GHE framework was chosen because of the ability to link any analysis to various other health systems analysis tools available through WHO. Although both frameworks rely on the same prevalence data, they differ in classification of some disease states.<sup>16</sup> In the GHE framework there are 22 disease subcategories, whereas in the GBD there are 21 disease subcategories. Both GBD and GHE taxonomies are publicly available for comparison of ICD-10 codes.<sup>15,17</sup>

During this study, multiple disease states had missing data due to ongoing updates of the GBD dataset. These

were: other maternal, other neonatal, other nutritional, other respiratory, other digestive, other genitourinary, encephalitis, intestinal nematode infections, otitis media, vitamin A deficiency, other nutritional deficiencies, exposure to forces of nature, collective violence, and legal intervention. These missing data are shown in tables with an asterisk and were excluded from analysis.

The final dataset extracted from the GBD 2010 consisted of all-age population prevalence for 119 GHE disease states organised into 22 disease subcategories. These data, representing 187 countries, were grouped according to geographic and epidemiological similarity into 21 regions, according to methods described in GBD 2010.<sup>14</sup> Listed alphabetically, these regions are: Andean Latin America, Australasia, Caribbean, central Asia, central Europe, central Latin America, central sub-Saharan Africa, east Asia, eastern Europe, eastern sub-Saharan Africa, high-income Asia Pacific, high-income North America, North Africa and Middle East, Oceania, south Asia, southeast Asia, southern Latin America, southern sub-Saharan Africa, tropical Latin America, western Europe, and western sub-Saharan Africa.

### Incident rates of surgical procedures

To estimate the global need for essential surgical procedures based on prevalence of diseases in each GBD region, we required national or multinational data against which to benchmark the relation between the prevalence of discrete disease states and the use of surgical services. Surgical encounters therefore needed to be rigorously and consistently documented in a national dataset with ICD coding for diagnoses and procedures. Another requirement was a well financed national health-care system with universal access for an entire population where it could be generally assumed that surgical care is provided when needed. Lastly, we needed a setting and strategy that would minimise the amount of unnecessary surgery captured in the analysis.

New Zealand satisfied the above criteria while also achieving excellent health outcomes with efficient use of resources. It has a strong, nationalised health-care system with universal access and a publicly-supported national repository of hospital discharge information from all public sector hospitals.<sup>18</sup> In 2010, overall life expectancy was 80·7 years in New Zealand and 80·2 in high-income countries (HICs) overall.<sup>19–21</sup> Similarly, maternal mortality was 12 per 100 000 livebirths whereas in HICs overall it was 15 per 100 000 livebirths. Under-5 mortality was also comparable at 6·4 per 1000 livebirths in New Zealand and 5·5 per 100 000 livebirths in HICs overall. These outcomes were also achieved with comparatively low cost. In 2010, total expenditure for health per capita in New Zealand was 25% lower (US\$3260) than in other HICs (\$4325). Lastly, the national rate of surgery is among the lowest of all HICs even when including estimates of operations from the private sector (6270 per 100 000 in 2012),<sup>22</sup> minimising the effect of cosmetic or potentially unnecessary surgery. For these reasons, New Zealand was

	Population, 2010	Estimated total surgical need	
		Absolute procedures volume	Procedures per 100 000
Andean Latin America	53 477 058	2 017 949	3773
Australasia	25 896 634	1 209 068	4669
Caribbean	43 514 856	2 210 372	5080
Central Asia	80 138 328	3 476 808	4339
Central Europe	119 065 155	6 565 893	5515
Central Latin America	231 138 168	7 820 648	3384
Central sub-Saharan Africa	96 543 102	6 038 802	6255
East Asia	1 397 940 667	57 821 123	4136
Eastern Europe	207 162 843	10 290 575	4967
Eastern sub-Saharan Africa	355 720 887	21 858 830	6145
High-income Asia Pacific	178 098 403	9 422 832	5291
High-income North America	340 096 725	15 805 859	4647
North Africa and Middle East	446 025 798	19 874 651	4456
Oceania	9 942 806	447 554	4501
Southeast Asia	610 448 769	25 794 258	4225
South Asia	1 613 194 931	72 919 681	4520
Southern Latin America	60 208 017	2 953 854	4906
Southern sub-Saharan Africa	70 498 978	3 590 736	5093
Tropical Latin America	201 818 241	7 226 989	3581
Western Europe	416 007 051	22 323 256	5366
Western sub-Saharan Africa	336 175 439	21 835 624	6495
Global total	6 893 112 854	321 505 362	4664

