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Global economic burden of unmet surgical need for appendicitis

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Abstract

Background: There is a substantial gap in provision of adequate surgical care in many low- and middle-income countries. This study aimed to identify the economic burden of unmet surgical need for the common condition of appendicitis.

Methods: Data on the incidence of appendicitis from 170 countries and two different approaches were used to estimate numbers of patients who do not receive surgery: as a fixed proportion of the total unmet surgical need per country (approach 1); and based on country income status (approach 2). Indirect costs with current levels of access and local quality, and those if quality were at the standards of high-income countries, were estimated. A human capital approach was applied, focusing on the economic burden resulting from premature death and absenteeism.

Results: Excess mortality was 4185 per 100 000 cases of appendicitis using approach 1 and 3448 per 100 000 using approach 2. The economic burden of continuing current levels of access and local quality was US $92 492 million using approach 1 and $73 141 million using approach 2. The economic burden of not providing surgical care to the standards of high-income countries was $95 004 million using approach 1 and $75 666 million using approach 2. The largest share of these costs resulted from premature death (97.7 per cent) and lack of access (97.0 per cent) in contrast to lack of quality.

Conclusion: For a comparatively non-complex emergency condition such as appendicitis, increasing access to care should be prioritized. Although improving quality of care should not be neglected, increasing provision of care at current standards could reduce societal costs substantially.

Background

It has been estimated that, each year, 143 million additional surgical procedures need to be done in low- and middle-income countries to prevent disability and reduce mortality[1]. The associated loss of economic productivity has been estimated at $12.3 trillion for the interval 2015–2030[1]. In addition to insufficient access to surgery, it has been recognized that outcomes of surgery can be suboptimal for many patients in low- and middle-income countries. This is reflected in the higher rate of perioperative mortality and surgical-site infections experienced by patients undergoing surgery in low- and middle-income countries compared with those in high-income countries[2,3]. This high-level evidence has been insufficient to prompt large-scale policy change and substantial investment in surgery. The cost to a given society of not providing adequate surgical care for specific conditions might provide direct evidence that more targeted investment in surgical services could be cost-effective.

Surgery is a treatment for many diverse conditions[4]. Although the magnitude of lack of access to quality surgical care has been estimated, developing a health service to provide such holistic surgical care for all conditions may not currently be attainable. It should, however, be within the reach of many countries to provide services to treat some conditions that are otherwise fatal and require a fairly simple procedure[5].

Appendicitis is a common condition, with an incidence of around 17 700 000 in 2019[6]. Although it leads to death or disability if not treated, timely surgical treatment results in a rapid return to normal function. It disproportionally affects younger populations, who are generally economically productive. Hence, lack of access to surgical treatment for appendicitis is likely to have substantial economic consequences for individuals and societies.

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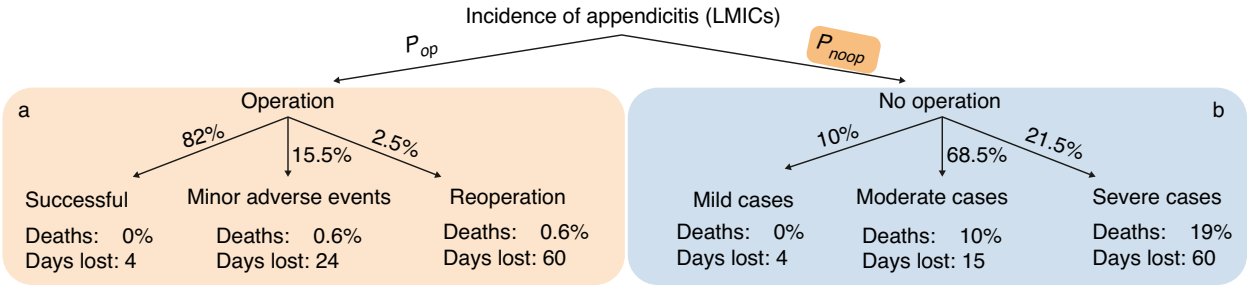
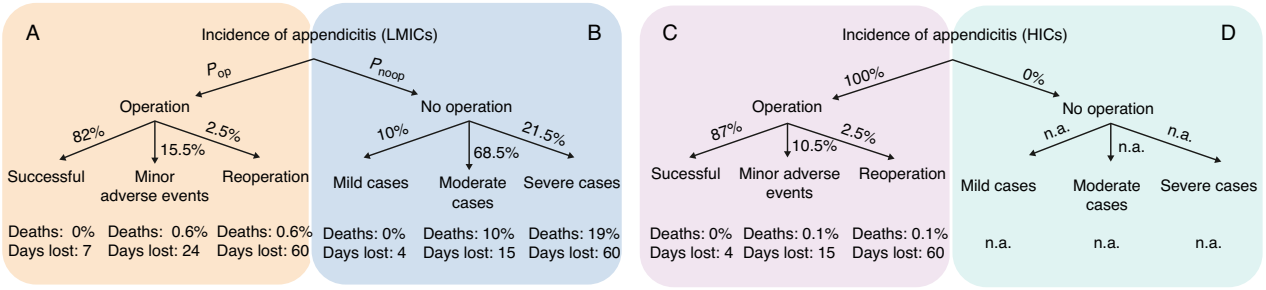
a Adverse events resulting from not providing surgery to the local standard



