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Time to include burden of surgical injuries after disasters in the Global Surgery agenda? An assessment of DALYs and averted burden by surgery after the 2008 Wenchuan earthquake

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ABSTRACT
Unlike other disasters, injury rates after earthquakes are still on the rise at a global scale. With an estimated one million people injured by earthquakes in the last decade, the burden of injury is considerable. Importantly, the surgical procedures carried out by healthcare facilities are capable to avert part of this burden. Yet both burdens remain unquantified using understandable metrics. We explored in this analysis a method to calculate them using disability-adjusted life years (DALYs), an internationally accepted measure expressing years of healthy life lost due to a health condition. We used data from a large standardised hospital database of earthquake-related injuries with complete information on International Classification of Diseases for injury and surgical procedures, sex and age information. DALYs and averted DALYs were calculated by injury types and per patient using disability weights available in the literature and expert opinion. We also suggested how DALYs might be further converted into an economic measure using approaches in the published literature. We estimated 10 397 DALYs as the earthquake surgical-injury burden produced in 1861 hospitalised patients treated in a single hospital (on average, 5.6 DALYs per patient). Our study also assessed that 4379 DALYs, or 2.4 DALYs per patient, were averted by surgery (42%). In economic terms, DALY losses amounted to US$36.1 million, from which US$15.2 million were averted by surgery in our case study. We urge to systematically estimate these impacts through improvements in the routine reporting of injury diagnoses and surgical procedures by health systems, potentially improving prevention policies and resource allocation to healthcare facilities.

INTRODUCTION
Earthquakes that cause significant loss of life and injury regularly affect the world. Just in the last decade, more than 350 000 people were killed and above one million injured

Summary box

- The injury burden due to earthquakes increased to one million people injured in the last decade, but we lack impact metrics.
- We provide a first estimate of disability-adjusted life years (DALYs) due to an earthquake in a large sample of 1861 hospitalised patients, totalling 10 397 DALYs from surgical injuries or on average 5.6 DALYs per hospitalised patient.
- Overall 4379 DALYs, or on average 2.4 DALYs per patient, were averted by surgery in our case study.
- We propose surgery DALYs and averted DALYs by surgery as a potential tool to raise awareness on the value of preventing injury burden from earthquakes and guide resource allocation in healthcare facilities.
- We recommend strengthening and standardisation of routine reporting of injury diagnoses and surgical procedures to facilitate wider implementation.

due to earthquakes.[1] Earthquakes ranked first in terms of disasters causing direct mortality and injury rates. Unlike other disasters, reductions in earthquake injury rates were more modest, and the global injury burden doubled from half a million (1996–2005) to a million (2006–2015) (table 1).

To adequately plan and provide care for the injured, knowledge on the burden of earthquake injury is essential. However, due to the earthquake disaster context, such data are rarely population-based. We still lack systematic reporting of injuries after disasters (and earthquakes in particular), which certainly limits our capacity to estimate the disability-adjusted life years (hereafter termed DALYs) due to natural disasters. Current DALY estimates from natural disaster and conflict provided by the Global Burden of Disease (GBD) studies

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Table 1 Global mortality and injury statistics by major disaster types, 1996–2015

Disaster type	Events (n)	Deaths	Injuries	Affected	Injury rate (per 10 000 affected people)	Mortality rate (per 10 000 affected people)
2006–2015						
Earthquake	248	357 092	1 008 824	81 154 443	124.3	44.0
Storm	966	173 695	178 849	306 587 291	5.8	5.7
Flood	1672	56 948	68 289	799 364 939	0.9	0.7
Landslide	178	9551	1542	2 827 169	5.5	33.8
Volcanic eruption	55	460	636	1 969 490	3.2	2.3
Wildfire	87	749	4143	2 372 149	17.5	3.2
1996–2005						
Earthquake	299	391 529	551 184	29 785 670	185.1	131.4
Storm	1019	65 430	229 766	320 925 715	7.2	2.0
Flood	1368	93 113	651 765	1 275 024 668	5.1	0.7
Landslide	198	8123	1939	1 104 387	17.6	73.6
Volcanic eruption	51	262	534	876 306	6.1	3.0
Wildfire	162	723	1662	500 133	33.2	14.5

