Deaths from acute abdominal conditions and geographical access to surgical care in India: a nationally representative spatial analysis

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Summary

Background Few population-based studies quantify mortality from surgical conditions and relate mortality to access to surgical care in low-income and middle-income countries.

Methods We linked deaths from acute abdominal conditions within a nationally representative, population-based mortality survey of 1·1 million households in India to nationally representative facility data. We calculated total and age-standardised death rates for acute abdominal conditions. Using 4064 postal codes, we undertook a spatial clustering analysis to compare geographical access to well-resourced government district hospitals (24 h surgical and anaesthesia services, blood bank, critical care beds, basic laboratory, and radiology) in high-mortality or low-mortality clusters from acute abdominal conditions.

Findings 923 (1·1%) of 86 806 study deaths at ages 0–69 years were identified as deaths from acute abdominal conditions, corresponding to 72 000 deaths nationally in 2010 in India. Most deaths occurred at home (71%) and in rural areas (87%). Compared with 567 low-mortality geographical clusters, the 393 high-mortality clusters had a nine times higher age-standardised acute abdominal mortality rate and significantly greater distance to a well-resourced hospital. The odds ratio (OR) of being a high-mortality cluster was 4·4 (99% CI 3·2–6·0) for living 50 km or more from well-resourced district hospitals (rising to an OR of 16·1 [95% CI 7·9–32·8] for >100 km). No such relation was seen for deaths from non-acute surgical conditions (ie, oral, breast, and uterine cancer).

Interpretation Improvements in human and physical resources at existing government hospitals are needed to reduce deaths from acute abdominal conditions in India. Full access to well-resourced hospitals within 50 km by all of India's population could have avoided about 50 000 deaths from acute abdominal conditions, and probably more from other emergency surgical conditions.

Funding Bill & Melinda Gates Foundation, Dalla Lana School of Public Health, Canadian Institute of Health Research.

Lancet Global Health 2015; 3: e646–53

This online publication has been corrected. The corrected version first appeared at thelancet.com on Oct 13, 2015

Published Online August 14, 2015 http://dx.doi.org/10.1016/S2214-109X(15)00079-0

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Introduction

Acute abdominal conditions, including peptic ulcer disease, appendicitis, and hernias are time-critical illnesses that need urgent surgical care. These are common, treatable conditions in high-income countries, but they remain important causes of premature mortality in India and many low-income and middle-income countries where access to surgical care remains poor.[1,2]

There is growing recognition that mortality and morbidity from surgical diseases in low-income and middle-income countries could be reduced significantly by scaling up basic, life-saving surgical care.[3] Reducing mortality from surgical diseases, including deaths from acute abdominal conditions, will require better knowledge of where deaths occur, and the barriers to accessing surgical care. In India, as in many other low-income and middle-income countries, limited population-based data exist to quantify the number and distribution of causes of death. About 75% of all deaths in India occur at home without medical attention[4] and in the absence of national civil registration with medical certification at time of death, alternative systems to determine causes of death are needed. Any national estimates of mortality can mask large and important variations in the risk of death within a country, especially where significant socioeconomic inequalities exist that affect disease risk and access to health care.[5] Robust methods to quantify deaths from acute abdominal conditions at the national and subnational levels and to relate mortality to access to surgical facilities are urgently needed in low-income and middle-income countries, but few studies have examined these priorities.

The Million Death Study (MDS) in India aims to determine the causes of death in 1·1 million nationally representative Indian households using enhanced verbal autopsy methods.[6] Here, we combine these study estimates of deaths from acute abdominal conditions with representative health facility and household demographical information to quantify the spatial distribution of these deaths within India. We further