Rationale: Which adverse events (mortality share/number of working days lost*) occur per case of appendicitis because the quantity of operations is insufficient in LMICs?

$$P_{noop} * (b - a)$$

b Adverse events resulting from not providing surgery to the highest standard



Rationale: Which adverse events occur because the care provision (quantity and quality) in LMICs is worse than in HICs?

$$(A + B) - (C + D) \Rightarrow (A + B) - C\dagger$$

Fig. 1 Calculation of expected mortality risk and number of absent days

a Resulting from not providing surgery to the local standard, and **b** resulting from not providing surgery to the highest standard. *Non-fatal cases. †Assuming that all patients with appendicitis undergo surgery in high-income countries (HICs), such that D = 0. LMICs, low- and middle-income countries; n.a., not applicable.

Table 1 Key statistics by WHO region

	Africa	Americas	Eastern Mediterranean	Europe	South-East Asia	Western Pacific	World
No. of countries	44	29	18	50	10	19	170
Incidence per 100 000, mean (s.d.)*	184.27 (72.21)	359.73 (185.64)	264.86 (47.48)	232.25 (45.75)	517.36 (526.16)	234.50 (111.59)	262.05 (177.08)
Surgical volume per 100 000, mean (s.d.)†	1167 (1305)	5635 (5158)	3305 (2243)	7890 (4463)	1784 (1878)	4637 (6365)	4557 (4767)
No. of appendicectomies per 100 000 (approach 2), mean (s.d.)‡	74.17 (62.19)	213.05 (236.18)	112.63 (73.14)	181.78 (137.17)	107.49 (87.45)	132.88 (97.81)	142.10 (142.65)
Unmet need (%) (approach 1), mean (s.d.)‡	76.65 (26.10)	24.59 (28.75)	35.48 (35.73)	8.20 (18.18)	67.21 (29.96)	40.23 (36.02)	38.65 (38.14)
Unmet need (%) (approach 2), mean (s.d.)‡	60.24 (27.19)	33.64 (32.62)	31.08 (31.57)	5.21 (15.18)	58.19 (36.95)	20.36 (28.37)	31.85 (34.15)
Wage per capita, mean (s.d.)§	6544 (7450)	17 609 (12 994)	18 437 (12 664)	28 174 (16 895)	6288 (3694)	20 689 (19 966)	17 618 (16 056)
Total population (millions)¶	979.14	974.59	659.54	913.32	1921.74	1844.54	7301.06

Approach 1 calculates unmet need for appendicitis assuming that the proportion of this unmet need is equivalent to the unment need for all conditions requiring surgery. Approach 2 calculates unmet need as the relative difference of estimated appendicectomies (calculated as World Bank income group-specific share of surgical volume) to the number of appendicitis cases. *Institute for Health Metrics and Evaluation Global Burden of Disease. †Holmer *et al.*[10]. ‡Detailed description available in *supplementary material S.3*. §Organisation for Economic Co-operation and Development, International Labour Organization (harmonized to 2015 US dollar purchasing power parity). ¶World Bank World Development Indicators. Country-specific inputs are shown in *supplementary material Table S9* and graphs of unmet need by region and income group in *Fig. S8*.

