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SURGERY IN LOW AND MIDDLE INCOME COUNTRIES

Geospatial Analysis of Trauma Burden and Surgical Care Capacity in Teso Sub-region of Eastern Uganda

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Abstract

Introduction Over 90% of injury-related deaths occur in low- and middle-income countries. Relating spatial distribution of injury burden and trauma care capacity is crucial for effective resource allocation. Our study assesses trauma burden and emergency and essential surgical care (EESC) quality in Teso Sub-region Eastern Uganda through a spatial analysis of trauma burden in relation to surgical capacity at the district level.

Methods In this study, we surveyed trauma patients presenting at Soroti Regional Referral Hospital (SRRH) and assessed EESC capacity of district hospitals. We used geospatial techniques to relate trauma burden and capacity and characterized delay using the three-delay framework.

Results We surveyed 131 trauma patients presenting to SRRH for trauma-related injuries from June 1 to July 15, 2017. Almost all trauma incidents (n = 129, 98.4%) occurred within a 2-h ideal drive time to SRRH. From time of injury to receiving care, median time totaled to approximately 9.25 h. District hospital exhibited decreased EESC capacity (personnel, infrastructure, procedures, equipment, and supplies (PIPES) score range 2.2–5.5, mean 4.2) compared to SRRH (PIPES score 8.1).

Conclusion Trauma patients face delays in each step of the care-seeking process from deciding to seek care, arriving at care site, and receiving treatment. Synergistic effects of a poor prehospital care, EESC deficiencies on district and regional levels, cost of seeking care contribute to delays that likely result in increased morbidity and mortality. Improved resource allocation, training at the district level, and strengthening system-level organization of emergency medical services could avert preventable death and disability.

Introduction

Trauma accounts for roughly 5.8 million deaths annually with over 90% of injury-related deaths occurring in low- and middle-income countries (LMICs) [1]. Poverty and lack of infrastructure in LMICs magnify the socioeconomic impacts of injury-related disability. Furthermore, health systems are often unprepared to manage the growing burden of injuries in resource-poor contexts [2]. Specifically, physical accessibility such as geographic distance or transportation time impacts outcomes before and after surgery [3]. Improving the timeliness of access to care is

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particularly relevant in trauma care, as every hour of delay can impact morbidity and mortality [1].

Ensuring essential resources are available within a minimum proximity to the injured patient is one critical way to improve timeliness of trauma care. Mapping spatial distribution of injury burden can identify geographic areas of high demand. Relating high-demand areas to facility-based trauma care capacity allows for effective resource allocation. Lancet Commission on Global Surgery proposed a 2-h limit of timeliness to access essential surgical procedures, with a target of ensuring access for 80% of the population by 2030. Currently, limited data exist depicting the proportion of population in LMICs that can access a facility with the capacity to perform Bellwether procedures within the 2-h limit [4].

The existing studies on access to emergency and essential surgical care (EESC) often underestimate situational intricacies such as transportation cost, socio-cultural factors, and road construction. Although 93% of populations in Sub-Saharan Africa theoretically live within 2 h of a hospital that carry out Bellwether procedures, barriers are thought to be much greater due to synergistic effects of cost, distance, and deficiencies at individual facilities [5]. Uganda is a low-income country with a decentralized health system comprised of government-run lower-level health centers, district hospitals capable of providing emergency surgeries, and major regional and national referral hospitals. According to the Ugandan National Household Survey, 86% of the Ugandan population access health services within a 5 km radius, underscoring the need to improve capacity at the local level in order to address the unmet surgical burden [6].

The purpose of this study was to characterize EESC supply and demand as well as delays that prevent timely access to surgery. Utilizing spatial analysis, geolocation of trauma incidences overlaid with surgical capacity helps determine whether current facilities meet the needs of the population's EESC demand. Identification of common barriers and causes of delay will provide targets for improving access to surgical care.