Panel: Research in context

Evidence before this study

We systematically searched PubMed and Embase with no specified start date up to July 31, 2015. We used the following PubMed search terms and translated appropriately for Embase: ("surgical procedures, operative" [MeSH] OR surgery[sh] OR "general surgery" [MeSH] OR "surgical condition" [tw] OR "surgical conditions" [tw] OR "acute abdomen" [tw] OR "acute abdominal" [tw]) AND ("mortality estimates" [tw] OR "burden of disease" [tw] OR "disease burden" [tw] OR ("household" [tw] AND "survey" [tw])). We further delineated by low-income or middle-income countries, and included nationally representative, population-based studies of mortality due to surgical conditions. We identified 791 studies, of which 12 were relevant. Nine studies used household surveys to estimate avertable mortality from surgical conditions, but none used ICD coding or verbal autopsy methodology to ascertain the cause of death. Instead, studies recorded surgically avertable deaths based on whether or not a household member of the deceased believed surgical care was needed at the time of death or based on a predetermined list of surgical syndromes. A population-based study in Pakistan correlated access to abdominal surgery with higher economic status and urban place of residence, but did not describe the avertable mortality burden due to unmet surgical need. A recent study modelled the avertable burden of four digestive diseases using 2010 Global Burden of Disease data and estimated that 65% of the disability-adjusted life years lost were avertable with surgical care at first-level hospitals. Finally, the 2013 Global Burden of Disease study showed that peptic ulcer disease remains the most common cause of death from digestive diseases globally, in keeping with the findings of this study.

Added value of this study

Our study results provide the first nationally representative population-based estimate of deaths from acute abdominal conditions in any low-income or middle-income country. Limited representative population-based data for surgical disease burden exists in other low-income or middle-income countries. As best as we can determine, this study is the first to relate mortality from surgical conditions to potential access to emergency surgical care and to account for socioeconomic variables that also affect access to facilities and mortality outcomes.

Implications of all the available evidence

Deaths from acute abdominal conditions, and likely other surgical emergencies, are strongly related to geographical access to well-resourced surgical facilities. About two-thirds of deaths from acute abdominal conditions in India could be averted by improving human and physical resources at existing district hospitals.

relate deaths from acute abdominal conditions to access to surgical facilities.

Methods

Setting and study sources

The Registrar General of India's Sample Registration System partitions India into about 1 million small areas following every decanal census,[7] from which about 7000 small areas are randomly selected for continuous monitoring of births and deaths through 6-monthly household visits by 800 non-medical staff. For any household with a death, the surveyors complete an enhanced form of verbal autopsy (the Routine, Reliable, Representative, and Resampled Household Investigation of Mortality with Medical Evaluation; RHIME) involving structured questions and a half page local language narrative with organised probing of about 12 key symptoms before death.[6] These records were converted to electronic records and sent to two of 140 trained physicians who assigned the final causes of death using International Classification of Diseases (ICD)-10 codes.[8] Methods and results of the MDS have been reported previously.[6,9] Acute abdominal conditions were defined as time-critical abdominal conditions that needed definitive surgical care within 24 h of the onset of symptoms, as recognised by a lay person, in order to prevent death. They were categorised by ICD-10 code (full list in appendix).[10] We included all MDS deaths during the calendar years 2001–03 at ages 0–69 years. Causes of death above age 70 years are more likely to be misclassified, and are less avoidable than deaths before this age.[4,6]

See Online for appendix

The Government of India designates community health centres and district hospitals to provide first-level surgical care.[5] District hospitals are the main health facilities providing such care because most community health centres have restricted capacity.[11] We defined access to surgical services from the nationally representative District Level Household and Facility Survey (DLHS-3)[12] done in 2007–08, which provided details on the level of resources for each of 565 district hospitals. We classified district hospitals into three levels of resources: basic district hospitals with no emergency surgery capabilities (n=182); intermediate district hospitals with availability of 24 h surgical and anaesthetic services (n=132); and well-resourced district hospitals with 24 h surgical and anaesthetic services, critical care beds, a blood bank, and basic laboratory and radiology departments (n=225). Two independent data extractors classified the DLHS-3 data for all district hospitals into these levels, with differences reconciled by one of the authors (JSN-K).

At the time of the study, India had 26 838 postal (PIN) codes, of which 4064 had both a death and enumerated underlying population (drawn from a 1998 household survey in the same units as the MDS).[13] The DLHS-3 excluded public hospitals from five large cities (Mumbai, New Delhi, Kolkata, Bangalore, and Chennai; total 2011 population of about 66 million or 5·5% of India's total) comprising 181 postal codes. Location mapping for district hospitals in the smaller states of Tripura and Nagaland, the state of Jammu and Kashmir, and a small union territory comprising 50 postal codes were not available, leaving 3833 postal codes for analyses. The geographical locations of population-weighted postal code centroids were calculated[14] using population data from the Global Rural-Urban Mapping Project.[15,16] Hospitals were geocoded using data from a commercial data vendor. Aspatial and spatial checks were done to verify the accuracy of geospatial data.