Source: EM-DAT.[1]

are based on direct mortality figures and were included as late as 2008.[2] Despite that over two million people were reported injured by earthquakes in the period covered by the GBD studies (1990–2016),[1] DALYs from disabling earthquake-related injuries have not yet been included in recent GBD assessments.[3 4] In contrast, the GBD study has also included data on the non-fatal disease burden in most recent efforts.[5 6] DALYs contributed by natural disasters (ie, exposure to forces of nature), excluding heat and cold exposure, ranged from 0.023% (in 2002) to 0.6% (in 2010) of the total GBD DALYs in current estimates.[6]

Knowledge on the injury profile from earthquakes is derived from facility-based studies. Fractures and lacerations are reportedly most common.[7] However, there is significant variation in the share of injury diagnoses, where fractures vary between 22% and 58.3%,[7–9] lacerations can range from 8.5% to 65%,[7 9] and crush injuries may account for between 3% and 20%[8–10] of all injuries. Given this variation it would be misleading to generalise from findings in one hospital to a larger population.

The aftermath of major earthquakes is characterised by lack of resources, and several papers highlighted that essential surgical interventions are very cost-effective even in such settings.[11 12] A main challenge in the postearthquake setting remains to ensure that healthcare provision is cost-effective and that it focuses on the main burden of the disease.

A number of authors have suggested DALYs to be a feasible metric to estimate the burden of surgical disease, including for traumatic injuries.[13 14] In several reports, DALYs averted by surgery have been used as a method to estimate the averted burden of surgical diseases.[14–18] Based on the method suggested by McCord and Chowdhury in 2003,[19] these articles estimated the averting effect of surgery for each diagnosis by combining the severity of an injury and the efficacy of the corresponding surgical procedure. To date, we have found no study that used DALY and DALYs averted by surgery to estimate the burden of injury in an earthquake setting. A main reason for this is that research in an earthquake setting cannot be planned; instead, it is opportunistic, rapidly set up and carried out, and usually uses retrospective data. Our study takes advantage of systematically collected data at an existing large hospital close to the epicentre of the 2008 Wenchuan earthquake (Sichuan, China) that received injured patients within hours of the earthquake. A data set of all injury diagnoses and surgical procedures for each admitted patient is rare after earthquakes.[9 20] This information can provide estimates of DALYs produced by earthquakes, and equally important assess how much of the burden may be averted by surgical procedures.

We sought to document the burden of surgical injuries after the Wenchuan earthquake and assess to what extent surgery can avert this burden.

Setting our case study

On 12 May 2008 an earthquake of magnitude 7.9 on the Richter scale struck the Wenchuan community in the Sichuan province (population 87 million) of China. The Chinese Ministry of Health reported 68 858 deaths, 18 618 missing and 374 000 injured.[21] This analysis used data from patients treated for earthquake-related injuries at the People's Hospital of Deyang City (PHDC) between 12 and 31 May 2008. PHDC is the largest level 3, grade 1, state-owned hospital in Deyang District.

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The hospital was the closest functioning hospital to the epicentre (99 km east) of the earthquake. PHDC has a capacity of 1200 beds, and has 30 medical departments, 1 intensive care unit and 4 departments with orthopaedics, general surgery, neurosurgery and neurology. It was largely undamaged from the earthquake and was open to receive any injured patient.

Within hours of the earthquake, patients started arriving at the hospital. The injuries and treatment given were routinely noted in paper-based patient files. All patients admitted to the hospital with earthquake-related injuries arrived within 19 days, totalling 1950, and around 40% of them presented within the first 72 hours after the main shock.

In early March 2010, two researchers (BvdO, MAM) from the Centre for Research on the Epidemiology of Disasters (CRED) visited the PHDC staff (QW, LP, GC, D-SZ) in China. After listing all variables available from patient files, the CRED-PHDC team jointly decided what variables were relevant, and subsequently extracted 52 variables including information on demographics, admission and discharge information, injury diagnosis (International Classification of Disease (ICD)-10)[9] and surgical and other procedures performed (with corresponding ICD-9-Clinical Modification-3 codes).[22] Thereafter, a data entry manual was developed. Data entry operators were trained using the data entry manual, and the CRED researchers checked the quality of the data entry process. Data entry was performed between 12 March and 5 May 2010 using an online, webserver-based data entry system developed by one of the authors (MAM). More details on the data collection and data entry have been described elsewhere.[9]

The original database included 1950 patients treated at PHDC after the earthquake. Out of these, 72 patient records were excluded due to severe missing data. We additionally excluded patients where trauma diagnoses were missing (n=12) or had missing data on age (n=5). Each patient had one to four injuries. We then excluded injury types that do not benefit from surgery (n=194) (table 2). The final data set included 146 injury types, encompassing 2864 injuries in 1861 patients.