Methods

Study design

We used a mixed-methods approach to assess trauma burden and surgical capacity in the Teso Sub-region of Eastern Uganda. This study was carried out in two phases: (1) a survey of trauma patients presenting at Soroti Regional Referral Hospital (SRRH) to ascertain demographic information and injury geolocation; (2) an assessment of EESC capacity at district hospitals in the sub-region that refer trauma patients to SRRH. We used geospatial techniques to relate trauma burden and EESC capacity. Furthermore, we adapted the three-delay framework which asserts that increased mortality is a result of three types of delays: delays in making a decision to seek care, reaching a health facility, and receiving adequate treatment [7–9]. We utilized this framework to understand nuances involved in barriers to trauma care.

Study setting

The Eastern region of Uganda is predominantly rural, where one in four people living in poverty [10]. The Teso Sub-region comprises over 1.9 million people from eight districts: Amuria, Bukedea, Kaberamaido, Katakwi, Kumi, Ngora, Serere, and Soroti. Each district is served by a district hospital and lower-level health centers [11, 12]. The Teso Sub-region currently lacks an organized pre-hospital emergency system, and most surgical cases are referred to SRRH, where the leading causes of emergency surgical presentations include trauma (45%), infection (23%), and acute intestinal obstruction (13%) cases [13].

Survey of trauma burden

This study prospectively captured all-age trauma patients presenting to SRRH for trauma care or emergency surgical care. Patients with non-trauma emergencies such as pregnancy complications, hernias, or cancers were excluded.

Following verbal informed consent, trauma patients or proxies were interviewed using a structured questionnaire, adapted from injury surveillance tools used in LMICs [14, 15]. Data on demographics, injury context, injury mechanism, injury geolocation, perceived barriers, transportation cost, as well as time of injury and care were collected. Patients were asked to identify landmarks near incident (i.e., road names, church, etc.) to collect geolocation. Using Google Maps (Google, Mountain View, California, USA), closest latitude and longitude coordinates were recorded.

Survey of district hospitals

The surgical capabilities of eight district hospitals were evaluated using a validated surgical capacity assessment tool, the personnel, infrastructure, procedures, equipment, and supplies (PIPES) survey [16, 17]. PIPES survey is a 105-item quantitative instrument that assesses the personnel, infrastructure, procedures, equipment, and supplies to yield a PIPES score with a minimum score of 0 and no maximum ceiling. The survey generates a PIPES index, allowing for comparison of hospitals in similar settings as a relative value [17].

Data analysis

Data were analyzed using R version 3.1.2. Descriptive analyses of the cohort are reported as frequencies, proportions, medians, and interquartile ranges. Pearson chi-squared and Kruskal–Wallis tests were used to compare categorical and continuous variables between groups, respectively.

Geographic information system (GIS) mapping software, ArcGIS, was used to plot locations of trauma incidents and hospitals [18]. Distances and travel time between each incident, closest district hospital, and SRRH were computed using Google Maps Distance Matrix API (Google, Mountain View, California, USA). Business Analyst (ESRI, Redlands, California, USA) was employed to model transportation time from each incident to SRRH and to determine proportion of incidents within modeled drive times of 30-min, 1-h, and 2-h bands.

Ethical approval

The protocol was approved by University of California-San Francisco Committee on Human Research and SRRH administration.

Results

Trauma patient cohort characteristics

We surveyed 131 trauma patients presenting to SRRH for trauma-related causes from June 1 to July 15, 2017. Most trauma incidents occurred at home (38.3%) or on the road (36.1%), and the most frequently encountered injury mechanisms included falls (43.1%), road traffic injuries (RTIs) (33.1%), and trauma derived from blunt force (16.9%). About 48% of falls were specifically from mango trees, and 74% of these falls were among pediatric patients. A majority of RTIs involved motorcycles (62.8%) or bicycles (20.9%), and helmet usage was only 16.7%. Most patients incurred a single serious injury (AIS $>$ 2) (62.6%), with the most common diagnoses including fractures (58.5%), head injuries (27.7%), sprains and dislocations (23.7%), bruises and abrasions (20.6%), lacerations or bites (8.4%), and burns (4.2%). (Table 1).