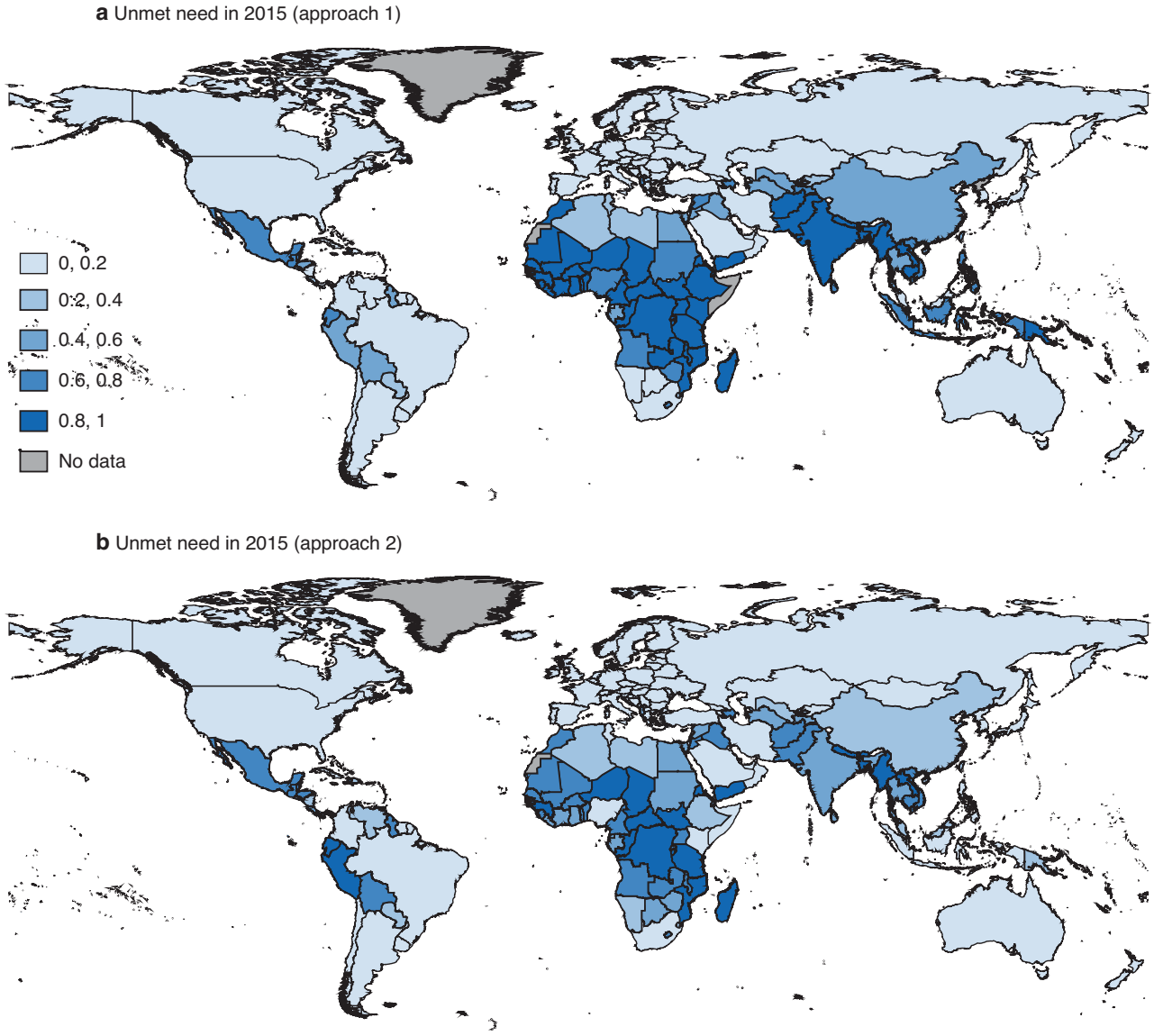


Fig. 2 Estimated share of unmet need in 2015 by country Calculated using

a approach 1 and **b** approach 2. Approach 1 calculates unmet need for appendicitis assuming that the proportion of this unmet need is equivalent to the unment need for all conditions requiring surgery. Approach 2 calculates unmet need as the relative difference of estimated number of appendicectomies (calculated as World Bank income group-specific share of surgical volume) to the number of appendicitis cases.

Effective treatment of appendicitis requires appropriate and timely surgery, necessitating ready access to acute services[7], unlike planned procedures that can be referred to a tertiary centre. Appendicitis can vary in severity from self-limiting infection to life-threatening peritonitis, depending on the development of irreversible, but unpredictable, gangrene. The safest treatment is, therefore, early surgery. Effective surgery for appendicitis is also reflective of local and district surgical services[8], and improved delivery is likely to have additional benefits for other common surgical conditions.

Estimates are available for the global incidence of appendicitis[6], the unmet need for surgery[1], and of harm from lack of access to quality surgery, including procedures for appendicitis[2]. However, there has been no previous estimation of the global economic burden associated with failure to provide access to quality care for appendicitis. Given that access to surgical treatment for appendicitis reflects local surgical care provision, such information is needed to inform discussions on the investment case for provision of surgical care at country, regional, and international levels[1,9].

This study assessed the economic burden (from loss of income) associated with unmet or delayed or substandard surgical care in low- and middle-income countries. The study focused on two types of indirect cost: lost income owing to premature death and lost income due to absenteeism and/or sick days.

Methods

This study calculated the economic burden in two scenarios: that resulting from not providing surgery at local standards in low- and middle-income countries; and that resulting from not providing surgical care in these countries at the standard available in high-income countries, which, based on the literature[3], was assumed to reflect optimal (high-quality) care.