Statistical analyses

Total and age-standardised death rates for acute abdominal conditions used the 1998 survey for population denominators with direct standardisation to the 2001 Census population. The total number of absolute deaths from acute abdominal conditions were calculated by applying the sample-weighted MDS proportion to the 2010 UN estimates of total deaths in India, as detailed earlier.[17] Spatial clustering analysis used the Getis-Ord Gi* method[18] to identify postal codes in spatial clusters with higher or lower numbers of deaths from acute abdominal conditions. This analysis yielded clusters of postal codes with high numbers of deaths from acute abdominal conditions and low numbers of deaths from acute abdominal conditions at the 99% confidence level (hereafter referred to as high-mortality clusters and low-mortality clusters, respectively). Sensitivity analyses used ordinary kriging and spatial scan statistics (SaTScan).[19] Euclidean distance (as the crow flies) from each death's population-weighted centroid of the respective postal code to the district hospital was calculated, and served as the main indicator for spatial access. Sensitivity analyses were completed using the two-step floating catchment area[20] and the provider to population ratio (staff and resources per 100 000 population within 50 km to describe district level coverage).[14] We did univariate and multivariate analyses of spatial access and socioeconomic factors in high-mortality versus low-mortality clusters to identify possible explanatory variables. Odds ratios (ORs) for spatial access to district hospitals in high-mortality versus low-mortality clusters were estimated by multivariate logistic regression. Comparison was made between the OR for spatial access in deaths from acute abdominal conditions versus non-acute surgical conditions of oral, breast, and uterine cancers. Calculation of avertable deaths at the population level under the scenario of full coverage of well-resourced district hospitals within 50 km, was made on the basis that odds of mortality for those currently living more than 50 km from a well-resourced district hospital would fall to the level of those living within 50 km of a well-resourced district hospital.

Role of the funding source

The funders 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

Of the 86 806 study deaths in individuals aged 0–69 years between Jan 1, 2001, and Dec 31, 2003, 923 (1·1%) deaths were from acute abdominal conditions. This value corresponds to an estimated 72 000 deaths from acute abdominal conditions nationally in India, when these proportions (weighted for sampling probability) are applied to the national death totals for 2010. The majority of study deaths were from peptic ulcer disease (733 [79%]). The median age of death was 53 years (IQR 38–62) and almost two-thirds of deaths were in men. 87% (807) of deaths from acute abdominal conditions occurred in rural areas and only 21% (192) of deaths from acute abdominal conditions occurred in a hospital (table 1). After adjustment for the sharp differences in age between deaths from acute abdominal conditions and other deaths, there were no major differences in place of death, illiteracy, alcohol, or smoking prevalence. At the community level, areas with deaths from acute abdominal conditions were likely to be poorer, as defined by the lower use of non-solid fuels for cooking, with slightly lower household density, compared with other MDS deaths, but otherwise we report no significant statistical differences.

	Acute abdominal deaths (n=923)	All other MDS deaths* (n=85 883)	p value
Individual level			
Age, years†	53 (38–62)	39 (3–59)	<0·0001
Male sex	588 (64%)	48 692 (57%)	<0·0001
Rural	807 (87%)	72 530 (91%)	0·013
Place of death			
Home	657 (71 %)	60 299 (72%)	0·72
Hospital	192 (21%)	14 672 (20%)	
Other place	47 (5%)	8065 (5%)	
Unknown	27 (3%)	2847 (3%)	
Illiteracy‡	516 (59%)	30 656 (59%)	0·69
Alcohol drinking‡	237 (27%)	12 557 (27%)	0·47
Smoking‡	369 (42%)	20 591 (42%)	0·43
Community level§			
Member of a scheduled caste or tribe	0·22 (0·10–0·43)	0·22 (0·08–0·41)	0·16
Latrine on premises	0·09 (0·02–0·34)	0·10 (0·02–0·37)	0·33
Use of non-solid fuels (gas, electricity, or kerosene) for cooking||	0·14 (0·24)	0·17 (0·27)	0·004
Illiteracy in ever-married women	0·67 (0·51–0·81)	0·69 (0·51–0·83)	0·023
Household density	2·80 (2·31–3·34)	2·85 (2·34–3·45)	0·013
Smoking prevalence¶	15 (7–24)	15 (7–23)	0·76
Alcohol drinking prevalence¶	5 (1–11)	5 (1–10)	0·31

p values from χ2 (categorical data) and two-independent sample *t*-test (scalar data) analysis. Sex was not reported for 74 deaths. Records with missing values were excluded for all variables. MDS=Million Death Study. *Percentages in all other MDS deaths for individual level variables, except age, were standardised to the age distribution of abdominal deaths. †Median (IQR). ‡Adult deaths only; for acute abdominal deaths, n=878; for all other deaths, n=58 385. §Median values (IQR) for the proportion of households in each category are shown except for non-solid fuel for acute abdominal deaths, n=888; and for all other deaths, n=80 095. ||Mean (SD). ¶Prevalence data are per 100 population.

