An estimation of the global volume of surgery: a modelling strategy based on available data

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Summary

Background Little is known about the amount and availability of surgical care globally. We estimated the number of major operations undertaken worldwide, described their distribution, and assessed the importance of surgical care in global public-health policy.

Methods We gathered demographic, health, and economic data for 192 member states of WHO. Data for the rate of surgery were sought from several sources including governmental agencies, statistical and epidemiological organisations, published studies, and individuals involved in surgical policy initiatives. We also obtained per-head total expenditure on health from analyses done in 2004. Major surgery was defined as any intervention occurring in a hospital operating theatre involving the incision, excision, manipulation, or suturing of tissue, usually requiring regional or general anaesthesia or sedation. We created a model to estimate rates of major surgery for countries for which such data were unavailable, then used demographic information to calculate the total worldwide volume of surgery.

Findings We obtained surgical data for 56 (29%) of 192 WHO member states. We estimated that 234·2 (95% CI 187·2–281·2) million major surgical procedures are undertaken every year worldwide. Countries spending US$100 or less per head on health care have an estimated mean rate of major surgery of 295 (SE 53) procedures per 100 000 population per year, whereas those spending more than $1000 have a mean rate of 11 110 (SE 1300; p<0·0001). Middle-expenditure ($401–1000) and high-expenditure (>$1000) countries, accounting for 30·2% of the world's population, provided 73·6% (172·3 million) of operations worldwide in 2004, whereas poor-expenditure (≤$100) countries account for 34·8% of the global population yet undertook only 3·5% (8·1 million) of all surgical procedures in 2004.

Interpretation Worldwide volume of surgery is large. In view of the high death and complication rates of major surgical procedures, surgical safety should now be a substantial global public-health concern. The disproportionate scarcity of surgical access in low-income settings suggests a large unaddressed disease burden worldwide. Public-health efforts and surveillance in surgery should be established.

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Introduction

Worldwide public-health initiatives have traditionally focused on surveillance and control of infectious disease, education, health promotion, and disease prevention. In recent decades, however, gains in life expectancy have changed previous trends of disease in low-income and middle-income countries, especially in the Middle East and Asia. With the so-called epidemiological transition that has accompanied industrialisation,[1] disorders afflicting populations are shifting from diseases of pestilence and infection that are an indicator of pre-industrial societies to those that are identified in industrialised and rising economies.[2,3] Ischaemic heart disease, cerebrovascular disease, cancers, and mental illness have all risen substantially in low-income, middle-income, and high-income countries.[4] Injuries also account for a large and growing amount of the disease burden as vehicular traffic and technical innovation increase around the world.[5] These trends are bound to continue.

Surgical services have long been recognised to be an essential if often expensive component of the public-health system. Surgery occurs in every setting from the most resource rich to the most resource limited, and the need has increased greatly with the shifting patterns of disease. However, little is known about the actual worldwide volume and availability of surgical care since only anecdotal evidence exists.

Because of this epidemiological transition, surgery will assume an increasing role in public health. In view of its complexity and risks, an understanding of the quantity and distribution of surgical interventions is therefore essential to guide efforts to improve its safety and redress shortages of such services. As part of WHO's patient safety programme,[6] we aimed to estimate the number of major operations undertaken worldwide, to describe their distribution, and to assess the importance of surgical care in global public-health policy.

Methods

Population and health databases

We gathered population and health data from WHO and the UN Population Fund. We obtained data for total

population, average life expectancy, death rate from HIV/AIDS, physician density, nursing density, number of hospital beds, gross domestic product, literacy rate, percentage of the population living on less than US$1 per day, and percentage coverage of vital registration of death (which is an indication of the ability of a country's capacity to gather statistical information) from the WHO's World Health Report 2006.[7,8] We also obtained per-head total expenditure on health at an international dollar rate from the World Health Report 2006 on the basis of analyses done in 2004. International dollar rates allow financial comparisons between countries on the basis of exchange rates, currency fluctuations, and the power of the dollar relative to local economic circumstances. The percentages for the population living in urban areas, aged older than 59 years, and aged younger than 15 years were obtained from information contained in UN reports.[9]

Surgical data sources

We gathered yearly data for volume of surgery from countries with available information by reviewing surgical statistics published in peer-reviewed journals and by contacting ministries of health, statistical and epidemiological agencies, and individuals who are involved with surgical audits. To ensure representative samples from different economic and health-resource settings, we divided countries into four groups that were defined according to their per-head total yearly expenditure on health: high-expenditure countries spending more than US$1000; middle-expenditure countries spending between $401 and $1000; low-expenditure countries spending between $101 and $400; and poor-expenditure countries spending $100 or less. Our literature search terms included "surgery", "rate", and "volume", along with individual country names, especially for countries with the three lowest expenditures. Our web-based searches of statistical agencies included searches in English, French, Spanish, Chinese, and Japanese.