**Table 1: Estimated need for surgical procedures in 2010, by regions of the world**

an optimum setting from which to derive a standard for surgical care.

We used previously-defined index rates of procedure for each disease state of the GHE from New Zealand.<sup>10</sup> Rates of procedure were defined as the likelihood of each disease state requiring an inpatient surgical procedure in one calendar year. Rates of procedure were calculated by compiling ICD-10 codes from the New Zealand National Minimum Dataset. Using the primary cause of admission, we aggregated hospitalisations into disease states according to the WHO GHE and determined whether or not the admission was associated with an operation in a binary fashion (ie, present or absent). Surgical procedures were defined as any procedure requiring general or neuroaxial anaesthesia. Using these results and New Zealand disease and condition prevalence from the GBD 2010 study, we determined the incident rate of procedures per disease prevalence. A more detailed description of methods is available by Hider and colleagues.<sup>10</sup>

The analysis of index rates of surgical procedures in New Zealand was structured to err on the conservative side by restricting the analysis to the inpatient setting. Additionally, the analysis did not include inpatient surgical procedures performed outside the public sector, procedures performed under local anaesthesia, outside the operating room, or multiple procedures (ie, reoperations) during the same hospital admission. These procedures were excluded because there could be a non-trivial proportion of surgical volume that is not clinically indicated and supply-sensitive surgery can contribute to wide variation in rates of surgery between countries.<sup>23</sup> In some settings, the component of overall surgical volume that is performed on an outpatient basis approximates to 40–50% of total surgical procedure volume.<sup>24</sup> Collectively, the above precautions ensure the most conservative analysis possible for minimum rates of procedures.

### Analysis

To estimate the number of procedures needed in each epidemiological region, we extrapolated the need for surgical care for all disease states in our dataset. We accomplished this in two steps, outlined in the following equation. First, we multiplied the unique standardised incident rate of procedure (ROP) for each disease state (*i*) by the prevalence counts (*Prev*) of each disease state (*i*). Second, we summed the absolute volume of surgical procedures needed for all disease states within a subcategory and then for all subcategories (*n*) within a region. CIs for procedure volumes were not calculated

$$\text{Cumulative estimated need for surgical procedures} = \sum_i^n (ROP_i \times Prev_i)$$

because index rates of procedure were calculated at the population level from New Zealand.

Lastly, we normalised the cumulative volume of procedures needed in each region by that region's population in 2010 and reported the overall rate of surgery per 100 000 population. Populations for each