Laypersons, including family and friends (60.2%, n = 74) or bystanders (32.0%, n = 39), were typically the first responders following an incident. Ambulance (10.6%, n = 13), and police response (13.8%, n = 17), were present in a minority of cases. Patients were predominantly transported to their first care site by motorcycle taxis (63.8%, n = 81), followed by ambulance and police escorts (11.0%, n = 14), private cars (7.9%, n = 10), and bicycles (6.3%,

Table 1 Characteristics of the trauma patient cohort (n = 131)

Characteristics	n (%)*
Age (median, [IQR])	23 [10, 42]
Sex	
Male	82 (62.6%)
Female	49 (37.4%)
Education level	
None	14 (10.9%)
Primary	78 (59.5%)
Secondary	27 (20.9%)
University or College	10 (7.8%)
Occupation	
Farmer	75 (57.3%)
Small business owner	18 (13.7%)
Student	16 (12.2%)
Unemployed, unable to work	5 (3.8%)
Teacher	5 (3.8%)
Taxi driver	3 (2.3%)
Other	9 (6.9%)
Setting of injury	
Home	51 (40.2%)
Road/streets	48 (37.8%)
School	16 (12.6%)
Village/Bush	6 (4.7%)
Work	4 (3.2%)
Mechanism of Injury	
Falls	56 (43.1%)
Road traffic injuries (RTIs)	42 (33.1%)
Struck by blunt force	22 (16.9%)
Stab/cut	7 (5.4%)
Burns	4 (3.1%)
Number of serious injuries**	
1	82 (62.6%)
2	22 (16.8%)
3 or more	27 (20.6%)
First care site	
Regional hospital	54 (41.2%)
Private health clinic	24 (18.3%)
Health center	24 (18.3%)
District hospital	15 (11.5%)
Alternative medicine (incl traditional healers)	6 (4.6%)
Home	3 (2.3%)
Perceived barriers to care	
Cost	37 (28.2%)
Transportation	7 (5.3%)
Lack of staff	26 (19.8%)
Long wait times	47 (35.9%)
Lack of medication	18 (13.7%)
No barriers	17 (13.0%)