Table 2 Economic burden estimates

		Africa	Americas	Eastern Mediterranean	Europe	South-East Asia	Western Pacific	World
No. of countries		44	29	18	50	10	19	170
Mortality-related income losses								
Not providing surgery to local standard								
Approach 1	US $ (millions)	6219	9777	7808	1415	29 186	36 627	91 031
	% of GDP	0.1781	0.0352	0.1232	0.0050	0.2602	0.1337	0.0870
Approach 2	US $ (millions)	4445	13 316	6819	889	24 040	22 476	71 984
	% of GDP	0.1273	0.0479	0.1076	0.0031	0.2144	0.0820	0.0688
Not providing surgery to highest standard								
Approach 1	US $ (millions)	6305	9969	7919	1619	29 419	37 151	92 383
	% of GDP	0.1806	0.0359	0.1249	0.0057	0.2623	0.1356	0.0883
Approach 2	US $ (millions)	4532	13 508	6930	1094	24 273	23 000	73 336
	% of GDP	0.1298	0.0486	0.1093	0.0038	0.2164	0.0840	0.0701
Absenteeism-related income losses								
Not providing surgery to local standard								
Approach 1	US $ (millions)	95	154	122	23	446	622	1461
	% of GDP	0.0027	0.0006	0.0019	0.0001	0.0040	0.0023	0.0014
Approach 2	US $ (millions)	69	206	107	14	372	389	1157
	% of GDP	0.0020	0.0007	0.0017	0.0001	0.0033	0.0014	0.0011
Not providing surgery to highest standard								
Approach 1	US $ (millions)	165	318	214	206	631	1086	2622
	% of GDP	0.0047	0.0011	0.0034	0.0007	0.0056	0.0040	0.0025
Approach 2	US $ (millions)	141	367	200	198	561	863	2330
	% of GDP	0.0040	0.0013	0.0032	0.0007	0.0050	0.0032	0.0022
Total economic burden								
Not providing surgery to local standard								
Approach 1	US $ (millions)	6314	9931	7929	1437	29 631	37 249	92 492
	% of GDP	0.1808	0.0358	0.1251	0.0051	0.2642	0.1360	0.0884
Approach 2	US $ (millions)	4515	13 521	6925	903	24 411	22 865	73 141
	% of GDP	0.1293	0.0487	0.1093	0.0032	0.2177	0.0835	0.0699
Not providing surgery to highest standard								
Approach 1	US $ (millions)	6470	10 287	8133	1825	30 050	38 238	95 004
	% of GDP	0.1853	0.0370	0.1283	0.0064	0.2680	0.1396	0.0908
Approach 2	US $ (millions)	4672	13 875	7130	1291	24 834	23 863	75 666
	% of GDP	0.1338	0.0500	0.1125	0.0045	0.2214	0.0871	0.0723

US dollars are expressed in 2015 purchasing power parity. Absolute costs are the sum of the respective country-level costs by region; relative costs are absolute costs divided by the sum of country gross domestic product (GDP) by region. Approach 1 calculates unmet need as the relative difference of surgical volume to the minimum surgical volume proposed by the Lancet Commission on Global Surgery. Approach 2 calculates unmet need as the relative difference of estimated appendicectomies (calculated as World Bank income group-specific share of surgical volume) to the number of appendicitis cases. Country-specific results can be found in *supplementary material Fig. S10*, *Fig. S11*, and *Table S11*; intermediate results by region and income group in *supplementary material Fig. S9*; and sex-specific results by region in *supplementary material Fig. S12* and *Fig. S13*.

The economic burden attributed to scenario 1 could be avoided by increasing the coverage of operations to all who require them while keeping the standard of care in each country the same as it is currently. Scenario 2 involves increasing the coverage of operations to all who require them while increasing the standard of care in each country to be equivalent to that seen in high-income countries. Additionally, the study estimated the total economic burden experienced owing to the current state of care across countries, that is the consequences of providing surgical care of local standard to the proportions of people who currently receive care, and providing no surgical care to those who do not. *Supplementary material S.2* provides a detailed description of the method, and details of the data sources and indicator construction can be found in *supplementary material S.3*. The main analysis was conducted at country level, although some data inputs were available only at the level of country-income groups. The results are presented aggregated to WHO region in the main