Table 1: **Demographical data and place-of-death data (individual and community level) for 923 deaths from acute abdominal conditions and all other MDS deaths, aged 0–69 years, 2001–03**

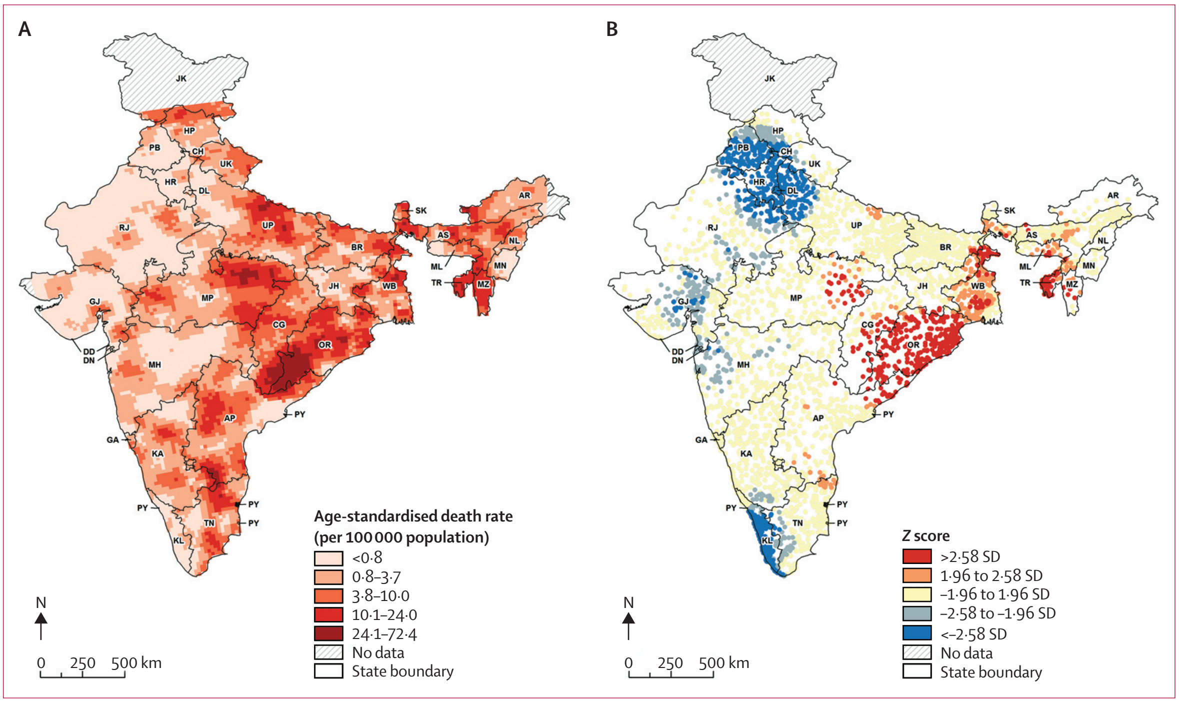

***Figure 1*: Geographical variation in age-standardised death rates, and high-mortality and low-mortality clusters from acute abdominal conditions in Indians aged 0–69 years**

Ordinary kriging analysis (A) and cluster analysis (B) of age-standardised death rates from acute abdominal conditions in India. Cluster analysis (Getis-Ord Gi* method) revealed a similar distribution of high-mortality and low-mortality values at the postal code level as seen with ordinary kriging. ArcGIS 10.1 was used to do cluster analysis and ordinary kriging. AP=Andhra Pradesh. AR=Arunachal Pradesh. AS=Assam. BR=Bihar. CH=Chandigarh. CG=Chhattisgarh. DD=Daman and Diu. DN=Dadra and Nagar Haveli. DL=Delhi. GA=Goa. GJ=Gujarat. HP=Himachal Pradesh. HR=Haryana. JH=Jharkhand. JK=Jammu and Kashmir. KA=Karnataka. KL=Kerala. MH=Maharashtra. ML=Meghalaya. MN=Manipur. MP=Madhya Pradesh. MZ=Mizoram. NL=Nagaland. OR=Odisha. PB=Punjab. PY=Puducherry. RJ=Rajasthan. SK=Sikkim. TN=Tamil Nadu. TR=Tripura. UK=Uttarakhand. UP=Uttar Pradesh. WB=West Bengal.