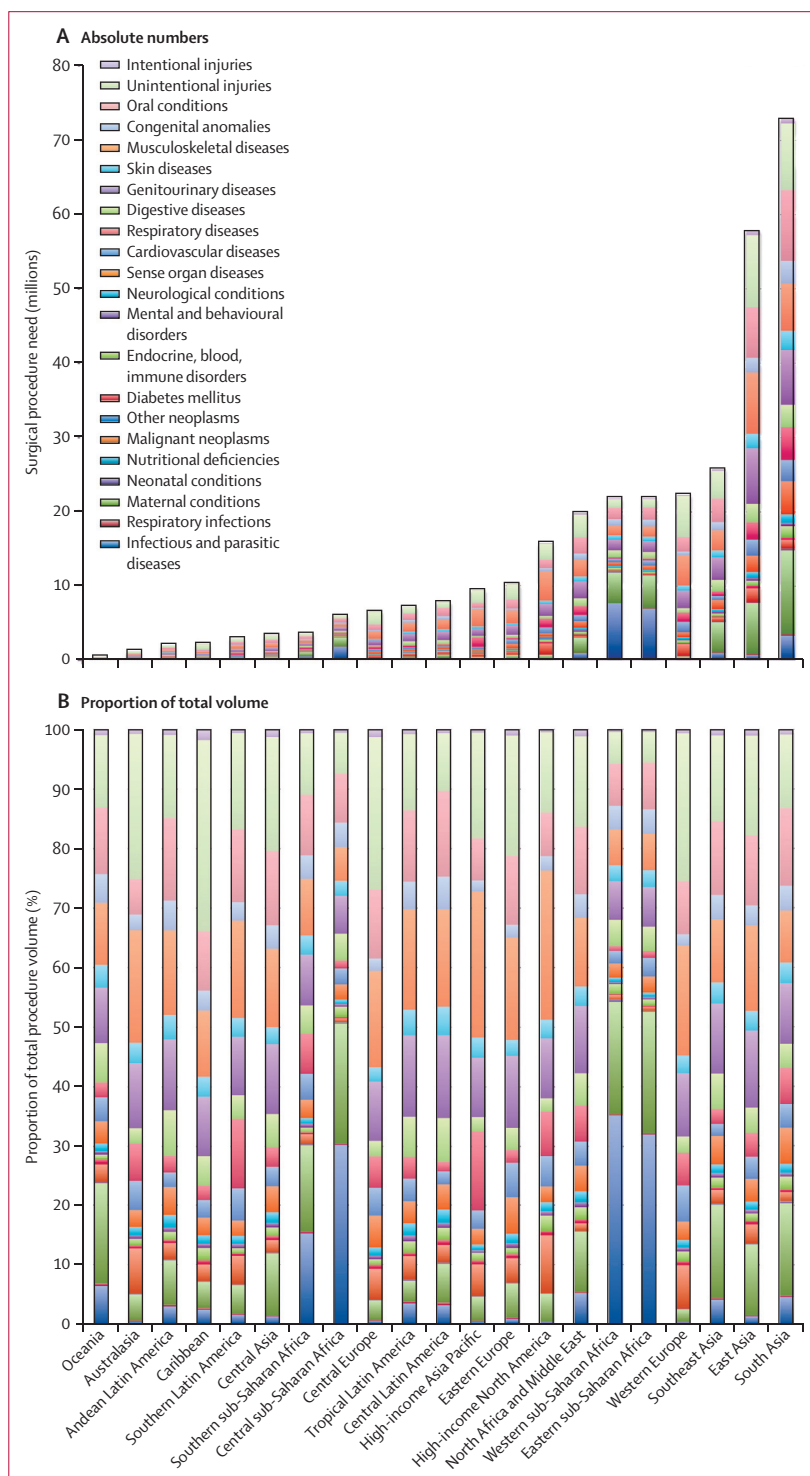


Figure: Estimates of need for surgical procedures by epidemiological region and WHO Global Health Estimate disease subcategory

	Absolute procedure volume
Communicable, maternal, perinatal, and nutritional conditions	64 212 226
Infectious and parasitic diseases	24 321 249
Respiratory infections	604 045
Maternal conditions	38 720 343
Neonatal conditions	435 178
Nutritional deficiencies	131 412
Non-communicable diseases	208 837 565
Malignant neoplasms	9 701 256
Other neoplasms	*
Diabetes mellitus	1 559 515
Endocrine, blood, and immune disorders	5 364 634
Mental and behavioural disorders	2 056 792
Neurological conditions	4 424 634
Sense organ diseases	13 516 348
Cardiovascular diseases	12 131 680
Respiratory diseases	14 642 321
Digestive diseases	13 852 308
Genitourinary diseases	33 902 440
Skin diseases	10 591 548
Musculoskeletal diseases	40 493 940
Congenital anomalies	11 551 218
Oral conditions	35 048 931
Injuries	48 455 571
Unintentional injuries	45 809 537
Intentional injuries	2 646 034
Total procedures	321 505 362

\*Indicates subcategory with missing GBD prevalence data.