Table 2 Excluded injury types

Excluded injury types	n
Concussion	30
Contusion of abdominal wall	3
Contusion of ankle	1
Contusion of eyeball and orbital tissues	1
Contusion of eyelid and periocular area	11
Contusion of finger without damage to nail	21
Contusion of hip	5
Contusion of other and unspecified parts of foot	7
Contusion of other and unspecified parts of lower leg	20
Contusion of other parts of wrist and hand	4
Contusion of shoulder and upper arm	1
Contusion of thigh	13
Contusion of thorax	61
Sprain and strain of ankle, part unspecified	1
Sprain and strain of other and unspecified parts of knee	1
Sprain and strain of unspecified cruciate ligament	2
Traumatic shock	6
Traumatic anuria	1
Partial thickness (blisters, epidermal loss) burn of trunk, unspecified site	2
Injury of muscle and tendon of abdomen, lower back and pelvis	3
Total	194

Analyses and DALY calculations

In this report, we used the term surgical management to describe the wider set of aspects that include surgical judgement and different options that may include conservative as well as non-surgical treatment. Nevertheless, the decision for conservative treatment requires surgical expertise. We used the term surgical treatment to describe surgical invasive procedures.[23]

We analysed the data set retrospectively and used DALY to estimate the burden of injury, in accordance with the GBD study.[24] We extracted age, sex and injury defined according to the ICD-10 from the PHDC data set to calculate DALYs. The injury types were grouped by type and body region affected. Averted DALYs were estimated based on McCord and Chowdhury's[19] method, by combining the severity of an injury and the efficacy of the corresponding surgical procedure.[19] Finally, we estimated the cumulative DALYs and corresponding averted DALYs for each injury group.

All injuries were assigned disability weights (DW) according to the 2004 GBD report.[4] When the required DW was absent from GBD, we used DW as published by Haagsma *et al* in 2008.[25] The age-specific values for years of life lost were taken from table 1 in the original GBD study.[24] We then estimated the efficacy of surgery in averting the burden of injury using the methodology suggested by Gosselin and colleagues.[18] The efficacy of surgical treatment equals DALYs averted by this treatment. It was calculated by combining the severity of an injury (likelihood of death or disability without treatment) and the efficacy of the corresponding surgical procedure (averting death or disability). Each of these two factors is given a weight ranging from 0 to 1 (table 3). The weights were determined by two specialists in general surgery (LW, JVS) with experience in management of surgical trauma both in high-income and low-income settings. Together they assessed the efficacy of surgical treatment and the corresponding surgical procedure for each injury group in accordance with the model of

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Table 3 Weights for averted disability-adjusted life years calculations*

	Weight
Severity of disease	
>95% fatal or disabling without treatment	1.0
<95% and >50%	0.7
<50 and >5%	0.3
<5%	0
Effectiveness of treatment	
>95% chance of survival or cure	1.0
<95% and >50%	0.7
<50% and >5%	0.3

*Gosselin *et al*, 2010.[17]

Gosselin and colleagues.[18] For example it was assumed that the probability of disability without treatment for a femur fracture was >50% and <95%, corresponding to a weight of 0.7. Similarly, as Gosselin and colleagues[18] have proposed, we assumed that the probability of cure with surgery was >50% and <95%, also corresponding to a weight of 0.7. As an example (and not based on these data), an isolated femur fracture in a 33-year-old man would be associated with 11.1 DALYs (Box 1). Hence, the averted DALY would be $11.1 \times 0.7 \times 0.7 = 5.4$. All analyses were performed using Microsoft Excel V.12.1.0.

Burden of surgical injuries and averted DALYs by surgery

The burden of surgical injuries corresponded to 10 397 DALYs (table 4). Superficial injuries were the most frequent injury (21.5%) but contributed to less than 1% of all DALYs. Lower leg fracture was the second most common (15.8%) but produced nearly 19% of all DALYs. Femur fractures were the eighth most common diagnosis (5.2%) and accounted for 10% of DALYs. Femur fractures were followed in frequency by crush injuries (4.1%), which represented 5% of the total DALYs.