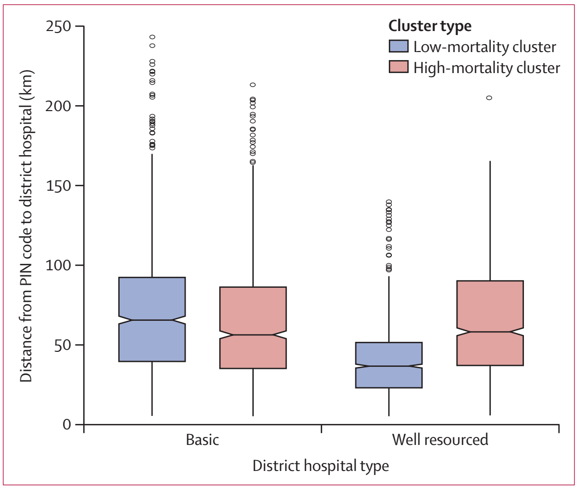

***Figure 2*: Distance to nearest basic district hospital versus well-resourced district hospital in low and high acute abdominal mortality clusters in Indians aged 0–69 years**

Distance is Euclidean (km) from the postal code population-weighted centroids to nearest hospital facility. Box plots are presented as median, and upper and lower "hinges" correspond to the first and third quartiles. The upper whisker of the plot extends from the upper hinge to the highest value within 1·5 times the IQR. The lower whisker extends from the lower hinge to the lowest value within 1·5 times the IQR. Data beyond the end of the whiskers are outliers and plotted as points.

There was substantial variation in the age-standardised death rates from acute abdominal conditions (figure 1). Clusters of high acute abdominal mortality occurred most commonly within the eastern states of Orissa, Tripura, and West Bengal and the central states of Madhya Pradesh and Chhattisgarh. Low-mortality clusters were seen in the states of Kerala and northwest India (figure 1). The mean age-standardised mortality rate per 100 000 people for the 3833 postal codes covering all deaths from acute abdominal conditions was 19·3 per 100 000, ranging from 42·6 per 100 000 in 393 high-mortality clusters, 18·9 per 100 000 in 2873 medium-mortality clusters, and 5·0 per 100 000 in 567 low-mortality clusters. This rate corresponds to an 8·6 times relative difference between high-mortality and low-mortality clusters. The distribution of both high-mortality and low-mortality clusters was similar to the mortality patterns seen with ordinary kriging analysis (figure 1) and SaTScan cluster analysis (appendix).

District hospitals with basic facilities were marginally closer in Euclidean distance to high-mortality clusters (52·6 km [IQR 31·1–83·2]) than to low-mortality clusters (62·3 km [IQR 35·4–90·0]; p=0·011; figure 2). However, well-resourced district hospitals were significantly farther from high-mortality clusters (54·5 km [IQR 33·1–87·3])