**Table 2: Estimated need for surgical procedures by WHO Global Health Estimate disease subcategory for the global population in 2010**

region in 2010 were extracted from publicly available descriptive statistics at the World Bank.<sup>25</sup>

### Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

### Results

In 2010, we estimate that 321·5 million inpatient surgical procedures were needed to address the global burden of disease. This number of operations amounts to a global per capita surgical need of 4664 per 100 000. The volume of need across the three broad categories of disease was: 64·2 million for communicable, maternal, perinatal, and nutritional conditions; 208·8 million for non-communicable diseases; and 48·8 million for injuries.

Absolute volumes of surgical procedure need varied by several orders of magnitude between epidemiological regions (table 1). Surgical need ranged from 447 554 in Oceania to 72 919 681 in south Asia. The regions with the

	Absolute procedure volume
Pancreas cancer	67 792
Melanoma and other skin cancers	132 908
Oesophageal cancer	140 727
Ovarian cancer	148 380
Leukaemia	177 956
Trachea, bronchus, lung cancers	213 733
Lymphomas, multiple myeloma	265 792
Liver cancer	275 360
Corpus uteri cancer	296 400
Stomach cancer	421 939
Prostate cancer	440 281
Mouth and oropharynx cancers	446 157
Cervix uteri cancer	654 803
Bladder cancer	728 914
Colon and rectal cancers	939 810
Breast cancer	1 191 838
Other malignant neoplasms	3 158 465
Total	9 701 255

**Table 3: Variation in surgical procedure need for disease states within the subcategory of malignant neoplasms of the WHO Global Health Estimate for the global population in 2010**

largest volume of need were also the regions with the largest populations—namely, south Asia, east Asia, and southeast Asia (table 1, figure A). Minimum rates of surgical need per population also varied between regions. After normalising the absolute volume according to population size in each region, the lowest rate of surgical need was in central Latin America and the highest, with almost a two-fold difference, was in western sub-Saharan Africa (table 1). The next highest rates of surgical need per population were in central sub-Saharan Africa and eastern sub-Saharan Africa (table 1). The median rate of need per capita at the regional level was 4669 operations per 100 000 in Australasia.

The need for surgical procedures also varied between disease subcategories and individual disease states (table 2). Global volume of procedure need for the 22 disease subcategories was lowest for nutritional deficiencies and highest for unintentional injuries. The subcategories with the next greatest absolute need were musculoskeletal diseases and maternal conditions (table 2). There was also variation within disease subcategories. For example, within the subcategory of malignant neoplasms, the need for surgical procedures differed by as much as two orders of magnitude between types of cancer (table 3). A full description of need for 119 disease states is available in the appendix.

The need for surgical procedures within regions was also heterogeneous and differed substantially from one region to the next (figure B). For example, surgical procedures for infectious and parasitic diseases accounted for 0·32% of procedures in western Europe (lowest), 3·0% in Andean Latin America (median), and

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35·3% in western sub-Saharan Africa (highest). Similarly, surgical procedures for maternal conditions varied from 2·1% in western Europe (lowest) to 7·5% in Andean Latin America (median) to 20·4% in eastern sub-Saharan Africa (highest).

Heterogeneity between regions is also evident in reviewing the single disease subcategory accounting for the greatest proportion of surgical procedures within each region. Accordingly, the disease subcategory with greatest surgical need was unintentional injuries in the Caribbean (32·1%), infectious and parasitic diseases in western sub-Saharan Africa (35·3%), and maternal conditions in southeast Asia (15·7%). Figure B displays the heterogeneity for all 22 disease subcategories across the 21 GBD regions.

