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Half a billion surgical cases: Aligning surgical delivery with best-performing health systems

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Abstract

Background—Surgical delivery varies 200-fold across countries. No direct correlation exists, however, between surgical delivery and health outcomes, making it difficult to pinpoint a goal for surgical scale-up. This report determines the amount of surgery that would be delivered worldwide if the world aligned itself with countries providing the best health outcomes.

Methods—Annual rates of surgical delivery have been published previously for 129 countries. Five health outcomes were plotted against reported surgical delivery. Univariate and multivariate polynomial regression curves were fit, and the optimal point on each regression curve was determined by solving for first-order conditions. The country closest to the optimum for each health outcome was taken as representative of the best-performing health system. Monetary inputs to and surgical procedures provided by these systems were scaled to the global population.

Results—For 3 of the 5 health outcomes, optima could be found. Globally, 315 million procedures currently are provided annually. If global delivery mirrored the 3 best-performing countries, between 360 million and 460 million cases would be provided annually. With population growth, this will increase to approximately half a billion cases by 2030. Health systems delivering these outcomes spend approximately 10% of their GDP on health.

Conclusion—This is the first study to provide empirical evidence for the surgical output that an ideal health system would provide. Our results project ideal delivery worldwide of approximately 550 million annual surgical cases by 2030.

Although 30% of the global burden of disease could benefit potentially from surgical management,^{1,2} surgery has not to date played an extremely prominent role in discussions of health-system strengthening.³ This lack of involvement has led to extreme variability in global surgical delivery across countries: some countries provide fewer than 150 operations per 100,000 in their population, whereas others provide almost 30,000.⁴

On January 17, 2014, Jim Kim, President of the World Bank called surgery “an indivisible, indispensable part of health care”⁵; this year, the third edition of the *Disease Control Priorities in Developing Countries* and the final report of *The Lancet* Commission on Global Surgery will both be released. Each will call for increased attention to and investment in surgery and for scale-up of the surgical infrastructure.

Similarly, both the United Nations (UN) and the World Health Organization have called for health systems that address not only the full health needs of their populations but also their financial risk protection as the world invests to reach these goals.^{6,7} Surgery is a cost-effective public health intervention⁸⁻¹¹; its expansion is likely to become necessary in many countries.

The need for scale-up, however, begs some questions. Given the tremendous variability in surgical volume across countries, how can scale-up decisions be made logically? Toward what goals should the global surgical community strive? Complicating these questions is the paucity of surgical data in international data registries, databases, and health surveys.

The ability of a health system to provide surgical procedures has some correlation with overall health outcomes. As we will demonstrate below, countries with greater rates of surgical procedures tend toward better health outcomes, but the correlation is not perfect. Of interest in this estimation, then, is whether the correlation linear: that is, do more procedures always correspond to better health outcomes?

Given these limitations in data availability, precise, country-specific surgical volume targets for scale-up are impossible to derive. What may be possible, however, is an estimate for surgical delivery based on what is known about surgical volume and the data available on common and very important health outcomes.

This report attempts to quantify the surgical volume in countries for which data are available and compare surgical volume with common health outcomes. We then use the surgical volume of each country to model what global surgical output would look like if all countries performed at the capacity of the index (target) country. Given that the current world surgical volume is known,¹² this will help to provide upper and lower bounds for what worldwide surgical volume could look like on the basis of how known nations perform presently.

Methods

Data sources

The number of procedures performed per 100,000 in the population used as their current surgical delivery was available for 129 individual countries, as well as for country-level groupings.⁴ Inputs into the health system of each of the 129 countries, namely health

expenditure per capita and the proportion of gross domestic product (GDP) devoted to health, were taken from World Bank estimates.^{13,14} Similarly, life expectancy, under-5 years of age mortality rate, maternal mortality ratio, and adult mortality were taken to represent the outputs of each health system.¹⁵⁻¹⁷ Global population prediction for 2030 was derived from estimates published by the UN.¹⁸

Univariate model construction

From the cases performed per 100,000, the overall number of cases performed globally at the current world population was calculated. This estimate was scaled linearly to predict the number of cases that would be performed at current levels for the global population in 2030. The number of cases per population in each of the countries for which data were available was then applied to the world population to determine how many cases the world would be performing were it operating at the level of each of these countries.

As an overlay, input and outcome measures from each of the 129 countries were plotted against the surgical numbers. In addition to the 4 outcome measures of life expectancy at birth, maternal mortality ratio, under-5 years of age mortality rate, and adult survival, a fourth outcome measure was constructed by linear summation of standardized values for the 4. Namely:

$$y = \frac{1}{4} \left[\frac{L}{\max(L)} + \frac{U}{\max(U)} + \frac{M}{\max(M)} + \frac{A}{\max(A)} \right]$$

where L represents life expectancy at birth, U represents the under-5 years of age survival rate per 1,000 live births, M represents the maternal survival ratio, per 100,000 live births, and A represents adult survival rate per 1,000.