*Percent based on non-missing values

**Abbreviated Injury Scale (AIS) $>$ 2

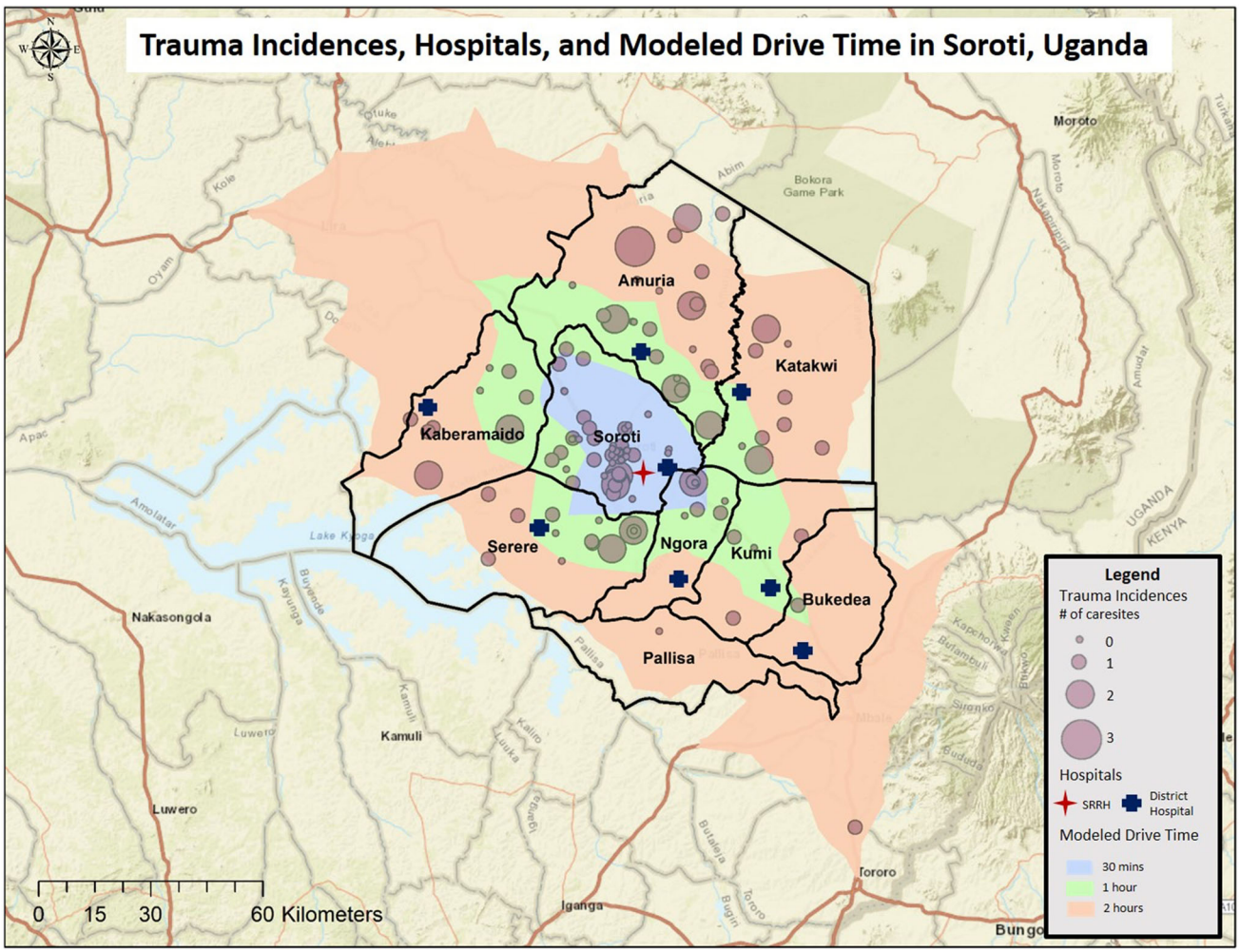

Fig. 1 Geospatial analysis of trauma incidences. Trauma Incidences (pink circles): Each pink circle represents one trauma event. The size of the circle is proportional to the number of lower-level clinics, district, and regional hospitals trauma patients went to access and receive trauma care before arriving at SRRH. For example, if the patient visited a Level II clinic and district hospital, their circle would be indicated with a circle of size 2. The larger the circle, the more sites patients visited before reaching SRRH for final care and therefore the greater amount of time spent in deciding and seeking care. Hospital (crosses): District hospitals are indicated with blue circles. Regional hospital (SRRH) is indicated with red cross. Modeled drive time: Modeled drive time of 30 min, 1 h, and 2 h is indicated by blue, green, and light orange bands, respectively

n = 8). Median duration from time of injury to time of care totaled to approximately 9.25 (9 h and 15 min). (Table 2). Median transportation cost was $2.28 [95%CI, 1.39–4.17].

Geospatial analysis of trauma incidents

Figure 1 displays the geospatial distribution of trauma incidents among the cohort, as well as locations of district hospitals and SRRH. The highest density of trauma incidents occurred near Soroti city center, followed by the northern district of Amuria. Conversely, a seemingly lower density of trauma incidents originated from the southeastern districts of Ngora, Kumi, and Bukedea. Median distance from injury location to the nearest district hospital was 12.5 km (range 0–72.6 km) and to SRRH was 27 km (range 0–140 km). A larger proportion of trauma incidents linked to patients who visited more than two care sites occurred outside the Soroti central district (n = 13 of 15, 86.7%). Almost all trauma incidents occurred within a 2-h ideal drive time to SRRH (n = 129 of 131, 98.4%).

Assessment of surgical capacity at the district level

We surveyed eight government-funded district hospitals in the Teso Sub-region using the PIPES survey. District facility PIPES index ranged from 2.2 to 5.5 with mean index of 4.2 (Table 3, Fig. 2). PIPES index scores for all district hospitals were lower than SRRH, with PIPES index of 8.1.