## Discussion

The global estimated need for surgical procedures is large and cuts across a broad spectrum of GHE disease states. Surgery is essential for addressing basic health needs globally, although the degree varies between epidemiological regions of the world and between disease subcategories. Our findings provide the first estimation of need for surgical services that is sensitive to each region's unique epidemiological profile (panel). These data fundamentally challenge the notion that surgical need can be met through vertical programming and reinforce the fact that a versatile surgical core should lie at the centre of health systems.

These results show how the development of surgical capacity might vary according to region. For example, in western sub-Saharan Africa, central sub-Saharan Africa, and eastern sub-Saharan Africa, two disease subcategories combined (infectious and parasitic diseases and maternal conditions) account for more than 50% of the need for surgical procedures. The same two subcategories account for less than 20% of procedure need in south Asia, east Asia, and southeast Asia and less than 10% in Latin American regions. The single disease subcategory accounting for the greatest proportion of surgical procedures within each region also varied. These results present an opportunity for ministries of health to repeat the analysis at the country level and to consider how current priorities align with population needs with regard to workforce capacity, regionalisation of service delivery, referral patterns, and financing. Without considering these divergent needs, prioritisation frameworks for scaling up surgical capacity will inevitably fail to maximise population health.

Our findings of surgical need are of comparable magnitude with other research and may be helpful in identifying initial targets for scaling up surgical capacity. Weiser and colleagues use multiple imputations of counts of surgery to estimate that the global volume of surgical output is large and growing, estimated to be 234·3 million procedures in 2004 and 312·9 million procedures in 2012.<sup>22,26</sup> According to their results, rates of surgery at the

country level range from less than 100 per 100 000 in parts of Africa to greater than 20 000 per 100 000 in parts of Europe. Our estimation of global minimum surgical need at 4664 per 100 000 globally, is a conservative estimate which rounds to 5000 procedures per 100 000 as a possible target for the initial development of surgical infrastructure. For some regions, such as western sub-Saharan Africa with a rate of surgical need estimated at 6495 per 100 000, this global rate will be insufficient. However, we consider it a modest initial goal that, if adopted by funding agencies and ministries of health, could lead to profound improvements in population health.

This approach has several policy implications for monitoring and evaluation at the country level. WHO previously endorsed a package of six standardised metrics to monitor the delivery of surgical services and among them was the volume of surgical procedures (per operating room or population).<sup>27</sup> Although this metric is useful in evaluating service use and efficiency, it does little to assess whether current services are meeting the needs of the population when significant proportions of patients do not access health-care services. Our method links hospital use with prevalence of diseases to bridge this gap and could be useful as a supplementary metric of coverage. Furthermore, as social and economic conditions improve in LMICs, demographic changes and epidemiological transitions inevitably ensue. As the prevalence of non-communicable disease rises, ministries of health can use our method to follow trends in prevalence of diseases and anticipate impending surgical needs within the health-care system.

Another potential use for this method is to compare estimates of surgical output with estimates of overall surgical need to ascertain the unmet component of surgical need. Based on global data from 2012, Weiser and

### Panel: Research in context

#### Systematic review

The preparation of this manuscript included an extensive PubMed literature review in the areas of global burden of disease, clinical indicators relevant to surgery, and frameworks for monitoring and evaluation of health systems. This review contributed directly to the current paper, the Disease Control Priorities Project, volume 3, and the *Lancet* Commission on Global Surgery. As such, details of these reviews are published within these documents, as appendices to the same, or as stand-alone manuscripts. The global burden of disease is a useful framework to evaluate the comparative impact of discrete disease entities on population health in the form of death and disability. However, the current iteration of the global burden of disease study does not make reference to treatment modalities and the role of surgery is neglected. This is especially problematic when the comparative burden of conditions is used to justify the allocation of resources in global health.