Polynomial regression lines were fitted to each of the 4 measures plotted against the number of surgical cases per 100,000 provided by each country. The pseudo- R^2 for each regression curve was calculated by summing the square of the difference between the predicted and actual values, divided by the sample size times the variance of the actual values.

For each measure, the maximum was found by solving the first-order condition of the polynomial regression. If the maximum was within the list of countries, the country nearest that maximum was then selected and its surgical output applied to the world population. If the maximum was not, this was reported. Finally, financial inputs of the health system from each of these countries were determined, both nominally and along a similarly fitted polynomial regression.

Scatter plots and multivariate model construction

In addition to plotting outcomes against country ranking, we plotted outcomes against surgical output per 100,000. Logged regression curves fitted to these outcomes were compared against development goals proposed by the UN. A multivariate regression model was constructed to determine the association between the standardized outcome and number of surgical cases provided by each country, the population per-capita health expenditure,

per-capita gross domestic product, and urban proportion of the country. Nonlinearity in the fit was corrected with a Box-Cox power correction.¹⁹ Statistical analyses were performed in Microsoft Excel (Redmond, WA) and in R v3.0.

Results

Model fit

The fitted polynomial regressions for the selected outcome ranged in predictive ability. Pseudo- R^2 varied from 0.100 (composite outcome) to 0.605 (maternal survival).

Current use

At present, the world is estimated to perform 315 million cases or 4,469 cases per 100,000 in the population. This estimate is greater than previous estimates from 2008,⁴ but the increase is almost completely attributable to an increase in the global population.

At the lowest end, if the world operated at the level of the Democratic Republic of Congo, it would provide 10.1 million cases/year. To point out this disparity, if the world operated at the level of high-expenditure countries, it would provide nearly 800 million cases per year. Estimated numbers are given in Table I.

Aligning use with outcomes

Figure 1 shows maternal survival per 100,000 live births plotted against surgical provision overlain with a fitted polynomial regression line. An inflection point is noted at the level of Zimbabwe (5,168 cases per 100,000 in the population). Similar regression lines were fitted for the adult survival rate per 1,000, and the under-5 years of age survival per 1,000, life expectancy at birth, and the linear composite measure of all four outcomes. Maxima were found for under-5 years of age survival (Kuwait, 5,971 cases per 100,000), and the composite outcome (Iraq, 5,409 cases per 100,000). No maximum was found for the other 2 outcomes.

Table II shows the number of cases the world would provide if the world operated at the level of each of these optima, at the present moment and extrapolated to 2030. Table II also shows the regressed health system inputs needed to achieve these outcomes. To achieve the optimal outcomes noted, approximately 10% of a country's GDP would need to be spent on health.

Figure 2 presents a scatterplot of maternal survival per 100,000 live births against surgical provision with a logarithmic regression line. To achieve a maternal mortality rate of fewer than 40 deaths per 100,000, which is the proposed target for the post-2015 sustainable development goals, countries should provide approximately 6,200 cases per 100,000 in the population, which translates into 442 million cases annually around the world.

Taking country characteristics such as size, urban/rural breakdown, and GDP per capita into account in a multivariate regression pushed the optimal number of cases greater. Figure 4 shows this multivariate regression for maternal survival. The optimal number is at

approximately 6,500 cases per 100,000 in the population, which translates into approximately 460 million annual surgical cases globally.

Discussion

Currently, the world delivers approximately 315 million surgical cases per year. Optimal health outcomes when they can be found lie between 5,000 and 6,000 surgical procedures per 100,000 in their population, which translates to between 360 and 460 million cases per year globally. When population growth is taken into account, these estimates increase further to between 430 million and 550 cases by 2030.

Surgery is an integral part of a functioning health system.³ Surgical delivery, however, varies more than 200-fold among countries, from as low as 144 cases per 100,000 in the population to as high as 29,000.¹² The ability of a health system to deliver surgery does not, however, correlate perfectly with health outcomes. Although surgical delivery by a health system does increase as countries become more wealthy, there is significant variability among countries within different World Bank income groups (Fig 1 and Table I), and outcomes conditional on surgical delivery, also vary widely (see, for example, Fig 2).