Table 2 Three-delays analysis for trauma patient cohort

Delay	Median (h)	IQR (h)	(*n*)
Delay 1—seeking care			*n* = 110
Time from injury to decision to seek care	1.25	[0–12]	
Delay 2—reaching care			*n* = 92
Time from decision to 1st care site	1.0	[0.6–2]	
Time from decision to arrival at SRRH	6.0	[2.5–20.5]	
Delay 3—receiving care			*n* = 117
Time from arrival at SRRH to receiving trauma care	2.0	[0.8–6]	

Table 3 Personnel, infrastructure, procedures, equipment, and supplies (PIPES) surgical capacity assessment summary

Category	Personnel, infrastructure, procedures, equipment, and supplies (pipes) score									
	District									Regional
	Amuria	Katakwi	Kaber-amaido	Serere	Ngora	Kumi	Bukedea	Soroti	Overall	SRRH
Personnel (P)	3	6	3	7	2	2	1	2	3.3	10
Infrastructure (I)	4	2	3	4	3	2	4	5	3.4	8
Procedures (Pr)	25	20	21	28	30	6	8	19	19.6	34
Equipment (E)	12	10	7	12	9	10	13	12	10.6	16
Supplies (S)	7	13	5	7	6	3	5	7	6.6	17
PIPES score	51	51	39	58	50	23	31	45	43.5	85
PIPES index score*	4.9	4.9	3.7	5.5	4.8	2.2	3.0	4.3	4.2	8.1

*Calculated using the (Total PIPES Score/105) ×10

On average, district hospitals served a catchment area of about 25,000 people within a 20 km radius and contained 96.4 beds. About 37.5% of hospitals had oxygen supply and anesthesia machines, 12.5% had reliable running water, and none had consistent electricity, blood banks, or X-ray machines. On average, district hospitals were staffed by 0.38 surgeons, 1.38 general doctors (including obstetricians), 0.13 medical officers capable of providing anesthesia, and 7.8 paramedics or midwives. All health facilities self-reported ability to provide basic resuscitation and first aid, but few could perform interventions such as open fracture management (12.5%), cricothyroidotomy, amputation, cholecystectomy (25.0%), closed fracture management (37.5%). None had an intensive care unit, and few had emergency care (12.5%) or postoperative areas (25%). District hospitals carried supplies required for EESC (i.e., gloves, needles, sutures, and gauze). Most district hospitals (87.5%) had a government ambulance; however, patients were required to finance fuel.

Discussion

This study examines the geospatial relationship between trauma burden and surgical capacity in Teso Sub-region of Eastern Uganda and shows that district hospitals in the Soroti Region of Uganda are not well equipped to deliver EESC. While all five areas characterizing EESC capacity using the PIPES method were found to be inadequate, human resource and infrastructure availability were the most deficiency. Lack of physicians limits surgical care delivery at the district level. The presence of operating rooms at most of the surveyed district hospitals, however, suggests the potential to deliver EESC. While not currently widely accepted, task-shifting in which mid-level providers are trained to provide acute care may ameliorate shortage of emergency care services [19]. Inconsistent funding and criteria for ambulance use present significant challenges for prehospital care and inter-facility transfer. A prior study linked the lack of prehospital care and EESC capacity to higher injury-related morbidity and mortality [20].

A greater density of trauma incidents in the northern districts of the region presented to SRRH. This may be due to the propensity for patients in the southeastern districts to seek care toward urban centers in southern Uganda such as Mbale and Kampala. Moreover, existence of private hospitals in Kumi and Ngora may explain the lower volume of patients presenting to SRRH with trauma incidents originating from these areas. Injuries that occurred outside the district were more prone to visiting more than two care sites before seeking treatment at the regional level. This