Surgical management averted 42% of the burden of injury (4379 DALYs). Surgical management of superficial injury and intracranial injuries did not avert any DALYs in our calculations. A total of 31% of the crush injury DALYs were averted by surgery. The corresponding percentages for lower leg fractures and femur fractures were 48% and 69%, respectively (table 4).

Box 1 Disability-adjusted life years (DALYs) definition and formulas used in this analysis.

DALY=YLL+YLD
YLL is used to account the Years of Healthy Life Lost from premature mortality related to life expectancy in a population for a given cause, age and sex.
YLD measures the Years of Healthy Life Lost due to Disability.
YLD=I × DW × L, where I is the incidence, DW the disability weights, reflecting the severity of the disease, and L (average duration of the case until remission or death).

To the best of our knowledge, this is the first study that documents the burden of surgical injury at a front-line hospital after an earthquake measured in DALYs. Crush injuries after earthquakes have attracted significant attention in the literature[10 26–31] but represent a small amount of DALYs in our study, and their surgical treatment only contributed to a modest part of DALYs averted, especially when compared with other injuries.

Overall, 42% of all these DALYs might potentially be prevented by surgery. Comparing crush injuries with femur fractures, the two groups were relatively similar in number (n=117 and n=149, respectively), but surgical treatment of femur fractures averted 4.3 times more DALYs than surgery for crush injuries.

Age-adjusted DALYs from natural disasters increased by 515.5% between 1990 and 2010 assessments, although this was mainly due to Haiti earthquake.[4] However, and given that earthquake-related injuries are not currently considered in GBD estimates, we think that our result indicates that they should be in the near future.

Limits of our approach and ways forward

Our analysis has several limitations. The often resource-limited and chaotic environment seen after earthquakes might limit systematic data collection. However, the data set used in this study is robust as it is based on routine data collected from an existing health structure with relatively well-equipped hospital and relatively undamaged by the earthquake. In addition, the hospital has used ICD classification since 2003 and all doctors were trained in this methodology. Even though the data are from only one hospital and not population-based, one may assume that the material might not represent a snapshot of conditions requiring hospitalisation in an earthquake. Therefore to really ascertain this, further research will be needed to compare the injury profile at this facility with further hospitals dealing with injuries from this earthquake. Moreover, care is needed not to generalise our findings to the injured population by this or further earthquakes. To do so, population surveys are needed to capture those injured but not able to reach a hospital, those treated at less specialised centres, as well as those injured but not seeking care. Also, the DALY as a metric has received criticisms discussed thoroughly in the literature.[32–34] Nevertheless this metric system is the most widely used to measure burden of disease. The DWs used in the study were gathered from two different sources,[2 25] and this approach is not exempt from introducing additional inconsistencies into this study. Moreover, the scoring system for DALYs averted used in this study has to our knowledge not yet been externally validated. It is based on the arbitrary nature of weighting likelihood of successful outcome for a surgical treatment. Such an approach has an obvious risk for biases.

We have not performed cost-effectiveness analysis (CEA). Performing CEA could add other aspects of the relationship between surgical burden of the disease and the DALYs averted by surgery shown in this

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Table 4 Type and number of injuries, corresponding DALYs and averted DALYs at PHDC*

Type of injury	n (%)	DALY (%)	Averted DALY (% out of DALY)
Superficial injuries	616 (21.5)	68 (0.7)	0 (0)
Lower leg fractures	452 (15.8)	1929 (18.6)	925 (48.0)
Open wounds	266 (9.3)	661 (6.4)	289 (43.7)
Thorax injuries	263 (9.2)	1078 (10.4)	169 (15.7)
Shoulder, arm and hand fractures	248 (8.7)	782 (7.5)	374 (47.8)
Spinal fractures	196 (6.8)	1162 (11.2)	503 (43.3)
Intracranial injuries	161 (5.6)	868 (8.3)	0 (0)
Femur fractures	149 (5.2)	1027 (9.9)	712 (69.3)
Crush injuries	117 (4.1)	522 (5.0)	165 (31.6)
Pelvic fractures	110 (3.8)	529 (5.1)	259 (49.0)
Intra-abdominal injuries	102 (3.6)	498 (4.8)	201 (40.4)
Skull and facial bone fractures	98 (3.4)	938 (9.0)	551 (58.7)
Dislocations	48 (1.7)	81 (0.8)	57 (70.4)
Traumatic amputations	33 (1.2)	238 (2.3)	166 (69.7)
Nerve injury	5 (0.2)	16 (0.2)	8 (50.0)
Total	2864 (100)	10 397 (100)	4379 (42.1)