Because of the integral nature of surgery in a health system and because surgery has been shown to be cost-effective,^{8,9,11,20,21} the expansion of surgical delivery is necessary in many countries as they work to achieve universal health coverage.^{6,7} How far this expansion should go is unclear: should, for example, countries aim for surgical delivery mimicking that in the greatest-producing countries of the United States and Norway? Or does another goal align more closely with health outcomes?

By examining the surgical delivery of the best-performing health systems with respect to health outcomes as well as by constructing a composite outcome of health outcomes, we predict that the latter is more likely true. That is, maximizing surgical delivery does not necessarily lead to maximized outcomes. The goal for expansion should therefore, fall somewhere on the order of approximately 5,000–6,000 procedures for every 100,000 individuals in the population. This estimate of surgical delivery appears true whether an optimal number is found as in Fig 1 or whether outcomes are benchmarked to a global goal for maternal survival as in Fig 2.

There are obvious limitations to this report. No worldwide surgical outcomes are tracked, which means that the outcomes chosen in this paper are broad and not necessarily surgical.¹³⁻¹⁷ More importantly, these outcomes are dependent on surgery only inasmuch as they are measures of the capacity of a health system in general. For example, Maternal mortality ratio decreases with increased prenatal care, decreased fertility, and improved nutrition, among others. Our report does not attempt to make the case that delivering 6,000 surgical procedures per 100,000 individuals in the population will necessarily decrease maternal mortality. Our report does, however, argue that increasing a health system to the level at which maternal mortality achieves the proposed UN goals will likely also increase that health system to the level at which the health system will provide this surgical output.

In addition, the conclusions in this report are made from data available for only 129 countries, and as a result, the generalizability of these results to the world is not guaranteed. As Fig 2 shows, however, the correlation between the number of surgical cases provided by a health system and maternal mortality is quite robust. Finally, some of the best-performing countries identified have undergone the epidemiologic transition.²² Countries that have not yet gone through this transition or which face a “double burden” of disease²³ may require more surgical delivery than is estimated by this model.

As a measure of inputs into the health system, we examined the percent of GDP spent on health care in each of the 129 countries. There is substantial variability among countries on health care expenditures. As a result, nominal data were not presented and variability was smoothed by fitting a polynomial regression line to health expenditure to approximate what a best-performing health system would spend on health care. Best-performing health systems will spend approximately 10% of their GDP on health care. Although public spending on health care is one of many factors that influence outcomes, and it interacts with spending on education and sanitation, governance, and nationwide infrastructure, our results are consistent with previous results in which investigators showed the association between public spending on health and child mortality.²⁴

It is impossible to determine the *ideal* number of surgical procedures any health system, let alone the world at large, should perform; this report, however, attempts to give an approximate sense for the surgical output of a world whose health system operated at the level of the currently best-performing health systems. The causal direction of the correlations noted obviously cannot be inferred from our data; surgical delivery is likely to be better in robust health systems, and these same robust health systems generally are able to deliver better health outcomes. The fact remains, however, that strengthening health systems often is associated with increased surgical delivery, which itself is correlated with improved outcomes.

In conclusion, the health system that delivers best outcomes for life expectancy, under-5 years of age mortality, and maternal mortality provides approximately 5,000–6,000 surgical procedures per 100,000 in the population and spends approximately 10% of GDP on health. Were this level of surgical delivery to exist around the world, between 360 and 460 million surgical procedures would be performed annually; that number is expected to increase to more than half a billion procedures by 2030.

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Fig 1.

The best-predicted maternal survival occurs at approximately 5,200 surgical cases per 100,000 in the population are performed (quasi- $R^2 = 0.605$). See text for details.

Fig 2.

Surgical output and maternal mortality. To achieve the proposed UN goal of 40 deaths or fewer per 100,000 live births, countries should aim for approximately 6,000 surgical procedures per 100,000 in the population. The *horizontal line* corresponds to the UN goal.

Table I
How many cases would the world provide if it operated at the level of the following countries/regions

If the world operated at the level of:	Number of cases per y
Democratic Republic of Congo	10.1 million
Low-expenditure countries	47.0 million
Lower-middle-expenditure countries	280.5 million
Upper-middle-expenditure countries	340.4 million
Current global estimate	315.4 million
High-expenditure countries	788.3 million
Norway	2.1 billion

“Expenditure” groups countries by how much they spend on their health systems.

Table II
Local optima in outcomes and regressed and nominal health system inputs

To align with countries providing the best:	The world would look like:	Cases/y, 2012	Projected cases/y, 2030	Percent of GDP spent on health, regressed
Under-5 y of age survival	Kuwait	421 million	497 million	11.85%
Maternal survival	Zimbabwe	364 million	430 million	10.2%
Standardized outcome measure	Iraq	382 million	450 million	10.6%