We considered major surgery to be any intervention occurring in a hospital operating theatre involving the incision, excision, manipulation, or suturing of tissue, and that usually requires regional or general anaesthesia or profound sedation to control pain.[10,11] If caesarean sections or other invasive gynaecological and obstetric procedures were reported separately, they were included in the cumulative volume data. We also included outpatient operations meeting our inclusion criteria for major surgical procedures. We excluded procedures that were reported as minor surgery and non-invasive procedures—eg, respiratory therapy treatments or CT scans.

For countries for which we obtained the yearly nationwide volume of major surgical procedures, we calculated the surgical rate per 100 000 people on the basis of the WHO reported population size.[12] When surgical data were available for only a portion of a country, we calculated a province-wide surgical rate on the basis of the number of operations that were undertaken within the defined geographic region or district and the population of the area, and then extrapolated this rate to the remainder of the country.

Imputation of surgical rates

Surgical data were from different years for different countries. For data reported after 1998, we used the per-head total expenditure on health for the corresponding year in our model, with adjustment for inflation to 2004 US$ with the consumer price index for general inflation.[13] For data reported in 1998 or earlier, we used the 1999 per-head expenditure on health as the reference variable, again with adjustment for inflation to 2004 US$. Population data were taken from 2004, providing conservative estimates for surgical rates due to population growth.

Statistical analysis

We assessed predictors of national surgical rates by stepwise linear regression. Per-head expenditure and surgical rates were transformed, with the base 10 logarithm, to account for their right-skewed distributions and to keep any bias imparted by variability in the reporting of invasive procedures to a minimum. We first assessed a model relating surgical volume solely to per-head expenditure, and then assessed other candidate predictors, including the percentage of the population older than 59 years (with a higher percentage potentially associated with an increase in surgical volume), life expectancy, physician density, nursing density, and the number of hospital beds. Gross domestic product and poverty levels were tightly collinear with per-head total expenditure on health, and were therefore not included in the model.

Per-head total expenditure on health was strongly correlated with rates of major surgery in these countries (r^2=0·996) and was thus the only variable that was included in the linear model for estimation of surgical rates. In assessment of the model for heteroskedasticity, we noted that the countries spending $100 or less had a linear relation between expenditure and surgical rates (which probably reflects the contribution of relief organisations in producing a minimum surgical infrastructure in even the poorest settings). Because the slope of the regression line did not differ significantly from zero in these poor-expenditure countries (p=0·47), we separately modelled predictors of surgical rates between expenditure groups and differentiated between countries spending $100 or less per head on health care and those spending more than $100 on the basis of following formula:

$$\gamma=\beta_1 x_i+(\beta_2+\beta_3 \log \text{expenditure})(1-x_i)$$

where x_i=1 if expenditure is $100 or less or 0 if expenditure is more than $100 (no intercept), γ=mean log surgical rate, β_1=y-intercept of the line for countries

spending $100 or less, β_2=y-intercept for the line for countries spending more than $100, and β_3=slope of the line for countries spending more than $100.

To further assess the accuracy of the model's predictions we computed a cross validation r^2 for all countries in our dataset, comparing predicted versus reported surgical rates for each of our known countries after sequentially excluding that country from the regression model. We then used the sum of the squared differences between these predictions and the actual surgical rate to estimate the proportion of variance explained by the model.

For countries without published surgical rates, we used multiple imputation to generate estimated surgical rates with use of our predictive model.[14] The total number of operations for each country was then computed from its imputed surgical rate and population. 300 imputed datasets were generated to estimate the mean worldwide surgical volume along with a 95% CI that was calculated with twice the standard error of the variance. We undertook sensitivity analyses to understand the robustness of our conclusions to changes in variables that were used in the predictive model. We also compared key characteristics of countries with and without data, with adjustment for expenditure on health care, to establish whether surgical data were missing at random.

All statistical analyses were done with SAS version 9.1.