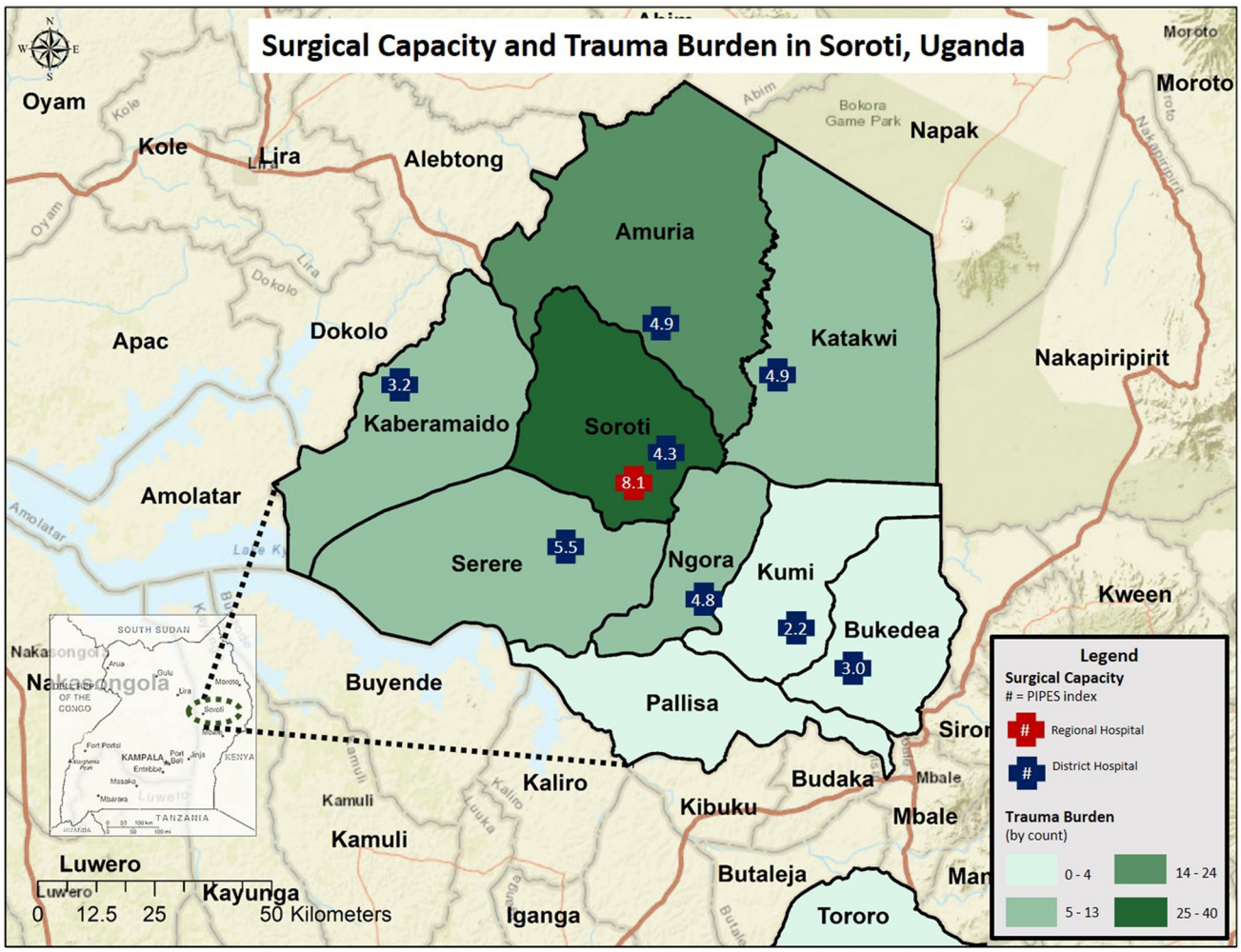

Fig. 2 Geospatial analysis of surgical capacity Geospatial distribution of surgical capacity and trauma burden density by region. Uganda National Map: Soroti region is marked with dotted green circle[13]. Hospital (crosses): District hospitals are indicated with blue circles. Regional hospital (SRRH) is indicated with red cross. Trauma burden: Trauma burden within each district of the sub-region is shaded in light green to dark green corresponding to the number of incidences from each district represented in this study

could be due to deficiencies in surgical capacity at the district level, causing patients to seek care at multiple sites, before reaching definitive care. Patients must decide between visiting a lower-level hospital with limited EESC capacity or delaying treatment by traveling farther to SRRH with higher capacity.