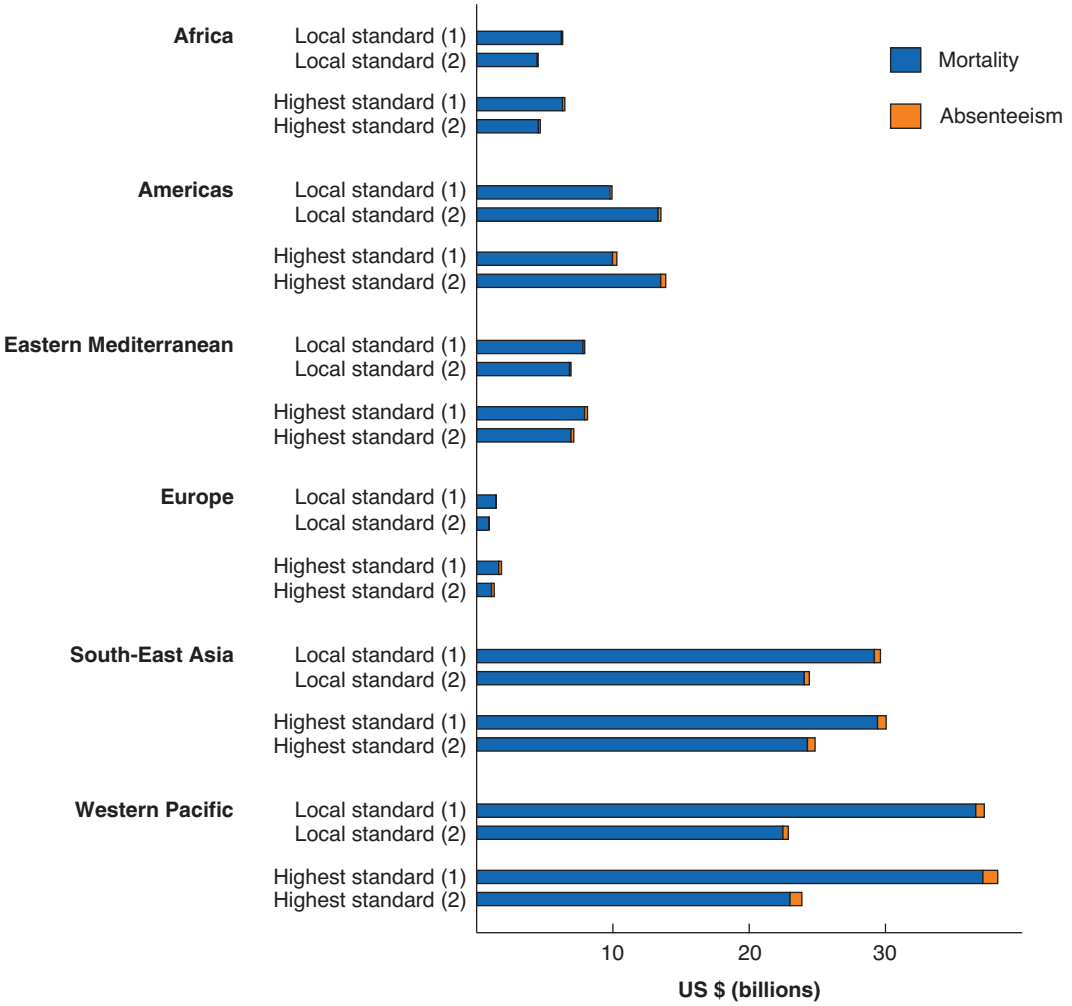


Fig. 3 Composition of economic burden

Economic burden is expressed in 2015 US dollar purchasing power parity. Approach 1 calculates unmet need as the relative difference of surgical volume to the minimum surgical volume proposed by the Lancet Commission on Global Surgery. Approach 2 calculates unmet need as the relative difference of estimated number of appendicectomies (calculated as World Bank income group-specific share of surgical volume) to the number of appendicitis cases.

text. The estimates are presented for the year 2015 as this was the latest year for which data from most sources were available.

Unmet surgical need

All scenarios required information on the number of individuals with appendicitis who do not receive any surgical care. For this, estimates of the incidence of appendicitis for a given country and 5-year age group in 2015 from the Global Burden of Disease project were used[6]. Data on numbers of appendicectomies performed (or the shortage of appendicectomies) were not available for most countries. Thus, the unmet need was estimated using the following two approaches. The first approach assumed a need for surgical volume of 5000 operations per 100 000 people, for all conditions that should be treated surgically, following the Lancet Commission on Global Surgery[1]. Using data on a country's total surgical volume delivered from Holmer *et al.*[10], the gap between surgical need and volume was defined as the unmet need. It was assumed that the proportion of unmet need for appendicitis is equivalent to that for all conditions requiring surgery.