Role of the funding source

The study was supported by WHO as part of the Safe Surgery Saves Lives project led by one of the investigators (AAG). The sponsor 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

We obtained surgical data for 56 (29%) of 192 WHO member states. Countrywide data were available for 48 countries; national totals for the remaining eight countries were extrapolated from data for a portion of the country. Of countries with countrywide data, 39 had specific data for the number of major surgical procedures from which we calculated a surgical rate on the basis of WHO population data, and nine provided rates of surgery from which we calculated the total volume of surgery for the country. Reported rates of surgery ranged from 148 per 100 000 population (Ethiopia) to 23 369 per 100 000 population (Hungary). Webtable 1 shows the countries for which data were obtained and the year that the data were gathered, along with the per-head total expenditure on health, the population size, the number of operations, and the rates of surgery.

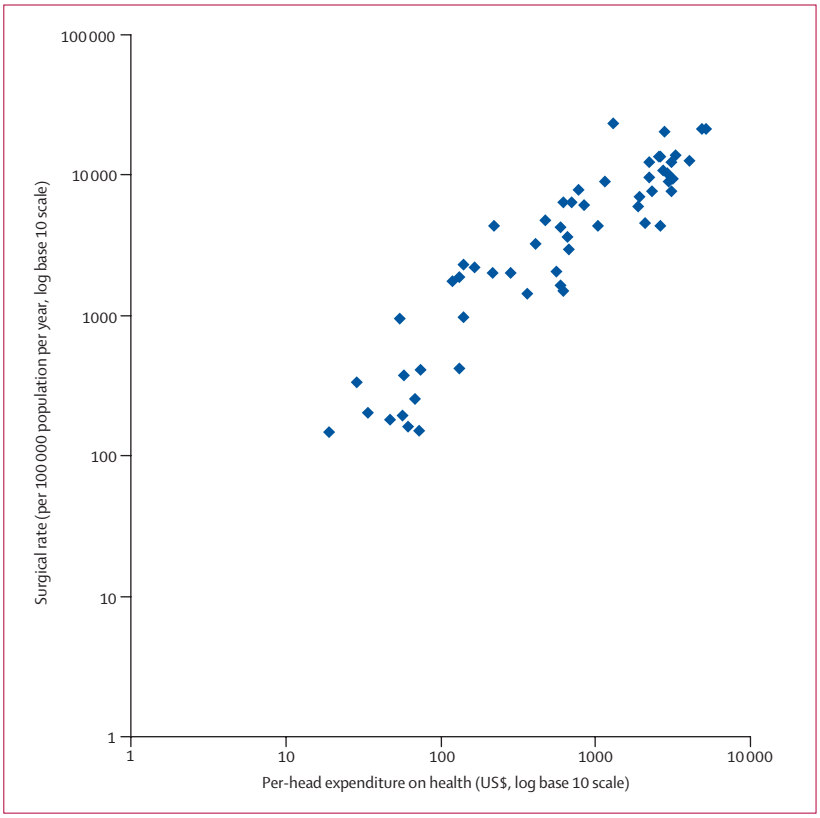

Figure: **Relation between surgical rate and total per-head expenditure on health (adjusted to 2004 US$) in 56 countries with known rates of surgery**
Spearman's r^2=0·996; p<0·0001.

Per-head expenditure on health was closely correlated with yearly surgical rates (r^2=0·996, p<0·0001; figure). We noted that as expenditure on health rose, so too did rates of surgery (figure). The results of our cross-validation assessment of this model showed that imputation accurately predicted surgical rates when the rate of surgery for a country with known data was eliminated from the model (r^2=0·868; p<0·0001).

Table 1 shows the characteristics of countries with and without available surgical data, adjusted for per-head expenditure on health. Average expenditure differed significantly between the two groups ($534 *vs* $237 for countries with and without data, respectively; p=0·0002), but after adjustment, we noted no significant difference in any of the measured covariates shown in table 1.

Webtable 2 lists every country for which we were unable to obtain surgical rates or volumes, along with its imputed surgical rate based on total expenditure on health. The estimated rate of surgery is the average of the 300 imputation sets, and the volume range represents the 99% prediction interval that was generated from the imputed data.