	High-mortality cluster n/mean (SD) distance (km)	Low-mortality cluster n/mean (SD) distance (km)	Odds ratio (95% CI)
Distance to nearest district hospital with basic facilities (n=182/565)			
<20 km	51/10·2 (5·8)	55/11·1 (5·9)	1·0
20–49·9 km	134/35·5 (8·8)	159/ 34·8 (9·2)	1·1 (0·6–1·8)
50–99·9 km	146/71·2 (13·9)	233/71·1 (12·5)	0·9 (0·5–1·6)
100 km and more	62/147·6 (31·0)	120/145·8 (36·5)	0·5 (0·3–0·9)
p for linear trend: χ^2 5·4, df=1, p=0·02			
Distance to nearest district hospital with intermediate level facilities (24 h surgical care) (n=132/565)			
<20 km	35/12·6 (5·0)	83/10·5 (6·1)	1·0
20–49·9 km	90/35·5 (9·0)	151/33·7 (8·7)	1·6 (0·9–2·8)
50–99·9 km	154/73·5 (14·9)	183/72·4 (14·5)	2·0 (1·1–3·4)
100 km and more	114/130·1 (25·9)	150/120·9 (13·1)	1·3 (0·8–2·3)
p for linear trend: χ^2 1·4, df=1, p=0·23			
Distance to nearest well-resourced district hospital (24 h surgical care, laboratory, radiology, blood bank, critical care) (n=225/565)			
<20 km	56/10·7 (6·1)	155/10·0 (6·2)	1·0
20–49·9 km	123/35·0 (7·7)	279/33·9 (8·5)	1·0 (0·7–1·5)
50–99·9 km	148/72·8 (14·5)	114/61·3 (10·4)	3·2 (2·0–5·1)
100 km and more	66/118·7 (18·5)	19/122·3 (10·7)	16·1 (7·9–32·8)
p for linear trend: χ^2 71·6, df=1, p<0·00001			

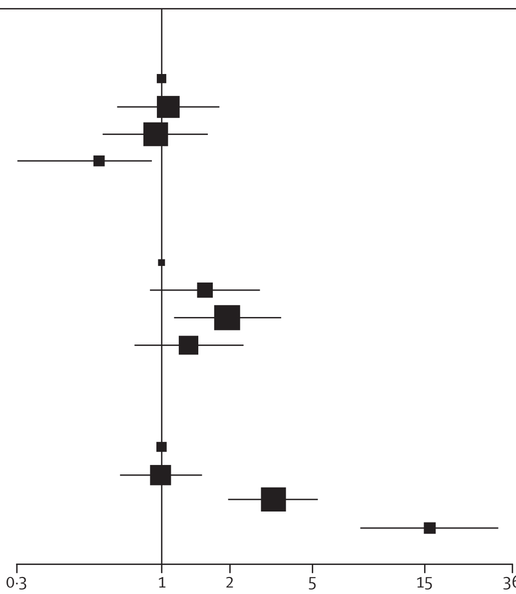

***Figure 3:* Geographical access (Euclidean distance) to surgical care and mortality risk from acute abdominal conditions at ages 0–69 years in India for high-mortality and low-mortality clusters at the postal code level**

Goodness-of-fit indices: Hosmer and Lemeshow test, χ^2 14·2, df=8, p=0·076; area under the curve of ROC curve 0·743 (95% CI 0·711–0·774). All variables were entered into the multivariate logistic regression model; covariates adjusted for were the proportion of non-solid fuel use and proportion of scheduled caste or tribe population. Further adjustment for education (using proportion of illiteracy as a proxy) did not alter the risk ratios significantly and did not improve the model (Hosmer and Lemeshow test, χ^2 20·0, df=8, p=0·010). Euclidean distances were calculated using PostgreSQL 9.1, PostGIS 2.0, and Quantum GIS Lisboa version 1.8.0. The horizontal axis is a log scale.

than from low-mortality clusters (32·5 km [IQR 18·8–48·4]; p<0·001).

Figure 3 shows no differences between high and low acute abdominal mortality clusters with increasing distance to a district hospital with basic facilities, after adjustment for distance to different levels of hospitals, proportions of the use of non-solid fuels for domestic cooking, and scheduled caste or tribe population in each cluster. The odds ratio (OR) of a postal code being a high-mortality cluster (over a low-mortality cluster) increased slightly with increasing distance from an intermediate district hospital, but rose notably with increasing distance from a well-resourced district hospital. The overall OR (high-mortality vs low-mortality cluster) for being more than 50 km away from a well-resourced district hospital was 4·4 (95% CI 3·2–6·0). These odds rose from 3·2 (95% CI 2·0–5·1) for living 50–99 km from a well-resourced district hospital to 16·1 (7·9–32·8) for living 100 km or more away. Sensitivity analysis using a multilevel model, coverage, and other geospatial methods confirmed these findings (appendix). No relation was seen between geographical access to a well-resourced district hospital and high-mortality clusters of three surgical conditions that are not time critical, namely breast, uterine cancer, and oral cancers, of which there were 1544 study deaths (appendix).