The second approach assumed that appendicectomies comprise a certain share of surgical volume, with that share varying depending on characteristics of the country. This approach was taken based on the knowledge that lower-income countries perform a larger volume of emergency and gastrointestinal procedures (such as appendicectomy), relative to total surgical volume, than high-income countries[11]. Given that data on volume of appendicectomies to surgical volume were not available for most countries, several steps were taken to derive these estimates. First, information on the ratio of appendicectomies to gastrointestinal surgery from 116 countries was taken from the COVIDSurg Collaborative, GlobalSurg Collaborative database[12]. Second, information on the share of gastrointestinal surgery relative to total surgical volume in low- and middle-income countries was taken from multiple publications identified in a systematic search of the literature, as listed in the *supplementary material Table S2*. Data from England's Hospital Episode Statistics were used as a proxy for data from high-income countries. Data from low-, middle-, and high-income countries are shown in the *supplementary material* to illustrate how the ratio of gastrointestinal surgery to total surgery varies between World Bank income groups. Although these data were used to calculate the predicted number of appendicectomies for high-income countries, it was assumed that there is no unmet need in such countries; thus, the resulting figures were not included in the estimation. Third, a

combination of these sources was used to predict the number of appendicectomies for each country based on its surgical volume from Holmer *et al.*[10]. The gap between a country's incidence of appendicitis and the predicted number of appendicectomies was then defined as the unmet need.

For both approaches, it was assumed that all patients with appendicitis in high-income countries receive surgical treatment. Organisation for Economic Co-operation and Development (OECD) data for 25 high-income countries in 2015 showed that, for most countries, the number of cases of appendicitis was very close to the number of appendicectomies performed[13,14].

Economic burden estimation

This study focused on two types of income loss: that resulting from early death and that associated with absenteeism. In the first step, the mortality and absenteeism outcomes of surgical treatment in low- and middle-income countries were estimated using surgical treatment at a standard received in low- and middle-income countries and that in high-income countries (as highest available standard), and outcomes of no surgical treatment at all (described in detail in *the supplementary material Section S2*). Estimates of the probabilities and mortality or absenteeism (days lost) outcomes were based on adverse events of surgically treated appendicitis from the GlobalSurg Collaborative database[3,15] (exact definitions are available in *supplementary material Table S2*). The outcomes of not surgically treating appendicitis in low- and middle-income countries rely on the literature summarized in the *supplementary material Table S6*. Multiplied by the share of unmet surgical need, this gave the expected mortality risk and the number of days absent from employment resulting from not providing surgery to the local or highest standard to an individual with appendicitis (*Fig. 1*).

In the next step, the expected mortality risk was multiplied by the age-specific incidence of appendicitis to obtain the total number of expected deaths for a given country and age group. The associated income losses were calculated by multiplying the number of expected deaths by the earnings the individuals were expected to have received if they had not died. Similarly, the expected number of absent days was multiplied by the share of unmet surgical need and the incidence of appendicitis to obtain the total number of expected lost working days for a given country. Absenteeism-related income losses were calculated by multiplying the lost working days by the average daily wage. Estimates of the average annual wage for each country were extracted from the International Labour Organization[16,17] and OECD[18] databases, and all costs were expressed in US dollar purchasing power parity (PPP), deflated to the year 2015. All costs were aggregated by WHO region to display the main results. Country-level results are available in the *supplementary material Fig. S16, Table S11*.

Results

Table 1 shows the key statistics used to calculate the economic burden of unmet surgical need by WHO region. The estimated share of unmet need was higher using the first approach than the second for all regions except the Americas. This was also evident at country level (*supplementary material Fig. S8*).

Country-specific shares of unmet need are shown in *Fig. 2*, which allows a more detailed comparison of the two approaches. For most countries, approach 1 yielded a higher unmet need than approach 2, whereas the reverse applied mostly to Latin American countries (*supplementary material Fig. S8*).

As an intermediate outcome, excess mortality resulting from not providing surgery to local standards was estimated at 4185 per 100 000 patients with appendicitis using approach 1 and 3448 per 100 000 using approach 2 across the whole sample (*supplementary material Table S10*). The rate was highest in Africa (8299 per 100 000 for approach 1 and 6522 per 100 000 for approach 2) and South-East Asia (7277 and 6301 per 100 000, respectively). The mortality rate from not providing surgery at the highest standard was slightly higher, on average 4237 per 100 000 (approach 1) and 3500 per 100 000 (approach 2) across the sample.

The resulting income loss estimates are shown in *Table 2*. Mortality-related income losses resulting from not providing surgery to the current local standard of care amounted to $91 031 million (2015 PPP) for all countries using approach 1, ranging from $1415 million for Europe and $36 637 million for Western Pacific. Using approach 2, the mortality-related income losses totalled $71 984 million, ranging from $889 million in Europe to $24 040 million for South-East Asia. Expressed as a percentage of gross domestic product (GDP), the economic burden ranged from 0.0050 per cent of GDP in Europe to 0.2602 per cent of GDP in South-East Asia using approach 1, and from 0.0031 per cent of GDP in Europe to 0.2144 per cent in South-East Asia using approach 2. The mortality-related income losses associated with not providing surgery to the highest standard of care were slightly higher, but very similar to the income losses of not providing surgery to local standards.