See Online for webtables 1 and 2

Table 2 shows the mean estimated surgical rate, volume, and population size stratified by level of health expenditure. Countries spending $100 or less per head on health care had an estimated average rate of surgery

	Countries with surgical data (n=56)	Countries without surgical data (n=136)	p value
Percentage of countries in sample, by region			0·11
African region	9 (16%)	37 (27%)	
American region	9 (16%)	26 (19%)	
Eastern Mediterranean region	5 (9%)	16 (12%)	
European region	23 (41%)	29 (21%)	
Southeast Asian region	2 (4%)	9 (7%)	
Western Pacific region	8 (14%)	19 (14%)	
Average population size (millions)	37·3 (17·9)	32·1 (11·2)	0·81
Average life expectancy (years)	67 (1·0)	66 (0·6)	0·47
Population living in urban areas (%)	54% (2·3)	56% (1·4)	0·41
Average literacy rate (%)	80% (2·3)	79% (1·3)	0·80
Population age structure (%)			0·18
<15 years	30% (0·9)	31% (0·6)	
15–59 years	59% (0·6)	59% (0·4)	
>59 years	11% (0·6)	10% (0·4)	
Average number of physicians per 1000 population	1·36 (0·47)	1·85 (0·29)	0·39
Average GDP in 2003 (US$)	5139 (267)	5368 (176)	0·49
Expenditure on health contributed by government (%)	59% (2·5)	59% (1·5)	0·93

Data are number (%) or mean (SE). All values are adjusted for per-head expenditure on health. GDP=gross domestic product.

Table 1: **Comparison of countries with and without available surgical data**

	Mean estimated surgical rate per 100 000 population (SE)	Estimated volume of surgery in millions (%; 95% CI)	Share of global population
Expenditure			
Poor-expenditure countries (N=47)	295 (53)	8·1 (3·5%; 3·4–12·8)	34·8%
Low-expenditure countries (N=60)	2255 (342)	53·8 (23·0%; 9·8–97·4)	35·0%
Middle-expenditure countries (N=47)	4248 (524)	34·3 (14·6%; 23·6–43·3)	14·6%
High-expenditure countries (N=38)	11 110 (1300)	138·0 (58·9%; 132·5–143·9)	15·6%
Overall			
Total global volume of surgery	..	234·2 (187·2–281·2)	..
Average surgical rate	4016 (431)	..	..

Expenditures are adjusted to 2004 US$. Poor-expenditure countries defined as per-head total expenditure on health $100 or less, low-expenditure countries as $101–400, middle-expenditure countries as $401–1000, and high-expenditure countries as >$1000. p<0·0001 for difference between expenditure groups.

Table 2: **Average national rate of surgery for countries in each category of health expenditure, with total volume of surgery contributed by each category**

of 295 major surgical procedures per 100 000 population per year. The rate increased to 2255 procedures for countries spending between $101 and $400, 4248 for those spending $401–1000, and 11 110 for those spending more than $1000 per head in total on health per year (table 2; p<0·0001 for equality of means by *F* test).

When we summed surgical volumes from countries with available and imputed data, the estimated total global surgical volume was 234·2 (95% CI 187·2–281·2) million major operations in 2004. Of these operations, 172·3 million (73·6%) occurred in high-expenditure or middle-expenditure countries—where 30·2% of the population resides—whereas the poorest 34·8% of the world's population received only 3·5% of all surgery undertaken (table 2).

Discussion

We have estimated that the global volume of major surgery in 2004 was between 187·2 million and 281·2 million cases per year. This result translates into about one operation for every 25 human beings, which has substantial implications for public-health planning. It exceeds by nearly double the yearly volume of childbirth—an estimated 136 million births occurred in 2006[15]—and is probably an order of magnitude more dangerous.[16–22]

Although death and complication rates after surgery are difficult to compare since the range of cases is so diverse, major morbidity complicates 3–16% of all inpatient surgical procedures in developed countries, with permanent disability or death rates of about 0·4–0·8%.[16,17] Nearly half of the adverse events in these studies were identified as preventable. In developing countries, studies suggest a death rate of 5–10% for major surgery.[18–20] Mortality from general anaesthesia is reported to be as high as one in 150 in parts of sub-Saharan Africa.[21] Infections and other postoperative morbidities are also a serious concern worldwide. With the assumption of a 3% perioperative adverse event rate and a 0·5% mortality rate globally, almost 7 million patients undergoing surgery have major complications, including 1 million that die during or immediately after surgery every year. Postoperative morbidity and mortality are probably far more common globally, but few countries have reliable information about inpatient death rates or other measures of adverse outcome. Therefore, our findings of volume of surgery undertaken suggest that surgical safety has now emerged as a substantial global public-health concern. Just as public-health interventions and educational projects have greatly improved maternal and neonatal survival,[22] so might analogous efforts in surgical safety and quality of care.