Trauma patients faced delays in each step of their care-seeking process from deciding to seek, arriving, and receiving care. Delays in receiving emergency surgery impacts future disability and mortality [21]. Spatial distribution of trauma incidences overlaid with ideal driving time showed that while most trauma incidences lie within a 2-h drive time to SRRH, total median delay from decision to seek care to receiving definitive assessment in our study cohort was 9.25 h. Using the three-delay framework, we showed that most patients experienced delays at each point in care-seeking experience. Even though the cost of care at public hospitals is free in Uganda, cost of seeking care was cited as a main barrier, likely stemming from the financial burden of work absence, transportation, and hidden costs in seeking care as shown in previous studies [22, 23]. Transportation cost alone at $2.28 could be a significant health expenditure where the average daily income is approximately $1.62 (6000 UG shillings) [24]. Furthermore, long wait times with median decision-to-intervention at the regional hospital suggest a lack of effective EESC delivery at the tertiary level [13]. The combining effects of a poor prehospital care system, EESC deficiencies at district and regional hospitals, cost of seeking care contribute to significant delays that likely result in increased morbidity and mortality. Increasing capacity at district hospitals and further studies characterizing individual delays can help inform policy that improves EESC delivery.

Combatting the growing injury epidemic in LMICs requires understanding of context, culture, and the existing systems within a local community. The trauma patient

cohort consisted of farmers, primarily injured from mango tree falls and RTIs, a transformation from a decade ago when drowning was the major cause of trauma in rural Uganda [25]. Falls from mango trees made up 20.6% of incidents, predominantly in the pediatric cohort, an injury unique to the community. Public health interventions such as youth injury prevention programs may be needed to impart safe interaction with fruit trees, using fruit pickers and avoiding climbing to heights beyond safe limits. In addition, helmet usage was severely lacking in most RTIs. Campaigns to increase use of helmets may be warranted, as rural communities increase motorcycle and vehicle use. Furthermore, involvement of laypersons in first response should be considered, especially given the lack of a structured prehospital system. While adaptive changes are needed to build a prehospital system, technical fixes may include training layperson as capable responders. Future surveillance through trauma registries can inform specific interventions.

Limitations

Several limitations to this study should be noted. Modeled drive time was based on speed of automobiles and cannot account for various seasonal, situational factors. The cross-sectional survey of EESC provides only a snapshot in time of the surgical capacity and cannot be generalizable to other regions of Uganda and Sub-Saharan Africa. Furthermore, the surveys were carried out over a limited period, not accounting for potential seasonal, temporal variations in injury patterns. As with hospital-based trauma studies, it is likely that we were unable to capture patients who died on scene, and we were unable to interview patients who may have received adequate care elsewhere, such as in private hospitals. Nevertheless, it highlights the significant gaps between trauma burden and EESC capacity.

The severity of patients' injuries may have influenced delays in seeking or receiving care. Injury severity scores were not calculated for individual injuries, and thus, subgroup analyses for moderate and severe injuries could not be conducted. Finally, our study did not assess the impact of delays on long-term morbidity and mortality.

Conclusion

Decreasing delay in reaching surgical care and increasing surgical capacity on a district level can improve EESC access and delivery and likely decrease morbidity and mortality due to injury. Trauma patients in this study faced time delays in each step of the care-seeking process from deciding to seek care, arriving at care site, and receiving treatment. Furthermore, district hospitals in Teso Sub-region of Eastern Uganda face gaps in infrastructure, human resources, capital, and reliable medical transport and often refer patients to the distant but better-equipped SRRH, resulting in delays. Improved resource allocation, training at the district level, formalization of referral, and strengthening system-level organization of emergency medical services could avert preventable death and disability. Further understanding of community-level barriers and delays can inform contextualized public health strategies and resource allocation to reinforce surgical access.

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Compliance with ethical standards

Conflict of interest There is no conflict of interest for each author in this manuscript.

Informed consent Informed consent was obtained from all individual participants included in the study.

Ethical approval The study was approved by University of California-San Francisco Committee on Human Research (IRB # 17-22513) and SRRH hospital administration.

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