*Sorted by the number of injuries.
DALY, disability-adjusted life years; PHDC, People's Hospital of Deyang City.

study. Regarding our economic evaluation of DALYs, it represents a first approximation of the economic burden of injury in a hospital treating patients injured in an earthquake.[35] Other methods such as the Value of a Statistical Life method have been used and should be fully considered for comparison in future studies.[36]

Policy implications

Our findings have several implications. On one hand, we show that DALYs methods can be applied quite straightforwardly to estimate the impact of disasters in terms of injury burden using acknowledged and understandable metrics. The DALYs generated by earthquakes provide a more tangible measure of overall impact and burden by injury type and can be used for resource allocation. The averted DALYs by surgery provide a direct measure of the savings on well-being linked to performed surgical procedures. These two measures can be translated in economic terms. A country's gross domestic product (GDP) per capita has been used as a measure to estimate the economic loss from DALYs.[35 37 38] A year of healthy life lost due to disability (or death) is a year that is not productive and not contributing to the GDP.[35] Each DALY then contributes to the average GDP per capita of the country of interest[35] valued at the year that the earthquake took place.[35] The cost in US dollars of the injured patients, considering a cost per DALY of 3471.248 current US dollars in 2008 (ie, the 2008 GDP per capita in value of the currency for that particular year), would be US$36.1 million, from which US$15.2 million were averted by surgery in one single hospital.

This is a key preliminary step to show policy makers and citizens what is the value of preventing the impacts of these natural disasters from occurring and the value of the surgical care received. Avoiding these catastrophes in the future could be achieved through reinforcement of the antiseismic requirements for new constructions, including public economic incentives in seismic zones to move away from vulnerable to earthquake-resistant buildings. The averted economic DALYs by surgery could be a good tool for hospital managers to negotiate funding for hospitals, in this case in the particular context of disaster management.

On the healthcare delivery side, our analysis highlights the need for a consistent approach to femur fractures as they produce considerable DALYs following an earthquake, a great part of which is avertable by surgery. There are several treatment options for surgical management of femur fractures, including immobilisation and external traction, internal fixation, external fixation and plaster. Traditionally, femur fractures in low-resource settings have been treated by tibia traction. Even if considered safe, this treatment option has several disadvantages, including long hospital stay and bad outcome. In recent years, nailing has been systematically tested and shown to be safe.[39 40] Several studies found nailing cheaper than traction and with better results.[41 42] However, more studies are needed before nailing becomes the treatment of choice for closed femur fractures following disasters such as earthquakes. This suggests that research is an important instrument to improve the outcome of the surgical procedure, which in turn may have positive repercussion on averted DALYs.

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Finally, injury burden due to disasters needs more recognition from well-established initiatives such as the GBD,[2] which currently does not take into account injuries in their natural disaster-associated burden.[6] Also the GBD estimates per se would be more realistic if a 5-year or 10-year average would be used instead of a single year, as large natural disasters are stochastic phenomena and one large disaster may drive (and bias) the trend calculation typically offered by GBD.[4] The year-to-year variability in the global burden of DALYs due to natural disasters can be currently estimated and consulted online, and this is an important step forward.[6] Additional alignment with the Global Surgery agenda might bring about additional benefits in terms of advocacy and standardisation of procedures such as an ICD equivalent of surgical interventions.[43 44]

CONCLUSION

This analysis showed that DALYs are a feasible metric to define the burden of surgical injury after earthquake and to estimate the averted burden by surgery. Potentially DALYs can be translated into economic losses, which has potential to be used as a policy tool. To allow this approach being used more widely, the missing link continues to be standardised good-quality data. Routine data collection is possible, as shown by our analysis, and will likely improve with the advent of new digital technologies, implying digital standardised patient records. A partnership to produce better estimates of the global burden of disasters into GBD and a partnership with the Global Surgery for the standardisation of surgical procedures might contribute to achieving these objectives. The averted burden by surgery highlights injury groups that otherwise risk to be neglected when allocating resources in response to such crises.

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