	Proximity to any district hospital (millions)	Proximity to well-resourced district hospital (millions)
<20 km	480 (41%)	261 (22%)
20–49·9 km	571 (48%)	412 (35%)
50–99·9 km	125 (11%)	362 (31%)
100 km and more	7 (1%)	148 (13%)
Total	1183 (100%)	1183 (100%)

Data are n (%). The Indian population by distance band was calculated using the Gridded Population of the World version 3 (GPWv3) Future Estimates for the year 2010 and a spatially enabled relational database (PostgreSQL 9.1 and PostGIS 2.0). Distances are Euclidean (km). Percentages do not add to 100% due to rounding.

***Table 2:* Proximity of the Indian population (2010) to any district hospital and to well-resourced district hospitals, stratified by distance band**

Table 2 shows the proximity of the 2010 Indian population to any district hospital and to a well-resourced district hospital. Although 89% of India's population lived within 50 km of any district hospital (and 41% lived within 20 km), only 57% of Indians lived within 50 km of a well-resourced district hospital (and only 22% lived within 20 km). Even at the lower 99% CI of the observed odds, this suggests that full availability of well-resourced district hospitals could avoid over

50 000 acute abdominal deaths in India at 2010 death rates.

Discussion

Acute surgical conditions are an important avoidable cause of premature death in low-income and middle-income countries, but have received scant attention as a public health priority.[3] In India, our nationally representative mortality survey found that acute abdominal conditions caused about 72 000 deaths in 2010, accounting for more deaths than maternal causes.[21] Acute abdominal deaths were more common in men and in those living in rural areas, and were associated with poverty. Widespread variability in the age-standardised acute abdominal death rates was observed, with rates being highest in the poorer eastern states of India. Population-based, nationally representative data, disaggregated to the postal code level, reveal that the odds of living in a high acute abdominal mortality cluster increased with increasing distance from surgical care. The greatest risks were among those who lived 100 km or more from a well-resourced district hospital. If these risks are causal, then full coverage of well-resourced district hospitals within 50 km could avert about two-thirds of the observed deaths from acute abdominal conditions in India each year.

Gross disparities in surgical access and outcomes between high-income countries and low-income and middle-income countries are known.[1,2] We document large inequities in surgical access within India. Peptic ulcer disease accounted for nearly 80% of all deaths from acute abdominal conditions. Peptic ulcer disease can cause gastric and intestinal perforation or bleeding necessitating urgent surgical care. The major cause of peptic ulcer disease is *Helicobacter pylori* infection, which remains endemic in much of India[22] and is strongly associated with poverty.[23] Deaths from acute abdominal conditions showed a marked east–west gradient, similar to the gradient recently shown for all-cause adult mortality.[24] Both gradients might be linked with historic childhood infection, including *H pylori*. After adjustment for poverty and the proportion of the population belonging to a scheduled caste or tribe, poor geographical access to a well-resourced hospital capable of providing emergency surgical care remained the strongest explanatory variable for high-mortality clusters. The relation between poor geographical access to surgical care and trauma mortality has been documented in high-income countries[25] and for maternal deaths in low-income and middle-income countries.[26]

Because acute abdominal conditions are time critical, geographical access to adequate 24/7 surgical facilities within 50 km, and ideally within 20 km, is crucial for reducing delays to definitive surgical treatment and associated mortality. Yet in 2010, 43% of the Indian population currently lived more than 50 km away from a well-resourced district hospital. In the absence of access to a motorised vehicle, such distances are challenging if not prohibitive to accessing timely care for surgical emergencies. Community health centres are supposed to serve as a first-level referral hospital but had severe resource shortages: in 2008, 35% did not have an operating room, 63% did not have a surgeon, 76% did not have an anaesthetist, and none met the criteria for a well-resourced hospital.[27] Our analysis suggests that improving geographical access to surgical care and improving existing hospital level resourcing (both human and physical resources) is needed in India and in other low-income and middle-income countries, where poorly accessible and under-resourced hospitals remain common, especially in non-urban areas.[28,29] The ability of a hospital to surgically manage acute abdominal conditions is predictive of access to other important emergency surgical procedures, including emergency obstetric surgery, open fracture management, and limb amputation.[30] Therefore, the total avertable surgical mortality from improving surgical access in India is likely to be substantially greater than that of deaths from acute abdominal conditions alone. Improving infrastructure at about 5500 district and community hospitals in India is an ongoing goal of the National Health Mission.[31] New community insurance schemes are intended to reduce financial barriers.[5] General improvements in living standards in India are likely to reduce rates of childhood infection with *H pylori*, and eventually the long-term consequences including stomach cancer[32] and deaths from acute abdominal conditions. Widespread eradication therapy for *H pylori* infection might further reduce deaths from acute abdominal conditions, but is restricted in India by high antibiotic resistance (85–100%) to current drug regimens.[23]