We recorded a disproportionately low volume of surgery in low-income settings, implying a disparity in access between rich and poor countries. Although less than a third of the world's people reside in countries with yearly per-head expenditures on health exceeding $400, roughly three-quarters of operations occur in this population. Conversely, the poorest third of the world's population—residing in countries in which per-head expenditure on health is $100 or less—receive just 3·5% of the operations that are undertaken worldwide. This finding strongly suggests the existence of a large unaddressed disease burden globally.

We chose to focus on operations occurring in operating theatres since these procedures are most

likely to involve high acuity, complexity, and risk for injury, complications, or death. We recognise that what might be done in an operating room in one setting can also be done in a clinic procedure room in another. Ambiguous procedures such as percutaneous interventions, endoscopy, radiographically-guided procedures, closed fracture reductions, and wound debridement might be regarded as major procedures but for the location of the intervention if done outside of a formal operating room. Conversely, so-called minor surgical procedures that are undertaken in an operating room such as abscess drainage or examinations under anaesthesia could be categorised as major. By standardising the definition, however, we have reduced the difficulties that would otherwise be posed by differences in practice patterns.

This study has, without question, major limitations that make our estimates necessarily provisional. The fact that less than a third of countries could offer data for surgical volume is an indication of not only how difficult making an accurate global estimate of surgery is, but also how inadequate present health-care surveillance is. Even for the countries for which we were able to obtain estimates of volume of surgery, virtually none had reliable information about inpatient death rates or other measures of adverse outcome. An absence of standardisation in data collection contributed to difficulties in data aggregation and interpretation. Countries using International Classification of Disease (ICD) data to assess volume of surgery might not count several operations in one patient. Billing data might miss private surgical care when gathered from a single payer system, such as government-run health insurance. Facility level surveys that are undertaken by governments typically omit private clinic and private hospital data. Furthermore, few countries reported outpatient surgical procedures and some did not capture specialty procedures such as gynaecological or orthopaedic operations. Some national data separated major from minor surgical procedures, but without clear definitions for the distinction. Finally, as indicated in webtable 1, estimates for some low-income and middle-income countries required extrapolation from regional data.

In view of these concerns, we did not try to estimate the exact volume of surgery that occurs worldwide, but instead the probable minimum volume. To avoid overestimates of surgery in the countries with data, we sought to use consistently conservative assumptions. We did not attempt to correct for the absence in some countries of data for any outpatient, private, or specialty surgery. We excluded minor surgical procedures in countries that counted them. When calculating surgical rates for countries supplying volume data only for years before 2004 (when surgical volume was likely to be lower) we did not adjust the data and we used updated population estimates (which have increased), to allow for a systematic underestimate. Similarly, regional data extrapolated across a country are probably an underestimate of national rates: in all but two cases they were obtained from rural hospitals serving very underserved districts, whereas most doctors and facilities capable of providing surgical services are found in urban areas.[8]

Additionally, legitimate concern exists about the accuracy of imputing from these estimates to the other 71% of the countries. We therefore assessed the data to establish whether there was any appreciable difference between countries with data for volume of surgery and those without. We obtained surgical data from countries representing all six WHO regions and differing levels of development, health systems, and population sizes and age structures. Once we accounted for per-head expenditure on health, we noted no significant residual differences between these groups on any of the key covariates. Thus multiple imputation protects against systematic bias. The excellent explanatory power of the model and the predictive ability upon cross-validation suggest that our calculations of the global surgical volume, although inevitably provisional, offer a meaningful and reliable estimate. However, although the imputation model can be expected to produce a reliable estimate of aggregate global volume of surgery, estimates for any individual country, as shown in webtable 2, can be imprecise.

Our findings suggest that surgery now occurs at a tremendous volume worldwide, in settings both rich and poor. The implications are substantial. This unappreciated worldwide growth shows a great need for public-health efforts to improve the monitoring, safety, and availability of surgical services, especially in view of their high risk and expense. A public-health strategy for surgical care is paramount.

Contributors

TGW, SER, WRB, and AAG were responsible for the study conception and design. TGW, KDT, and ABH acquired the data. TGW, SER, SRL, and AAG analysed and interpreted the data. TGW drafted the report, which was critically revised by TGW, SER, ABH, WRB, and AAG. All authors read and approved the final report.

Conflict of interest statement

We declare that we have no conflict of interest.

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