Similar to the mortality-related income losses, absenteeism-related income losses associated with not providing surgery to local standards were lowest in Europe and highest in Western Pacific when estimated using either approach. In Europe, income losses were $23 million for approach 1 and $14 million for approach 2; in Western Pacific, losses were $622 million and $389 million respectively. However, the difference between income losses of not providing surgery to local *versus* highest standards was much larger than for the mortality estimates. For South-East Asia, the economic burden increased by about 50 per cent, for all other regions except Europe between 75 and 120 per cent, and for Europe it increased 8-fold (approach 1) or 13-fold (approach 2).

Combining mortality and absenteeism-related income losses, the global economic burden of not providing surgery to local standards amounted to $92 492 million using approach 1 and $73 141 million using approach 2. The additional economic burden of not providing surgery to the highest standard was $2512 million for approach 1 and $2525 million USD for approach 2. The economic burden of unmet access to surgical care at local standards comprised between 87 and 97 per cent of the total economic burden in all regions except Europe (*supplementary material Fig. S15*).

Absenteeism-related income losses contributed to a small fraction of the economic burden of unmet surgical need for appendicitis, irrespective of the approach employed or benchmark (*Fig. 3*). The absolute economic burden was highest in South-East Asia and Western Pacific, but the difference between the two approaches was large for both regions. However, even the lower estimates for both regions yielded some 1.5–2-fold higher absolute costs than most other regions.

Discussion

This study has identified a substantial absolute and relative economic burden associated with failure to provide adequate or

quality surgical services for the treatment of acute appendicitis. This economic burden, although substantial for any low- or middle-income country, varied by more than 50-fold across different geographic regions.

Reduction in mortality and morbidity, and thus reduction in patient's income losses, through provision of surgery requires that surgical care can be accessed and that care, once accessed, is of high quality. The Lancet Global Health Commission on High Quality Health Systems[19] has suggested that lack of quality care is a greater contributor to lives lost than lack of access. In the present analysis, the economic burden was calculated both in terms of improving access to local quality of care and improving access to care at the best global standard. This was done with the aim of teasing apart the relative contributions of lack of access and lack of quality to the economic burden. It is notable that, for treatment of appendicitis, major improvements can be achieved by improving access to care delivered at local standards, and that the additional benefits from meeting the care standards of high-income countries, which were taken to be reflective of high quality, are relatively marginal. This suggests that most benefit can be gained by improving access to care at standards already attained within a geographic region. At first glance, this stands in contrast to the findings of a previous study[20] that calculated the unmet surgical need of digestive diseases in low- and middle-income countries in terms of disability-adjusted life-years (DALYs). It was found that 45 per cent of the current surgically avertable burden in terms of DALYs could be avoided with scaled up access to higher-quality surgical care (defined by a lower case fatality rate). This may be explained in part by differences in methodology, but most likely relates to the impact of surgery on mortality from different digestive diseases. Simple emergency surgery for appendicitis has a substantial effect on mortality, maximizing the impact of reduced access.

Appendicectomy was selected because it is an emergency procedure required worldwide, and for which every surgeon receives training. Unlike specialist procedures, accessing any surgically ready facility should enable appropriate care. For more complex procedures, lack of appropriate surgical expertise is more likely to influence outcomes adversely. The present study found that improving access to appendicectomy at current local standards of care can substantially decrease mortality. This shows that, despite calls for improved quality, access should not be neglected, especially for the most common emergency procedures. Although they did not compare outcomes resulting from lack of access *versus* lack of quality, other studies[21,22] have shown that lack of access to surgical care is a huge issue in low- and middle-income countries, particularly for emergency conditions[7]. Access is a multidimensional problem, encompassing service availability, and geospatial, financial, and sociocultural considerations. Solutions therefore require engagement of multiple stakeholders[23,24]. Although dimensions of geospatial, financial, and sociocultural considerations certainly need to be addressed, they offer complex challenges[25]. However, given the relative simplicity of surgery for appendicitis, it may be that service availability issues can be addressed more readily by task-shifting or sharing, to compensate for the worldwide shortage of surgeons[10]. Task shifting or sharing has been applied successfully to caesarean section and inguinal hernia in some contexts[26,27]. Increasing the availability of technicians could grow surgical services more rapidly than can possibly be achieved through traditional training. This solution could enable out-of-hours surgery in local hospitals and also release surgeons to provide increased diagnostic and perioperative care (which is particularly important in the emergency setting). It could also enable increased efficiency of theatre utilization. Improved access to emergency appendicectomy will thereby provide benefits in surgical care that reach beyond the treatment of appendicitis.