Our study shows the importance of population-based mortality data to understand outcomes resulting from a lack of hospital care. Earlier studies in low-income and middle-income countries drawn mostly from hospitalised patients, including the Global Burden of Disease Study, are unable to bridge this important gap in knowledge.[33] Indeed, reliance on data from hospitalised patients might significantly underestimate the true mortality burden from deaths from acute abdominal conditions because many deaths occur at home.

Despite relatively few acute abdominal deaths meeting our strict definition criteria we were able to show geographical clustering of acute abdominal mortality. We excluded deaths from non-specific abdominal or pelvic pain in our study. This exclusion might lead to a slight underestimation of total mortality from acute abdominal conditions. We were unable to ascertain a definitive pathological cause for the acute abdominal presentation using verbal autopsy methods. The majority of deaths from acute abdominal conditions in our study were attributed to peptic ulcer disease at physician coding, however some of the deaths recorded as peptic ulcer disease might have been due to other causes of intestinal perforation such as typhoid, because these have similar clinical presentations. However, regardless of the underlying pathological cause of the acute abdomen, the requirement for timely access to appropriate surgical services to avert deaths from acute abdominal conditions remains the same. We could not include private hospitals in our analysis. However, almost 90% of deaths in this study were in rural areas where there is typically little private emergency surgical care in India.[5] We were unable to map the location of district hospitals in Jammu and Kashmir, a small union territory, and two small northeastern states, one of which, Tripura, also had high rates of death from acute abdominal conditions. Therefore, we might have underestimated the effect of access on the risk of death from acute abdominal conditions. We adjusted for the effects of poverty, and caste and tribe, but other unmeasured factors might explain the variance in the risk of being a high-mortality or low-mortality cluster. The 2001–03 causes of death patterns might also have changed in recent years, thereby affecting our forward extrapolations of total deaths from acute abdominal conditions in India in 2010. However, the proportions of deaths from acute abdominal conditions to all-cause mortality were generally stable between 2001 and 2008 in hospital-based mortality data in urban India.[34] Barriers to accessing surgical care are often multifactorial.[35,36] Whereas we show the significant importance of geographical proximity to a well-resourced hospital capable of providing surgical care 24 h a day, seven days a week, other factors might also affect access and utilisation of surgical services, including health literacy, health-seeking behaviour, and financial barriers. In addition to poor proximity to care, these factors might contribute to the high rates of death outside of a health facility seen in this study. Community perceptions of the quality of health care services can also affect uptake and utilisation, and safety and quality also affects surgical outcomes.[37,38]

Geographical access to well-resourced district hospitals providing emergency surgical care might therefore also increase community utilisation of such health services, if they are perceived to be not only closer, but also reliably available and of high quality. There are some limitations to the measurement of geographical access used in our study. The use of the postal code centroids for large dispersed rural areas could misrepresent actual access to surgical facilities. Euclidean distances are likely to underestimate actual road distance or travel times faced by patients in India by at least 30% (Hsiao M, unpublished). Socioeconomic and geographical factors can also result in differential access to transport options and variable transport times, even when road distances are constant.[39] Ensuring universal access to well-resourced hospitals, ideally within 50 km, could decrease deaths from acute abdominal and other emergency surgical conditions.

Contributors
MH and PJ conceived the study. JSN-K, AJD, JP, SHF, and PSR analysed the data. AJD, PJ, and JSN-K wrote the paper. All authors were involved with data interpretation, critical revisions of the paper, and approval of the final version. PJ is the guarantor.

Declaration of interests
We declare no competing interests.

Acknowledgments
This study is supported by grants from the Bill & Melinda Gates Foundation (through the Disease Control Priorities Project) and the Centre for Global Health Research. PJ is supported by the University of Toronto and a Canada Research Chair, and AJD is supported by the Canadian Institutes of Health Research. We thank Natasha Correa for assistance in data extraction and Mehak Bhatia for assistance with figure production. The opinions expressed in this Article are those of the authors and do not necessarily represent those of the institutions with which they are affiliated or of the Government of India.

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