#### Interpretation

To our knowledge, this study is the first estimation of global need for surgical procedures. These data suggest that the need for operations is large and that surgical care is indicated across a broad spectrum of conditions. Future efforts should focus on explaining variation in rates of surgical need between regions and improving the quality of data available for such analyses at the country level.

	Minimum need (cases)	Met need (cases)	Ratio of met need: total need	Minimum estimated unmet need	
				Surgical cases	Cases per 100 000
Andean Latin America	2 017 949	2 049 740	1.02	0	0
Australasia	1 209 068	2 223 308	1.84	0	0
Caribbean	2 210 372	2 079 323	0.94	131 050	301
Central Asia	3 476 808	2 566 375	0.74	910 432	1136
Central Europe	6 565 893	5 887 535	0.90	678 358	570
Central Latin America	7 820 648	10 641 853	1.36	0	0
Central sub-Saharan Africa	6 038 802	1 845 823	0.31	4 192 980	4343
Eastern Asia	57 821 123	29 864 615	0.52	27 956 507	2000
Eastern Europe	10 290 575	12 043 858	1.17	0	0
Eastern sub-Saharan Africa	21 858 830	4 303 082	0.20	17 555 748	4935
High-income Asia Pacific	9 422 832	13 942 850	1.48	0	0
High-income North America	15 805 859	63 453 370	4.01	0	0
North Africa and Middle East	19 874 651	17 759 640	0.89	2 115 011	474
Oceania	447 554	392 358	0.88	55 196	555
Southeast Asia	25 794 258	13 313 319	0.52	12 480 939	2045
Southern Asia	72 919 681	15 128 131	0.21	57 791 550	3582
Southern Latin America	2 953 854	3 496 878	1.18	0	0
Southern sub-Saharan Africa	3 590 736	3 299 735	0.92	291 000	413
Tropical Latin America	7 226 989	10 390 483	1.44	0	0
Western Europe	22 323 256	56 258 614	2.52	0	0
Western sub-Saharan Africa	21 835 624	2 926 117	0.13	18 909 507	5625
Total	321 505 362	312 900 000*	..	143 068 278†	..

\*Total operative volume is based on the global imputed estimate and not a result of summation within the column.

†Total unmet need is based on the gap between total need and unmet need and does not include surgical output above minimum rates. As such the value is not based on simple subtraction within the row.

**Table 4: Estimation of met and unmet need for surgical procedures (met need data reproduced from Weiser and colleagues<sup>22</sup>)**

colleagues<sup>22</sup> estimate that surgical output at the regional level ranges from 392 358 per year in Oceania to 63.4 million per year in high-income North America, with dramatic disparities between countries and regions even after normalising for population size (table 4). Some regions perform as many as four times the minimum rates of surgical need (ie, high-income North America, with 15.8 million procedures needed and 63.4 million performed), while others fall far behind (eastern Sub-Saharan Africa, with 21.9 million procedures needed and 4.3 million performed; table 4). We roughly calculate the global unmet need by identifying 12 of 22 regions with current surgical output falling below estimated minimum need and tabulating the surgical gap, or additional volume of procedures needed to meet the need, to be 143.1 million operations.

Of note, Weiser and colleagues use the following definition in surgical counts: “any intervention occurring in a hospital operating theatre involving the incision, excision, manipulation, or suturing of tissue, usually requiring regional or general anaesthesia”.<sup>22</sup> This is quite similar to the definition in our modelling, differing in that Weiser and colleagues include private practice procedures, outpatient

procedures, and procedures done under regional anaesthesia where data were available. Considering that the availability of these data was restricted to HICs in Weiser and colleagues’ analysis, the effect of any mismatch between their estimations and ours would artificially inflate the excess volume of surgical output in HICs but have little or no effect on the estimations of surgical output in LMICs. As such, our calculations are less helpful in determining excess in HICs but should be reliable estimates of surgical gap (or minimum unmet need) in LMICs. As there continue to be advances in medical informatics in LMICs, these rough approximations of unmet need can and should be improved.

