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.

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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***

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

See Online for webappendix

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.

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