Although training surgical providers comes at a cost, if countries can raise revenue from earnings forgone as a result of morbidity or mortality associated with lack of access to quality care for appendicitis, and invest 5 per cent of this into improving services, as a recommended minimum share of public spending on health[28], this could easily cover the costs of training. These findings can be put into perspective by taking India as an example. According to Global Burden of Disease data, India had an incidence rate of appendicitis of 121 per 100 000 in 2015 (world median 240 per 100 000), or about 765 000 cases in the age group 20–64 years, for which the economic burden was calculated. The present study estimated an unmet need for 653 000 people (85 per cent) in approach 1, and 418 000 people (55 per cent) in approach 2. Total costs for not providing surgery to a local standard amounted to $14 086 million in approach 1 and $9017 million in approach 2. In contrast, total care costs were 3616 rupees or $69.5 for an appendicectomy at a tertiary care hospital in India in 2010–2011[29]. If India could invest 5 per cent of the foregone earnings (for example, extracted through taxation) in surgical care, this would free up resources to provide 10.1 million (approach 1) or 6.5 million (approach 2) additional appendicectomies, thus closing the gap in surgical need. Such service development would inevitably provide wider benefits, particularly in emergency surgical care, as no service is provided in isolation. Measuring the societal impact of such an investment would be expected to demonstrate substantial additional improvements in care and associated societal benefits.

Although the results as a whole are striking, there are some nuances within the findings that are worthy of explanation. The economic burden, relative to GDP, of unmet surgical need was highest in South-East Asia, followed by Africa. Africa and South-East Asia had the greatest economic burden as both had a comparatively high share of unmet surgical need according to the estimates. For South-East Asia, a large contributor to the economic burden was the high incidence rate in Nepal, Bhutan, and Bangladesh according to the Global Burden of Disease data. Without these outliers, South-East Asia would have ranked second after Africa. The ranking differed between economic burden relative to GDP and absolute economic burden of unmet surgical need. The absolute economic burden was highest in Western Pacific and South-East Asia, followed by the Americas, Eastern Mediterranean, and Africa. For Western Pacific, relatively high wages led to higher income losses, whereas the high unmet need and the extreme incidence rates contributed further to the high economic burden for South-East Asia. For most regions, the income losses were higher using approach 1 compared with approach 2; the reverse was, however, true for the Americas, and was also evident at the country level. This seemed to be driven by a combination of comparatively high surgical volume with an even higher incidence rate. For the first approach, the gap between actual surgical volume and the need to achieve a surgical volume of 5000 per 100 000 was considered to estimate the unmet need. As the surgical volume was quite high in the Americas, this resulted in a reasonably low unmet need when using approach 1. Still, the surgical volume was not high enough to counterbalance the very high incidence rate, such that the estimate of unmet need in approach 2 exceeded the estimate of approach 1.

There are limitations to this study. The main constraint is the availability of data on appendicitis incidence, outcomes, and

appendicectomies in low- and middle-income countries. The Global Burden of Disease project provides country-level estimates of the incidence of appendicitis, but these diverge from administrative data in high-income countries, probably owing to different data sources (see *appendix S.3*). Still, the Global Burden of Disease data are the only nationally comparable and comprehensive incidence data available. Additionally, there are large gaps in the surgical outcomes data, particularly in the emergency setting. Uniquely, this study benefited from accessing the raw data in the COVIDSurg Collaborative and GlobalSurg Collaborative studies which provided global prospectively collected outcomes data. The extrapolation to all low- and middle-income countries might not be accurate for the context of every country, and might obscure variations between certain countries. Similarly, there are no reliable global data to distinguish outcomes by age or sex. As the extrapolation is based on comparable data from several low- and middle-income countries, the results should yield reasonable estimates. Furthermore, because of uncertain and conflicting data on appendicectomies, two analyses were provided in an attempt to provide two different angles on unmet need. The assumption is that the approaches give a reasonable second-best option in the absence of data on appendicectomies performed. Finally, the models are static, in the sense that feedback mechanisms were not incorporated. For example, the models do not account for changes in surgical quality if the access to surgical care increases. Yet, the direction of such feedback mechanisms is likely to depend on many different factors, so any assumptions regarding such mechanisms would be highly debatable.

This study has shown that, for many low- and middle-income countries, investment in the provision of emergency surgery for appendicitis can be cost-effective by substantially reducing the economic burden of the illness. Development of local and district surgical services could have a positive knock-on effect, enabling access to care for other surgical emergencies and even elective procedures. This additional benefit will need to be evaluated in prospective studies, but might be substantial.

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Supplementary material

Supplementary material is available at *BJS* online.

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