These results also carry an important message pertinent to global health governance. There is a potential for policy makers to perceive a tension between greatest need in absolute numbers and greatest need in rates per 100 000 (table 1). The two regions with greatest absolute volume of surgical procedure need (south Asia and east Asia) are disproportionately influenced by two very populous middle-income countries (China and India, respectively). However, the two regions with the greatest surgical need per 100 000 are western sub-Saharan Africa and eastern sub-Saharan Africa, both of which are replete with low-income countries. A utilitarian approach might prioritise capacity building in the direction of the “greatest good for the greatest number”, whereas an approach rooted in social justice might prioritise development for underserved populations with the greatest disadvantage. These data make it clear that the need for surgical procedures worldwide affects many people in diverse settings and that if surgical capacity is developed in an either/or manner it is unlikely that the Sustainable Development Goals will lead to a grand convergence in health status by 2035.<sup>28</sup>

This study has several limitations that merit attention. One is that prevalence-based estimates of disease are not ideally suited to encapsulate the complexity of surgical need.<sup>29</sup> A simple example is circumcision, shown to reduce HIV transmission by as much as 60%,<sup>30</sup> which is not done for a disease state, but rather to prevent the occurrence of disease. Another example is bariatric surgery, effective in the treatment of obesity, which is performed to treat a highly prevalent epidemic in HICs that is not included within the GHE taxonomy. Owing to examples such as these, we expect subsequent estimates of surgical need to increase as frameworks are adapted to reflect surgical services. The greatest limitation to exploring the implications of such discrepancies is the paucity of data. To overcome this barrier, we recommend that national registries be developed to capture clinical encounters in LMICs that are consistent with burden of disease categories. An ideal starting point is the framework of four digestive diseases, four maternal-neonatal conditions, and treatable injuries recommended by the Disease Control Priorities, volume 3.<sup>9</sup>

Another limitation is that our definition of surgery limits the interpretability of results. The presence of a surgical procedure was defined as a binary variable and does not

differentiate between the myriad types of surgical procedure, resource use, complexity of care delivery, or health consequences. Although our methods provide a broad estimation of the scope of the surgical need across disease states and geographic regions, they do not have the granularity to help policy makers and health-care administrators make concrete decisions about financing and resource allocation in their current form. Furthermore, our definition of surgery excludes non-operative management of many disease states (eg, bowel obstruction) that occurs on surgical wards. To contribute to the scaling up of surgical services in underserved populations, the current method should be applied to country-level data and explored in closer detail to make estimates relevant for the allocation of human and physical resources.

There is also an inherent limitation to benchmarking rates of procedure in a single country and then extrapolating those rates to other regions because this intrinsically reproduces key assumptions and bias. The association between a disease state and the provision of surgical care depends on contextual factors that might change the safety profile of procedures between settings, such as the availability of banked blood, post-operative ventilators, or the ability to transfer to higher levels of care. Pertinent to our analysis, index rates of procedure were calculated in New Zealand exclusively from the public sector in an effort to produce conservative results. However, if a hypothetical procedure A is performed in the private sector 5% of the time and hypothetical procedure B is performed in the private sector 50% of the time, our modelling strategy based exclusively in the public sector would be unevenly conservative between disease states. In other scenarios, the need for surgery might be tied to disease severity and medical management. For example, hospital admissions for communicable diseases of the GBD required an operation 2.1% of the time in Sweden but 17.0% of the time in South Africa, reflecting underlying differences in disease severity.<sup>31</sup> Owing to the fact that patients in LMICs are more likely to have undertreated infections than those in New Zealand, this aspect of our modelling strategy will underestimate extrapolations of global surgical need, but the extent and variation by disease state is unknown. Future efforts to estimate surgical need should capitalise on ongoing improvements in data access to evaluate the effect of benchmarks from diverse settings on this modelling strategy's results and explore the variation in rates of procedure between regions.

Finally, our estimations do not ensure the appropriateness of individual surgical services. We extrapolate the frequency with which GHE disease subcategories require a surgical procedure without specifying what procedure that might be or whether the treatment decision was justified according to clinical guidelines and standards of care. This omission is especially important when one disease state has multiple surgical treatment options, such as internal versus external fixation in a context of long-bone fracture or in complicated presentations such as

polytrauma and intra-abdominal catastrophes where multiple procedures must be planned and coordinated. Appropriateness criteria are especially important because we do not account for unethical disparities in surgical care within the index country or potentially unnecessary surgery in LMICs.<sup>32</sup> Although appropriateness criteria have been developed by expert consensus panels for a limited number of surgical procedures in HICs, it is beyond the scope of this analysis to address this concern methodologically beyond the careful consideration of a benchmark country already described in our methods.<sup>23</sup>

In light of these limitations, it is worth reiterating that this analysis errs on the side of conservative estimates in multiple ways. For example, we did not account for hospital admissions during which more than one procedure was performed (6% of total procedure volume in New Zealand).<sup>10</sup> Additionally, ICD-10 codes that were missing in the GBD 2010 prevalence data were highly associated with inpatient surgical procedures, accounting for 25% of all surgical procedures in the index country, but these procedures were not included in global estimations due to unavailable GBD 2010 prevalence data in each region. We also know from independent clinical databases that procedures done in private hospitals in the index country can account for up to 25% of procedures in select disease states (eg, knee arthroplasty); because private hospitals do not report procedures in New Zealand's national minimum dataset, these procedures were also omitted from global extrapolations. We also excluded outpatient procedures, bedside procedures, and surgical procedures under local anaesthesia. For these reasons, it is not surprising that current counts of surgical procedures in New Zealand from Hider and colleagues (7840 procedures per 100 000 population) are nearly double our current estimates for Australasia (4669 procedures per 100 000 population).<sup>10</sup>

Furthermore, we did an almost identical sensitivity analysis in the USA using the Nationwide Inpatient Sample and the GBD 2010 framework and found comparable inpatient rates of procedure for the broad GBD disease categories: 24% for communicable, maternal, and neonatal diseases (*vs* 16% in New Zealand), 34% for non-communicable diseases (*vs* 32% in New Zealand), and 35% for injuries (*vs* 30% in New Zealand).<sup>1</sup> Despite the fact that national procedure output differs significantly between the two countries (29 399 per 100 000 in the USA; 6270 per 100 000 in New Zealand), the comparable scale of these rates of procedure validates the assumption that excess surgery was largely eliminated by our extensive exclusion criteria.<sup>22</sup>

In conclusion, we report a large volume of surgical need, estimated at one procedure per 21 people alive today, with a global rate of surgery of 4664 per 100 000. Although the estimated need varies according to disease epidemiology, there is a remarkable consistency in our estimates across different countries and settings. This method could be useful in advocating for initial targets to meet procedure need. Future research should focus on

improving data quality and availability, validating rates of procedure in different settings, and incorporating measures of population health into policy-oriented frameworks for monitoring and evaluation of surgical capacity in underserved populations.

#### Contributors

JR, TGW, PH, and SWB were responsible for the study conception and design. JR, TGW, and PH analysed and interpreted the data. JR drafted the report, which was subsequently revised by TGW, SWB, PH, LW, RG, and SWB. All authors read and approved the final report.

#### Declaration of interests

We declare no competing interests.

#### Acknowledgments

We acknowledge the assistance of the Institute for Health Metrics and Evaluation in provision of prevalence data from the Global Burden of Disease Study 2010 and the Perioperative Mortality Review Committee and Health Quality and Safety Commission, Wellington, for provision of New Zealand data.

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